The Director General

Maisons-Alfort, 31 May 2022

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

on the "Use of microsensors to monitor the quality of indoor and outdoor air"

ANSES undertakes independent and pluralistic scientific expert assessments.
ANSES primarily ensures environmental, occupational and food safety as well as assessing the potential health risks they may entail.
It also contributes to the protection of the health and welfare of animals, the protection of plant health and the evaluation of the nutritional characteristics of food.
It provides the competent authorities with all necessary information concerning these risks as well as the requisite expertise and scientific and technical support for drafting legislative and statutory provisions and implementing risk management strategies (Article L.1313-1 of the French Public Health Code).
Its opinions are published on its website. This opinion is a translation of the original French version. In the event of any discrepancy or ambiguity the French language text dated 31 May 2022 shall prevail.

On 21 December 2018, ANSES received a formal request from the Directorate General for Health (DGS), the Directorate General for Risk Prevention (DGPR) and the Directorate General for Energy and Climate (DGEC) to conduct the following expert appraisal: Review of knowledge on citizen's use of microsensors for monitoring the quality of indoor and outdoor air.

1. BACKGROUND AND PURPOSE OF THE REQUEST

Sensor systems, also known as microsensors or low-cost sensors (LCSs) because of their small size and low initial purchase cost, have been developing rapidly in recent years. Their popularity can be explained by several factors:

- the relatively low initial purchase cost of these technologies compared to the measuring instruments used in reference methods;
- their ease of use and adaptability, which offer a variety of application areas to a broad range of users;
- growing public awareness of air pollution and its health impact;
- the development of "crowdsourcing"[1] citizen sciences and a growing interest among the population in producing and sharing data;
- growing demand and interest in connected objects (the Internet of Things[2]) from parts of the population;
- a need to improve knowledge of the large-scale spatial and temporal distribution of air pollution, and to cover different microenvironments;
- advances in electronic engineering and computer science enabling management of the large amounts of data generated.

These technologies have been and still are the subject of a multitude of studies in different potential application areas. However, the use of sensor systems raises several questions, such as their metrological reliability, the management, use and interpretation of the resulting data and, ultimately, their relevance in addressing air quality issues.

In this context, the DGS, DGEC and DGPR issued a formal request to ANSES on 21 December 2018, asking it to:

1. conduct a review of studies using microsensors and the profiles of their users;
2. assess the strengths and limitations, and the complementarity with respect to conventional measurement, of data from microsensors used by citizens to characterise exposure in order to interpret the health implications;
3. discuss the legal status of the data generated by microsensors.

In the remainder of this document, the term "sensor system" will be used instead of microsensor, according to the definition proposed by the French Standardisation Organisation (AFNOR).

[1] Crowdsourcing is the outsourcing of a task to amateur contributors

[2] Manifestation of the Internet in the real world concerning objects, cars, buildings and other elements connected to a physical Internet network by an electronic chip, sensor or sensor system. This network connectivity enables the retrieval, storage, transfer and processing (without discontinuity between the physical and virtual worlds) of the related data, regardless of its geographical origin. Abbreviated to IoT ((AFNOR FD X43-121, 2021).

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)".

It 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 the Working Group on Microsensors. The methodological and scientific aspects of the work were presented to the CES between March 2020 and March 2022. The work was adopted by the CES on "Assessment of the risks related to air environments" at its meeting on 10 March 2022.

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.

The experts' declarations of interests are made public via the website: https://dpi.sante.gouv.fr/.

In order to answer the questions in the formal request, the work was organised into two expert appraisal reports. The first report (Volume 1) presents the following information:

- proposed definitions and prerequisite knowledge on sensor systems, the data generated and the stakeholders involved in their implementation;
- overview of projects relating to the assessment of sensor systems and projects involving citizens, drawing on literature reviews and reference reports on the topic;
- focus on the specific case of carbon dioxide (CO_2) sensor systems, because of the recommendations on measuring CO_2 in indoor public spaces as a means of fighting limiting the spread of COVID-19, and the variety of equipment available;
- review of studies focussing on the use of sensor systems for individual exposure assessment, with a discussion of their potential advantages and limitations;
- identification of key points to consider to ensure that data generated by a sensor system can contribute to the assessment of individual exposure;
- discussion of the use of sensor systems for assessing the health effects of air pollution once the data generated have been deemed "valid", i.e. they comply with the key points of the previous step;
- discussion of the specific case of private users of sensor systems;
- discussion of the legal status of data generated by sensor systems.

This work also included a review of the profiles and motivations of sensor system users, based on a literature summary and a dual survey, presented in a complementary expert appraisal report (Volume 2).

3. ANALYSIS, CONCLUSIONS AND RECOMMENDATIONS OF THE WORKING GROUP AND THE CES

3.1. Results of the expert appraisal

3.1.1. Definitions and prerequisite knowledge

- Definition of sensor systems:

The definitions adopted by the Working Group are those proposed by the French Standardisation Organisation (AFNOR) in its documentation on air quality sensors (FD X43-121, 2021):

- Sensing element: "A device that transforms an observed physical value into a usable value such as an electrical signal, whose amplitude is relative to the concentration of the target pollutant in the air";
- Sensor: "A device with at least one sensing element for recording information on the value to be measured, and with an electronic system for data acquisition and processing";
- Sensor system: "Equipment integrating at least one sensor or sensing element and software to detect a quantity and/or measure a concentration of compounds (gas, aerosol) over a predefined interval".

Portable sensor systems[3] are devices worn by individuals, whereas fixed sensor systems are devices installed in an indoor or outdoor environment at a given location[4].

- Available technologies:

Sensor systems operate according to four types of measurement principles: semiconductor and photoionisation (for gas only), electrochemical cells and optical detection (for gas and particulate matter).
The metrological performance and costs of the particulate matter, black carbon and gas sensors are presented in Annex 1 and summarised here.
Metal-oxide (MOX) semiconductor sensors are among the least expensive on the market and are valued for the wide range of gases they can detect – in particular, certain volatile organic compounds (VOCs). They have short response times and a sensitivity and limit of detection suited to the levels targeted for monitoring ambient air and indoor environments. Their energy consumption and limited battery life are a hindrance for embedded applications. Strong cross-interference (between measurement conditions, certain co-pollutants and the target pollutant) have also been reported. This last point can be corrected by supervised learning.
Electrochemical cell systems are sought after for their selectivity, particularly regarding inorganic gases. However, this solution is more expensive and has two major disadvantages: a limited lifespan and a long response time, which is especially problematic for rapid pollution dynamics, for example during mobility phases.

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[3] The terms "personal sensor system" and "individual sensor system" are sometimes used in the literature.
[4] The term mobile sensor system is generally used in the transport sector. It encompasses the use of in-vehicle sensor systems fitted by default and also the movement of people equipped with portable sensor systems.

