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Recommendations for the revision of the ambient air quality directives (AAQDs) regarding modelling applications

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on behalf of FAIRMODE

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Contents

Abstract

The Forum for Air Quality Modelling (FAIRMODE) is a European network to exchange experiences and competences on the use of air quality models in the context of the Ambient Air Quality Directives. Its purpose is to identify and promote the use of good practices for air quality modelling and to propose harmonized ways to assess the quality of model-based air quality applications by EU Member States. The recommendations in this document are part of FAIRMODE's contribution to the on-going revision of the EU Ambient Air Quality Directives (Directives 2008/50/EC and 2004/107/EC, hereafter AAQDs) initiated by the European Commission and are an update of the previous recommendations to the Fitness check of those Directives (Thunis et al. 2019).

This document builds on the existing recommendations from FAIRMODE provided in 2019 regarding modelling applications. The current document has been revised in view of the latest consensus on the maturity of modelling applications and their uses for air quality management purposes.

It provides strategic and technical recommendations where there is significant level consensus within the FAIRMODE expert community. It identifies how and where these recommendations may be included in the context of the revision of the AAQDs.

These recommendations would require additional work of Member States were they to be implemented and would have implications for the work of the FAIRMODE network concerning the development of relevant guidance documents to support the recommendations.

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Executive summary

Policy context

The Forum for Air Quality Modelling (FAIRMODE[1]) is a European network to exchange experiences and competences on the use of air quality models in the context of the Ambient Air Quality Directives (AAQDs). Its purpose is to identify and promote the use of good practices of air quality modelling in the context of the AAQDs (assessment, management, information to the public and reporting to EEA and EC) and to propose harmonized ways to assess the quality of model-based air quality applications by EU Member States (MS).

The recommendations in this document are FAIRMODE's contribution to the on-going revision of the EU AAQDs (Directives 2008/50/EC and 2004/107/EC) initiated by the European Commission. The recommendations also address the Implementing Decision 2011/850/EC on the reciprocal exchange of information and reporting on ambient air quality (also known as IPR, the acronym for Implementing Provisions on Reporting) and Commission Directive EU/2015/1480 amending several annexes to Directives 2004/107/EC and 2008/50/EC.

The Fitness check of the AAQDs finalised by the Commission in November 2019[2], evaluated the relevance, effectiveness, efficiency, coherence, and the EU added-value of the AAQDs. In particular, the Fitness check addressed to what extent the AAQDs have successfully defined methods to monitor and assess air quality to ensure that representative and high-quality assessment regimes are in place in all Member States. The conclusion of the Fitness check was that while "the AAQDs have been broadly fit for purpose, there is at the same time scope for improvements to the existing framework such that good air quality be achieved across the EU". It emerged from this Fitness check that additional guidance, or clearer requirements in the AAQDs themselves, could help to make monitoring, modelling and the provisions for plans and measures more effective and efficient.

These issues have been discussed and addressed by the network. This document provides strategic and technical recommendations where the scientific consensus within FAIRMODE indicates that robust conclusions can be drawn and identifies how and where to include these recommendations in the AAQDs, the IPR Decision and supporting Guidance documents. These recommendations could affect the work of Member States, were they be implemented, and would have implications for the work of the FAIRMODE network itself, specifically concerning the development of dedicated guidance documents to support the recommendations.

Given the increased robustness of air quality modelling applications across Europe and the identified need from the Fitness check to strengthen provisions on monitoring, modelling, and air quality planning under the AAQDs, **the main recommendation from FAIRMODE is to secure and enable an extended use of modelling for air quality applications.** The use of air quality modelling needs to be strengthened in the following air quality applications:

- Assessment of air quality levels, identification of hotspots, estimation of the extent of exceedances and of the