Photoionisation detectors (PIDs) are popular as indicators of total VOCs and have a very short response time, but their price often limits their use to sensor systems that are less accessible to the general public.

For CO_2, non-dispersive infrared sensors (NDIRs) have excellent metrological performance and should be preferred to any other technology.

Lastly, for particulate matter, optical technologies based on infrared diffraction are widely available on the market. The mass concentration is deduced from a count of the number of particles, regardless of their type. The sensing element is modestly priced and it is the airflow chamber[5], the associated data processing and the precautions taken when using the device that guarantee the quality of the data obtained from the complete sensor system.

- Sensor system use chain and associated terminology:

The diagram in Figure 1 shows a typical use of a sensor system.

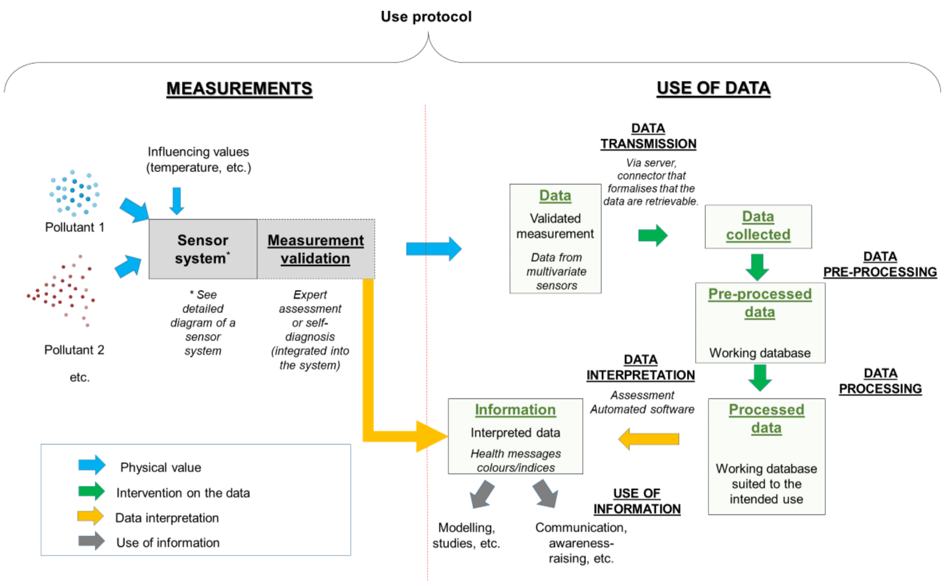

Figure 1: Typical use of a sensor system

The main steps in the sensor system use chain can be summarised as follows:

- Measurement: detection or measurement of the concentration of a compound (gas, aerosol) over a predefined time interval. This step includes a measurement validation phase corresponding to a check of the sensor system's correct functioning that can either be integrated in the system (self-diagnosis) or carried out using external

[5] "Airflow chamber" means a compartment in which the sensing element, sensor or sensor system is placed, and whose geometry is specifically designed to optimise airflow, either passively or actively (e.g. with a pump) and thus maximise the sensor system's overall response to the target pollutants.

expertise. This step also includes the recording of metadata and context attributes that describe the measurement setting and environment;

- Data transmission and storage: this step depends on the communication mode used by the sensor systems and the arrangements for storing data on a remote server, memory card or mobile device;
- Data pre-processing: establishing a consistent working database by identifying and removing artefacts and background noise, and dealing with missing values;
- Data processing: transformation of data for specific uses and analyses (for example, creation of variables, spatial and temporal aggregation, enhancement with external data such as station measurements). An estimate of individual exposure can then be provided based on the three elements of time, place and concentration;
- Data interpretation: specific analysis of the processed data according to the purpose of the measurements. This step requires expertise but can also be integrated in the sensor system, which then provides information such as health messages, pollution indices or recommendations based on indicators defined by the manufacturers.
- Use of information: the interpreted data are referred to as information and used to communicate and raise awareness among the population. They can also be used in modelling systems or research studies. When these devices are intended for private use, the general public will usually have direct access to the information provided by the sensor system.

There can be a validation process at each step to ensure that the various operations have been carried out in a way that is consistent with and appropriate to the purpose of the measurements.

■ Discussion of the indicators used by the manufacturers of sensor systems:

Most manufacturers of sensor systems, especially those intended for the general public, not only give a numerical value for the concentrations of measured pollutants, but often suggest different ways of interpreting these values. Each manufacturer can propose its own indicators for each of the measured pollutants or calculate an air quality index from the total concentrations of the measured pollutants. These indicators are sometimes based on existing air guideline values, such as those proposed by the World Health Organization (WHO), but this is not always the case and is not always explicitly stated by the manufacturers. The associated references and the way in which these indicators or indices are established are generally not documented.

The sensor system may display a comparison of the measured values with the predetermined indicators:

- A colour variation according to the level of the values measured in relation to the predetermined indicators;
- A semantic categorisation of the pollution level or its health impact in relation to the predetermined indicators.

Sensor system data are acquired in near-real time. However, guideline values such as those of the WHO are generally associated with hourly or even daily or annual exposure durations, which are much longer than the measurement interval of sensor systems. These guideline values cannot therefore be used to interpret point concentrations measured by sensor systems. Moreover, these guideline values are established at the population level and cannot be compared with individual exposure data. There is therefore a clear discrepancy between the interpretation of data from sensor systems and any resulting health interpretation at the individual level.

■ Stakeholders involved in the implementation of sensor systems:

The different stakeholders involved in the implementation of sensor systems and identified by the Working Group are: suppliers of the sensors or sensor systems, initiative/project sponsors, operators, users, data disseminators and legal data controllers. The latter have a key role to play, as the data generated by sensor systems fall within the scope of the General Data Protection Regulation (GDPR).
It should be noted that the same legal or natural person can play one or more roles.

3.1.2. Overview of projects on sensor systems

The Working Group identified many projects in different potential application areas for sensor systems.
The main standardisation work is carried out in Europe by the working group on air quality sensors within the European Committee for Standardisation (CEN/TC 264/WG 42). A first report on gaseous pollutants was expected in April 2022. In France, AFNOR published in December 2021 a booklet entitled "Concepts on the use of sensor/sensor system type devices" (FD X43-121). Lastly, in 2020, the French National Institute for Industrial Environment and Risks (Ineris) and the National Metrology and Testing Laboratory (LNE) introduced voluntary certification of sensor systems for monitoring ambient air quality at fixed points (Air'Quality Sensor).
Several studies to assess sensor systems have also been carried out in France, Europe and the United States. The main ones are as follows:

- National proficiency testing for air quality monitoring sensor systems (Central Laboratory for Air Quality Monitoring – LCSQA);
- AIRLAB Challenges;
- Joint Research Centre (JRC) laboratory and field assessment work, intercomparison exercise as part of the European EuNetAir project;
- Work by the US Environmental Protection Agency (US-EPA);
- Work by the US Air Quality Sensor Performance Evaluation Center (AQ-SPEC).

The analysis of this work shows that the field of sensor system assessment is changing rapidly. The studies have different objectives and are based on protocols and criteria that differ within the same country, from one country to another, or from one pollutant to another. The expected performance levels depend on the sensor system and its intended purpose. However, under conditions equivalent to those recommended by air quality monitoring regulations, the sensor systems have lower data quality objectives than those achieved by the devices used in reference methods.

Many projects involving citizens have also been carried out to date or are under way, with different aims. Some of them seek to inform and raise awareness about air pollution. Other projects have led to the development of platforms for viewing and sharing data from sensor systems.

Regarding these projects, it is important to distinguish the following:

- Platforms from open-source projects, the main ones being *Sensor.Community* and *AirCasting*. These rely exclusively on data from sensor systems.
- Platforms operated by manufacturers and distributors of sensor systems, which aggregate different sources of air pollution data. These platforms do not distinguish between data generated by sensor systems and data from other sources (reference measurement stations or modelling).

3.1.3. Special case of CO_2 sensor systems

The market for CO_2 sensor systems has expanded rapidly as a result of the COVID-19 epidemic and ministerial circulars recommending or requiring that CO_2 be measured in the indoor air of public spaces.
CO_2 is an indicator of indoor air containment but not of its quality. Sensor systems should be selected and assessed with care as regards the technologies used to provide reliable information on the CO_2 concentration in the air (e.g. measurement principle, self-calibration, control of sensor drift).

3.1.4. Review of studies focussing on individual exposure assessment

Estimating individual exposure should preferably be based on portable measuring devices that allow direct characterisation of the different microenvironments frequented by individuals.

■ Contributions of sensor systems for assessing individual exposure

Due to their small size and low initial purchase cost, sensor systems offer many opportunities in the area of individual exposure assessment:

- A substantial increase in the number of measurements and improved spatial and temporal coverage: increase in the number of participants equipped with portable sensor systems, in the number of measurement points in a microenvironment and/or in the number of equipped microenvironments, especially in places that have been overlooked or rarely studied. This growth in the number of sensor systems worn by an individual or placed in a microenvironment enables different pollutants to be measured;
- For portable sensor systems: more ergonomic and lightweight sensor systems means a greater likelihood that they will be worn correctly by participants. In recent years, improvements in sensor systems have focused on their battery life, design and ergonomics, making them easier and more comfortable to use (e.g. acoustic comfort) and therefore potentially more acceptable;
- A higher temporal resolution enabling, for example, a detailed study of the different microenvironments contributing to an individual's total exposure.

■ Limitations of sensor systems for assessing individual exposure

The main limitations of sensor systems in the area of individual exposure assessment are listed below:

- Limited metrological quality, lack of selectivity of sensor systems and sensitivity to interfering factors;
- In some cases, non-comparability[6] of the data generated between sensor systems or between a sensor system and a measuring device used in a reference method;
- Global costs related to the implementation of sensor systems;
- Environmental impact, due to the limited lifetime of the sensor systems;
- Maintenance operations that are not formalised or rigorously followed;
- Constraints related to the acceptability of wearing sensor systems over long periods of time to assess long-term exposure, and to the proper use and correct positioning of the sensor systems;
- For some sensor systems, constraints related to a lack of connectivity, for people living in areas not covered by telephone networks ("white zones");
- Constraints related to the consideration of personal data protection.

■ Studies on individual exposure assessment using sensor systems

A relatively small number of studies on the use of sensor systems to assess individual exposure were identified in the literature or *via* the international consultation and hearings (N = 62). The number of studies actually assessing the health effects of air pollution was even smaller (N = 11). The identified studies had a variety of objectives, ranging from the simple measurement of concentrations in air to a quantitative assessment of individual exposure, or even of the inhaled dose, and the associated health effects.

An analysis of these studies showed that the sensor systems used are restricted to the research field and are not accessible to the public mainly due to their cost. Furthermore, almost half of the identified studies do not mention any metrological qualification of the sensor systems.

3.1.5. Key points to consider to ensure that data generated by a sensor system in a study can contribute to the assessment of individual exposure

The key points to consider to ensure that data generated by a sensor system in a study[7] can contribute to the assessment of individual exposure are firstly, the intrinsic parameters of the

[6] "Non-comparability" refers to the fact that two sensor systems, or a sensor system and a measuring device used in a reference method, do not necessarily share the same measurement units, the same physical principles of detection, the same conditions of use, the same metrological performance, etc. despite focusing on the same target pollutant. Consequently, comparing data from one or other of these measurement tools does not always make sense.

[7] The use of sensor systems in a study framework should be distinguished from the use of sensor systems.

sensor system and secondly, the information that needs to be mentioned in the study in order to use the data generated by a sensor system to assess individual exposure.

These key points were identified by considering the different purposes for which sensor systems are used and each link in their chain of use. The criticality of each key point was then rated in relation to the target objective, and according to the different possibilities of implementing sensor systems (fixed / portable / mobile):

- Essential: If information on the key point is not available, the measurement cannot be used to assess individual exposure;
- Useful: Knowledge of this key point improves the quality of interpretation or confidence in the result;
- Optional: Knowledge of this key point helps refine the interpretation.

All the key points are presented in Annex 2.

Among the key points rated as essential, it is important to ensure that:

- The sensor system can specifically identify the pollutant to be measured;
- The sensor system has been metrologically pre-qualified, i.e. its specifications[8] have been checked for compatibility with the intended purpose;
- The reliability of the data has been documented, especially with regard to data quality and the robustness of data transmission;
- The sensor system is used correctly and this use is documented, e.g. its positioning, ensuring that the spatial and temporal coverage is sufficient and provides representative measurements;
- All the environments frequented, activities planned and unforeseen events have been described.

3.1.6. Health interpretation of data generated by sensor systems in a study framework or by comparison with health reference values

For conducting epidemiological studies, because of their advantages and limitations in assessing individual exposure, sensor systems appear to be particularly appropriate for assessing short-term exposure, i.e. from a few hours to a few days, rather than long-term exposure. Individual exposure measurements can be used to refine dose-response relationships with health indicators collected at the individual level.

Furthermore, for conducting quantitative health risk assessments (QHRAs) or quantitative health impact assessments (QHIAs), the suitability of the data generated by the sensor systems and the health values (toxicity reference values – TRVs, or concentration-risk relationships) should be discussed with regard to:

- Time: the data generated by the sensor systems should be expressed over a time interval comparable to that for which the TRV or concentration-risk relationship was established (QHRA) or consistent with the selected study period (QHIA);

[8] Performance in relation to determination of a measurand such as a concentration.

- The variable measured by the dose-response relationships;
- The study population: the sensor systems should be deployed in sufficient numbers to be representative of the study population, given that interpretation at this level is only possible on a population scale.

3.1.7. Specific case of private users of sensor systems

The data from some sensor systems may mislead individuals about what they think they are "measuring". This is because the sensor system provides an indication of the concentration measured in the air at a specific time and place. This concentration does not reflect the individual's integrated exposure over time. In addition, individual data from a sensor system generated in near-real time cannot be compared to an indicator based on a guideline value or a TRV/concentration-risk relationship established at population level for a longer interval, to inform the user about a potential health risk.

Moreover, the descriptions such as "air microsensor" or "air quality sensor" used by some manufacturers/distributors of sensor systems can be confusing. Equating the measurement of one or more air pollutants with "air quality" masks the complexity of the issue of air pollution, whether in indoor or outdoor air.

Furthermore, sensor systems are useful for relative and qualitative comparisons of concentration levels to which individuals are exposed in the different microenvironments in which they live, provided that these sensor systems are metrologically valid and used correctly. Sensor systems are also useful for identifying possible sources of pollution and acting accordingly.

The compilation and use of privately generated data for research purposes is hampered by the many disparities associated with these data, in the absence of a protocol for the use of sensor systems. Furthermore, comparing the generated data with health values raises the same issues as those discussed for QHRAs/QHIAs (time, value measured by the dose-response relationships, representativeness of the study population).

It is argued that the huge volumes of individually generated data could be used to smooth out their imperfections, but this remains an open question. Lastly, these huge volumes of data may be able to approximate the exposure of a study population and enhance the mapping and modelling of air pollution.

3.1.8. Legal status of data generated by sensor systems

The deployment of sensor systems by individuals raises the issue of personal data protection when the data generated by these systems are associated with geolocation data that could lead to the natural persons participating in the acquisition of these data being identified, whether directly or indirectly. Most of the time, data from a measurement in the air will be personal data in relation to its geolocation.

The data controller is responsible for verifying compliance with the framework for the protection of natural persons with regard to the processing of personal data (General Data Protection Regulation-GDPR). The legal basis for the collection and processing of personal data is the consent of participants, which is given on the basis of information on the purpose of the data processing, the duration of data storage, and a reminder and guarantee of the recognised rights of the persons concerned (right to access, rectify, object to, withdraw, for the entire duration of data storage). If the data are rendered anonymous, the obligations of the GDPR no longer apply. However, the complete anonymisation of personal data is a complex process. Data made available as "open data" must comply with the GDPR.

3.1.9. Review of the profiles and motivations of sensor system users

The developments presented in the report (Volume 2) are based on both a literature summary and analytical reflections on the issue of citizen measurements of air quality. A dual survey of project sponsors *via* interviews and of sensor system users through two online questionnaires also provided quantitative and qualitative results. Questionnaire A, intended for participants in supervised measurement campaigns, was distributed *via* project coordinators[9], and questionnaire B, intended for private users, was distributed *via* communication networks of the *Sensor.Community* platform in France, and more rarely by sensor system manufacturers interviewed for the expert appraisal.

The information collected *via* the online questionnaires mainly concerned participants in supervised measurement campaigns: 151 respondents for questionnaire A compared with 8 respondents for questionnaire B. The low response rate for questionnaire B was due to difficulty gaining access to private users of sensor systems, in the absence of networks to disseminate the questionnaire widely. As a result, the information presented in the *ad hoc* part of the report almost exclusively concerns participants in measurement campaigns.

The report's conclusions were as follows:

- Health was reported as being the primary reason for participation;
- Assisted measurement was seen as guaranteeing the success of the projects (training, maintenance, taking of measurements and intelligibility of measurements): this underlines the importance of the collective nature of citizen campaigns;
- The socio-demographic profiles identified in this study were both expected and unexpected. In most cases, the participants were highly educated. Profiles of labourers and technicians among individuals involved in associations were also identified. "Technophile" profiles were also noted among individual users having built their own sensor systems.
- Sensor systems make a decisive contribution in terms of improving knowledge on pollution and good practices. Sensor systems help acquire or consolidate knowledge about air pollution and its measurement techniques, and lead individuals to change their way of thinking about air pollution;
- Most participants were willing to pursue measurements and actions, resulting in:
    - more in-depth knowledge, the development of good practices for the user's own health and that of others;
    - the initiation of actions concerning modes of travel and lifestyles.

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[9] Projects contacted in order to distribute Questionnaire A: Polluscope, Captothèque, BBclean, Ambassad'air, Captothèque and Qalipso.

3.2. Conclusions of the CES

The field of sensor systems has been growing rapidly in recent years, with a multitude of technologies available on the market and an increasing number of studies and projects on the topic.

- Review of projects on sensor systems

Until now, studies of sensor systems have mainly focused on assessing their metrological performance, in the absence of a regulatory framework for comparing these devices with the measuring instruments used in reference methods. This has led to several projects designed to inform users about the capabilities of sensor systems and guide them on the choice of device according to the intended use. The accuracy and reliability of measurements from sensor systems, although highly variable depending on the technology and pollutants[10], are still lower than those expected in the reference methods. However, improvements are under way. In addition to metrological quality, other parameters to consider when choosing a sensor system are its size, battery life, portability and price. Besides the possible environmental impact of the deployment of sensor systems, this parameter may be a criterion when choosing these devices, taking into account factors like lifespan, place of manufacture and data storage and transmission methods. Since 2010, many projects involving citizens have been carried out to raise public awareness about air pollution. Platforms for viewing and sharing the generated data have emerged, initially intended for study participants but then opened up more widely. Some manufacturers also offer their own mapping tools, although it is not always clear how to distinguish between data from sensor systems and other data from reference measurement stations or modelling.

This wider access to data on air quality provided by sensor systems is in addition to the data produced by approved air quality monitoring associations (AASQAs) and could therefore lead the public to query the differences observed between data from sensor systems and official data. These discrepancies are due to several factors, in particular the lower metrological quality of the sensor systems compared with the reference methods for official data, and differences in spatial and temporal resolution (area and period of data integration). These new sources of data are also leading institutions to change their practices and consider how to use these devices and the data they generate for various purposes (raising awareness, changing behaviour, monitoring, etc.).

- Use of sensor systems to assess individual exposure to air pollution

Sensor systems offer many opportunities in the area of individual exposure assessment. Thanks to miniaturisation, portable sensor systems can easily be worn by individuals during their daily activities. This enables the devices to integrate the different microenvironments frequented and the exposure conditions specific to each individual, with measurements in near real time. On a larger scale, the initial purchase cost and small size of the sensor systems also leads to a multitude of measurement points and devices being deployed in microenvironments that have been overlooked or rarely studied to date. However, the metrological quality of the pollutant concentration measurements remains the main limitation of these systems.

Sensor systems have only recently begun to be used for assessing individual exposure to air pollution. Projects in this field vary widely in terms of means and associated objectives, ranging from feasibility studies with very few participants to multi-year projects involving large

[10] For example, black carbon sensor systems offer better accuracy and reliability than VOC sensor systems.

populations. In almost all the studies, the sensor systems are devices reserved for the research field (higher costs, more complex implementation) or developed specifically for the needs of the study. Half of the publications do not explicitly refer to any metrological qualification of the sensor systems (even though it can be assumed that the teams have ensured the validity of the system used), thereby limiting the confidence placed in the results. None of the studies refer to any qualification of sensor systems used while on the move. This may be due to the emerging nature of mobile applications and their assessment protocols.

Although these devices are easy to wear, the acceptability of wearing them for long periods of time can be problematic and their battery life is still limited, which makes them more suited to studying short-term exposure. In the identified studies, the sensor systems were used for short periods (1 week to 10 days), sometimes repeatedly. Exposure assessment was based on space-time-activity budget data and sometimes on mobility surveys. Data from sensor systems are regularly supplemented by data from reference measurement stations and/or modelling.

Sensor systems are therefore seen as devices that complement the data sources or exposure assessment methods already used in exposure science studies. In addition, sensor systems could help optimise mapping (on spatial and temporal scales) and large-scale models, thus helping to improve the estimation of exposure to air pollution.

- Key points to consider to ensure that data generated by a sensor system can contribute to the assessment of individual exposure

The analysis showed that besides the metrological accuracy of the sensor system, which is still the main condition for assessing individual exposure, many other points need to be satisfied. Among these key points, those related to the contextualisation and implementation of the sensor system(s) (representativeness and spatial and temporal coverage, description of the microenvironments frequented, activities planned and unforeseen events) are paramount.

- Health interpretation of data generated by sensor systems in a study framework or by comparison with health reference values

With regard to health, the use of exposure data generated by sensor systems (deemed valid) with a view to conducting a QHRA or QHIA requires consideration of whether these data are aligned with the dose-response relationships established for hourly, daily or annual exposure that will be used to quantify the health risk. Suitable use therefore requires that measurements from sensor systems be integrated over the same interval as that used to establish the dose-response relationship. In addition, these measurements need to be repeated over the year in order to be representative of the exposure studied over the medium or long term. Furthermore, data generated by a portable sensor system, integrating the different sources to which an individual is exposed, cannot be considered as representative of population exposure. It is therefore important to ensure that the sensor systems are deployed in sufficient numbers to be representative of the study population.

Moreover, while sensor systems are particularly relevant for studying the short-term effects of air pollution at the individual level, they can also contribute to assessing the effects of air pollution on larger scales (fixed sensor systems and/or via improved mapping and models).

- Specific case of private users of sensor systems

The private use of sensor systems is valuable for identifying sources or places of exposure, or spatial and temporal variations, provided that the device has been metrologically qualified and the conditions of use are appropriate. Understanding the measurement data requires a certain degree of expertise, in particular a good knowledge of the capabilities and limitations of sensor systems. In most cases, the sensor systems provide visual information on the level of pollution, or messages on the health risk (colour codes, alerts). Such information should be treated with caution, as the way in which it was developed is usually not explained and is unsuited to near-instantaneous measurements. An adequate understanding of the information would also require a good knowledge of the different health reference values and the way in which they have been established. Support in correctly understanding this information is therefore essential. Lastly, equating the measurement of one or more air pollutants with "air quality" masks the complexity of this notion, which cannot be reduced to just a few pollutants, whether in outdoor or indoor air. As an example, so-called "air quality" sensor systems only measure CO_2 in indoor air, or particulate matter in outdoor air.

The use of sensor system data generated by individuals on a massive scale, outside any study framework, is hampered by metrological limitations. It could be argued that huge volumes of measurements could compensate for this low metrological quality, but this would require the use of sensor systems with different technologies and/or calculation algorithms.

Moreover, massive use of sensor systems by individuals poses difficulties in compiling the data generated. These difficulties may, for example, be related to the metrological quality, the implementation methods, the accessibility of the generated data, or the information provided by different sensor systems. This field of study, which is still in its early stages, may require investigation of the methods of data collection, processing and dissemination.

- Review of the profiles and motivations of sensor system users

The review of the profiles and motivations of sensor system users (Volume 2) showed that sensor systems can be a means for scientific mediation and citizen participation, provided that "citizen sensor" groups are supported during measurement campaigns. These campaigns, engaging groups with diverse profiles whose primary motivation is their health and that of their families, therefore lead the participants to adopt new habits in their living and travelling behaviour. Some technophile users are also motivated by making all or part of their own sensor systems. Most of the people questioned reported an improvement in scientific knowledge and an increase in technical skills on all aspects of air quality (physico-chemistry of pollution, health effects, socio-geographical disparities).

- Legal status of data collected by sensor systems

Lastly, great care needs to be taken with the use of data generated by sensor systems in terms of personal data protection when their use enables the person carrying out the measurements to be identified, whether directly or indirectly. In Europe, the use of personal data is governed by the GDPR, which provides a general principle on the collection and processing of personal data. The data controller is a central player who must ensure that personal data is respected.

- Outlook

The popularity of sensor systems, their technological developments and easy access are contributing to a market that is developing outside any regulatory framework. The use of sensor systems by a growing number of users and experts is leading to a multitude of data, and technological advances in the measurement chain are increasing everyone's expectations regarding the level of data quality.

There is great potential for progress in the principles of detection. Although the market for sensing elements has changed little in recent years, solutions derived from research, such as the use of new functionalised nanocomposites, measurement using acoustic waves or quartz microbalances, or the miniaturisation of optical or photoacoustic methods, could lead to new technological breakthroughs in the short or medium term.

In addition, a major improvement in performance is expected from deploying these sensing elements in units where the airflow chamber has been designed and optimised to maximise their response; the integration of functionalised filters and the physical compartmentalisation between the measurement space and the acquisition electronics will also help limit cross-interference and the influence of parameters such as humidity, temperature and electromagnetic waves.

Lastly, recent advances in data processing and artificial intelligence should also increase the quality of the information delivered by sensor systems.

3.3. Recommendations of the CES

The CES is making the following recommendations for manufacturers and distributors of sensor systems, private users, research players and public authorities.
The CES alerts these various stakeholders to the fact that because of their geolocation, data from sensor systems may constitute personal data, potentially including information on users' lifestyles. **The CES therefore recommends that all stakeholders ensure compliance with the regulations on personal data protection (GDPR), drawing on the recommendations of the French Data Protection Authority (CNIL).**

3.3.1. Recommendations for manufacturers and distributors of sensor systems

The CES recommends that developers, manufacturers and companies marketing sensor systems:

- continue efforts to improve the metrological quality of sensor systems;
- document information on metrological performance, conditions of use and interpretation of the generated data, and make it accessible to all users. On this point, the CES encourages sensor system manufacturers to participate in the various assessment schemes for sensor systems, ranging from inter-comparisons with a reference method (AIRLAB Challenges, LCSQA proficiency tests) to voluntary certification of their performance with regard to the Ambient Air Quality Directive[11] (LNE/INERIS – Air'Quality Sensor);
- conduct or support research into the physical principles of detection, for both gaseous and particulate compounds;
- develop sensor systems for pollutants of health interest, especially those identified by the WHO[12] and other official agencies[13], and multi-pollutant sensor systems.

The CES points out that data from sensor systems can be compared with air quality guidelines if the data generated in near-real time are integrated over an adequate interval. Moreover, the CES reiterates that these guideline values, defined at population level, are unsuitable for interpreting a risk at the individual level. The CES therefore suggests that relative exposure indicators be developed that allow an individual measurement to be viewed in relation to comparable measurements. This would help inform users about their exposure in relation to

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[11] Directive 2008/50/EC on ambient air quality and cleaner air for Europe
[12] https://www.euro.who.int/__data/assets/pdf_file/0013/301720/Evidence-future-update-AQGs-mtg-report-Bonn-sept-oct-15.pdf
[13] ANSES, LCSQA, OQAI, US-EPA.

that of others, or about their own exposure over a given period of time and in a given microenvironment.

3.3.2. Recommendations for private users of sensor systems

The market for sensor systems is evolving, with a multitude of devices having varying levels of performance. As the relevance of a sensor system depends on its intended purpose, the CES recommends that individuals or groups wishing to obtain and implement one or more sensor systems:

- find out about public metrological assessments, related to the AIRLAB Challenges (Airparif), aptitude tests (LCSQA) or voluntary Air'Quality Sensor certification (LNE/Ineris), or about international work, in order to choose a sensor system that is suited to the intended use;
- read existing documentation (user instructions provided by sensor system manufacturers and distributors, reports, online platforms) in order to:
    - implement the sensor system: functioning, correct use (wearing, location), technical limits (interference, potential drift over time);
    - understand the information provided by the sensor systems and the resulting recommendations:
        - nature of the pollutants measured in view of the health issues of air pollution;
        - knowledge of the indicators currently used by sensor system manufacturers with regard to regulatory limit values or guideline values for air quality;
        - recommendations for good practices to limit exposure to air pollution (modes of transport, ventilation, etc.).

3.3.3. Recommendations for researchers

The CES points out that sensor systems offer opportunities for assessing individual exposure to indoor and/or outdoor air pollution.

- Recommendations for conducting studies using sensor systems to assess individual exposure to indoor and/or outdoor air pollution

In order to carry out such studies, the CES recommends that project sponsors wishing to use sensor systems, like the users themselves, begin by finding out about public metrological assessments. The choice of a fixed or portable sensor system should take the purpose of the study into account. For portable sensor systems, the device should be ergonomic to avoid altering the wearers' behaviour and best reflect their actual exposure.

The CES also recommends:

- complying with all the key points defined in this expert appraisal to ensure that data generated by a sensor system can contribute to the assessment of individual exposure (see Annex 2);
- ensuring that sensor systems are properly maintained[14];

[14] Calibration before deployment, check for drift, battery level/charge status and its possible influence on the signal, comparison of sensors/reproducibility test, check of sensing elements' lifespan.

- assisting study participants in the correct use of the devices, and in understanding the data generated and how they are used.

In addition, the CES recommends:

- further developing public databases of studies using sensor systems to assess individual exposure.

Lastly, the CES encourages:

- broad and operational sharing of feedback from projects using sensor systems to assess individual exposure;
- the deployment of multidisciplinary projects bringing together skills in metrology, data science, exposure science, epidemiology and human and social sciences, given the multitude of disciplines involved in this type of project.

■ Recommendations for improving knowledge of the health risks associated with air pollution

The CES recommends that the opportunities offered by sensor systems be considered for:

- improving estimates of individual exposure;
- acquiring exposure data in places that have been overlooked or rarely documented;
- studying the contribution of different microenvironments to the overall exposure of individuals;
- studying the determinants of exposure;
- studying the links between exposure and health.

The CES stresses that sensor systems can be coupled with devices measuring heart rate or respiratory rate to enable a more detailed study of additional exposure indicators such as the inhaled dose.

Lastly, the CES has identified opportunities for research:

- on the development of methods for collecting and processing huge amounts of data to pair them with other data on the determinants and/or effects of exposure;
- on the use of sensor systems in patient support and therapeutic education.

■ Recommendations for research into the development of sensor systems:

The CES recommends developing work on:

- the integration of huge amounts of data from heterogeneous sources, from collection through to processing;
- sensor system networks, in particular, advanced management and calibration techniques, optimisation of their deployment;
- data qualification;
- the development of automation and data pre-processing methods;
- the implementation of mobile sensor systems and the assessment of how mobility affects the quality of the measurement.

Furthermore, the CES recommends developing research work combining atmospheric modelling and dense and/or mobile networks of sensor systems.

3.3.4. Recommendations for public stakeholders (agency, authorities, etc.)

The CES recommends that public authorities:

- introduce the assessment or certification of sensor systems according to their intended use;
- encourage the development and funding of multidisciplinary research projects, in particular for exposure assessment and interpretation of the health impact;
- obtain feedback from current projects on the use of sensor systems to assess individual exposure;
- encourage the provision of information from assessments of sensor systems to users;
- raise awareness among users about the correct use of sensor systems and about understanding and interpreting the information generated.

In particular, for institutions responsible for air quality monitoring, the CES recommends:

- continuing discussions on the integration of data from sensor systems with data produced by current monitoring networks, in consultation with all the players involved.

4. AGENCY CONCLUSIONS AND RECOMMENDATIONS

The French Agency for Food, Environmental and Occupational Health & Safety endorses the conclusions and recommendations of the CES on “Assessment of risk related to air environments” presented above.

The Agency stresses that the emergence of sensor systems (also called microsensors), combined with the population's growing awareness of the health impact of air pollution and the strong growth in the use of connected objects, has initiated a wave of democratisation over the past decade in the field of air quality monitoring, which until now had been reserved for research and regulatory monitoring.

The Agency notes that despite their limited metrological quality, sensor systems offer many opportunities for addressing the various issues related to indoor and outdoor air pollution, particularly through improved spatial and temporal coverage and the possibility of studying the various microenvironments contributing to an individual's total exposure. Nevertheless, an accurate exposure assessment needs to be based on studies that meet the criteria/lists of key points identified in the expert appraisal, in order to reinforce data quality. The Agency calls for caution regarding the interpretation functions sometimes integrated in the sensor systems, as they are based on data timescales and thresholds that are unsuitable for assessing an individual health risk. The Agency therefore informs private users of sensor systems that these devices can currently only be regarded as tools to promote awareness, solely enabling them to perform a relative and qualitative comparison of the concentration levels to which they are exposed, or to identify possible sources of pollution, so they can act accordingly to reduce their exposure (for example by modifying their travel behaviour).

Specifically regarding the measurement of CO_2, especially in establishments open to the public and in view of the many sensor systems on the market, the Agency stresses that the devices should be selected with care in order to provide reliable information that is suited to the intended purpose.

Furthermore, the Agency insists that sensor systems are not suited to communicating at the individual level about a potential health risk to the user from air pollution. On the other hand, it may be possible to use huge volumes of privately produced data to approximate the exposure of a population and enhance the mapping and modelling of air pollution, thus contributing to the assessment of the effects of air pollution on a larger scale.

In addition, the Agency is currently considering how to raise the awareness of its expert committees and gradually introduce into its expert appraisals the various components of the exposome[15], such as multi-source, multi-substance and multi-hazard exposures, which depend, among other things, on lifestyle habits and the urban, rural and social environment. In this context, sensor systems are proving valuable in making the exposome concept operational in environmental health studies, by improving knowledge of individual exposure and health risks associated with air pollution.

Lastly, the Agency notes that citizen initiatives more broadly involve players with many different types of knowledge[16] working to preserve a common good. The Agency therefore highlights the value of setting up experiments and initiatives in research and participatory science in the field of environmental health, based on sensor systems in a given region, in order to improve knowledge production. This would also provide an opportunity to conduct methodological discussions on the building of expert/non-expert knowledge, and promote social cohesion and the development of scientific and technical culture within the population associated with the process. This contribution of knowledge and a better understanding of the problems associated with air pollution are elements that favour citizen action to tackle the issue of air quality.

Dr Roger Genet

[15] ANSES proposes the following definition for the exposome: "The exposome corresponds to all the exposure to chemical, biological and physical agents, both harmful and beneficial, in interaction with the living environment and the psycho-social context, experienced by a living organism from its conception through to the end of its life, complementing the effect of the genome in order to explain its state of health."

[16] Computer science, engineering, metrology, electronics, chemistry, geophysics, geography, sociology, design, data science, etc.

KEY WORDS

Micro-capteurs, Systèmes capteurs, air intérieur, air extérieur, exposition individuelle, pollution atmosphérique, effets sanitaires, sciences participatives, profils, motifs d'engagement

Sensors, indoor air, outdoor air, personal exposure, air pollution, health effects, participatory science, profiles, motivations

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ANNEX 1: METROLOGICAL PERFORMANCE AND COSTS OF THE MAIN TYPES OF PARTICULATE MATTER, BLACK CARBON AND GAS SENSORS

Technologies	Compounds measured	Advantages	Disadvantages	Cost
Semiconductor	NO_2, O_3, CO, VOCs, TVOCs	- Good sensitivity (µg/m^3 to mg/m^3). - Short response time (from a few seconds to a few minutes).	- Generally non-selective. - Interference with CO_2 for TVOC measurement and vice versa. - Long-term instability. - Power consumption due to the heating element	€
Electrochemical cell	NO, NO_2, SO_2, O_3, CO	- Good sensitivity (µg/m^3 to mg/m^3). - Low power consumption.	- Strong interference from environmental conditions such as humidity and/or temperature. - Sensitive to interfering chemicals within the same oxidant family (e.g. interference from O_3 on NO_2 measurement). - Rather long response time (several minutes to several tens of minutes). - Lifetime directly related to exposure concentration.	€€
Photoionisation detector (PID)	- Inorganic compounds (ammonia, chlorine)	- Good sensitivity (up to mg/m^3 or even tens of µg/m^3).	- Non-selective: simultaneous detection of organic compounds whose ionisation energy is lower than the energy of the UV lamp.	€€€

Technologies	Compounds measured	Advantages	Disadvantages	Cost
	- Volatile organic compounds (list varies depending on the UV lamp used, normally a 10.6 eV lamp)	- Short response time (a few seconds).	- Sensitivity to high humidity (RH>70%). - Rapid drift in response over time.	
Optical measurement (IR absorption spectroscopy)	CO, CO_2	- Good sensitivity (a few hundred to a few thousand ppm). - Short response time (from 20 to 120 s). - Low drift over time	- Sensitive to environmental conditions (temperature, humidity and pressure).	€€
Optical counting (photometry, nephelometry)	Particulate matter	- Good sensitivity (a few µg/m^3). - Short response time (a few seconds, provided there is a suitable airflow chamber)	- Uncertainty induced when calculating mass concentration from the number count by assuming an ideal aerodynamic diameter that does not take the particle type into account. - Clogging of the photosensitive cell - minimum diameter detected = 300 nm	€
Optical measurement (transmittance)	Black carbon	- Excellent sensitivity (a few hundred ng/m^3). - Short response time (minute)	- High uncertainty with regard to the thermo-optical reference measurement - Use of consumables for sampling (high cost)	€€€

Technologies	Compounds measured	Advantages	Disadvantages	Cost
€: from a few euros to a few dozen euros; €€: from a few dozen euros to a few hundred euros; €€€: from a few hundred euros to a few thousand euros.				

ANNEX 2: LIST OF KEY POINTS TO CONSIDER TO ENSURE THAT DATA GENERATED BY A SENSOR SYSTEM CAN CONTRIBUTE TO THE ASSESSMENT OF INDIVIDUAL EXPOSURE

Key points to consider – Quality of the measurement

Key points	Requirements	Criticality		Objectives	Intrinsic to the sensor or available in the study
		Fixed	Portable /Mobile		
Identification of the pollutant to be measured in the target environment	Specific identification essential	Essential		Any objective	Intrinsic
Monitoring of pollutant levels in the target environment	Ordinal scale	Essential		Any objective	Intrinsic
Initial assessments before handling / Metrological pre-qualification, Calibration if necessary	Consistency with the study context: manufacturer tests or laboratory tests or user tests under similar conditions of use	Essential		Any objective	Study
Reproducibility (variability between sensors under the same conditions of use)	Compatible with the study objective	Useful		Any objective	Study
Accuracy *(combination of trueness and precision)*	Compatible with the study objective	Essential		Measurement of concentrations	Study
		Useful		Other objectives	
Value of limit of detection and/or limit of quantification	As low as possible and compatible with the study objective	Essential		Exposure quantification, link with a health effect Measurement of concentrations	Intrinsic
		Useful		Other objectives	
Concentration range (min-max)	Compatible with the investigated environment	Essential		Any objective	Intrinsic
Measurement resolution	Compatible with the intended use	Essential		Any objective	Intrinsic
Knowledge of other parameters: drift, linearity, influence of T° or humidity, interference with other chemical species	-	Useful		Any objective	Intrinsic
Sensor response time	Must be able to detect rapid changes in the environment	Useful	Essential	Any objective	Intrinsic
Sampling frequency over the acquisition interval	Compatible with the study objective Understand the duty cycle: duration of the	Useful		Intrinsic	Intrinsic

Key points	Requirements	Criticality		Objectives	Intrinsic to the sensor or available in the study
		Fixed	Portable /Mobile		
	active state in relation to a periodic phenomenon				
Time stamping / synchronisation	-	Essential		Any objective	Intrinsic

Key points to consider – Contextualisation/Implementation of the sensor system

Key points	Requirements	Criticality		Objectives	Intrinsic to the sensor or available in the study
		Fixed	Portable /Mobile		
Knowledge of the means and timeframes for retrieving and/or transmitting data	Must be suited to the intended use. Know whether the data are accessible from the sensor or via a network.	Useful		Any objective	Intrinsic
Knowledge of how data are stored	In line with the study objective - Understand the type, capacity and duration of possible storage (local or remote)	Useful		Any objective	Intrinsic
Power supply	Specify the power source, and the impact on the measurement. If battery: accuracy of battery life checked	Useful		Any objective	Intrinsic
Position of the sensor system: fixed height, location (respiratory tract)	Must be suited to the purpose and representative (e.g. a VOC sensor positioned near a window will not be representative of the room)	Useful	Essential	Any objective	Study
Spatial coverage	Compatible with the study objective Used to determine the robustness of the study: Distribution of sensors in a way that is representative of a geographical area; Number of mobile sensor systems needed to represent a place (town, region, room, etc.).	Essential		Any objective	Study
Temporal coverage	Compatible with the study objective Check that the duration is appropriate (hourly, daily, monthly, season, measurement campaign).	Essential		Any objective	Study
Changes in the conditions of use (compared to the recommended conditions)	Know whether there are any changes, the reasons for them and the assessment of their impact (e.g. deterioration of the sample or aerosol)	Essential		Any objective	Study

Key points	Requirements	Criticality		Objectives	Intrinsic to the sensor or available in the study
		Fixed	Portable /Mobile		
(Geo)location *(GPS or other location definition)*	Must enable interpretation	Essential, subject to compliance with the GDPR		Any objective	Intrinsic or study
Description of the environments frequented: set of context attributes *(directly by filling in a logbook or indirectly via a signature search*)*	Compatible with the study objective Know the method for its implementation	Useful		Integrated exposure measurement	Study
	Understand: - the ventilation conditions of the indoor environments (at least the type of ventilation and general state of window openings); - the type of rooms for indoor environments - the weather conditions	Essential		Environment comparison	
	Compatible with the study objective Know the method for its implementation	Essential		Other objective	
Description of activities planned *(tasks performed, traffic data)* and unforeseen events *(construction site, incidents, pollution episodes, etc.)* *(STB + logbook)*	STB interval compatible with the study objective - Know the method for determining the STB for its implementation	Useful		Any objective	Study
Description of physical activity *(walking, running, etc.)* *Or other activities* *(STB + logbook, voluntary data or indirectly by deduction from other information)*	Compatible with the study objective Know the method for determining the STB for its implementation (voluntary data or +63	Optional		Any objective	Study

Key points	Requirements	Criticality		Objectives	Intrinsic to the sensor or available in the study
		Fixed	Portable /Mobile		
	indirectly by deduction from other information)				

** signature search, i.e. it may be possible to associate events occurring during the measurement with recorded signals: e.g. a sudden drop in concentration associated with a window opening, a sudden increase in concentration when there is a change in the microenvironment*
STB: space-time budget

Key points to consider – Data storage and accessibility + Data pre-processing

Key points	Requirements	Criticality		Objectives	Intrinsic to the sensor or available in the study
		Fixed	Portable /Mobile		
Accessibility to the user, study coordinator, general public	Adequate description	Useful		Any objective, while complying with the GDPR regulations in force	Study
Have a single working database – First level of processing	Description of the processing actions carried out Cleaning: *Coding or transmission error*	Essential		Any objective	Study
Corrections made by the user	Description of the processing actions carried out (Algorithm provided and justified. Preparation of the database: define the strategy for managing missing values, categorising values: outlier or suspect values, etc.)	Essential		Any objective	Study
Metadata pre-processed or not *(GPS position, loss of GPS data, STB, logbook, tags, etc.)*	Understand the quality of these metadata and whether they have been pre-processed	Essential		Any objective	Study

NB: Data pre-processing corresponds to validation of the raw sensor outputs and preparation of the database

Key points to consider – Data processing

Key points	Requirements	Criticality		Objectives	Intrinsic to the sensor or available in the study
		Fixed	Portable /Mobile		
Data transformation *(creation of variables, spatial and temporal aggregation, on variables, etc.)*	Description of the transformations carried out Know whether there have been any transformations and their type	Essential		Any objective	Study
Processing of censored data (< lower limit and > upper limit)	Understand the processing procedure	Essential		Any objective	Study
Enhancement with external data *(e.g. measurements at stations, air quality model outputs, weather, POI, traffic, geographical data, etc.)*	Description of the enhancement carried out Source of the external data	Useful		Any objective	Study
Statistical methods, methods for analysing concentration data, data mining, etc.	Description of the method	Essential if processing carried out		Any objective	Study
Ability to process a large volume of data and in a time suited to the intended use	-	Useful but essential if large-scale context		Any objective	Study
Method of exposure assessment (duration, location, concentration)	Relevance of the method	Essential if subject of the study		Exposure quantification	Study
Method of analysing the link between exposure (duration, location, concentration) and health effects, inhalation dose (according to activity and age, etc.) and individual response	Relevance of the method	Essential if subject of the study		link to health effect	Study

Key points to consider – Interpretation

Key points	Requirements	Criticality		Objectives	Intrinsic to the sensor or available in the study
		Fixed	Portable /Mobile		
Heuristic and reflective discussion/conclusion by the authors on the given elements of the study	Understandable	Useful		Any objective	Study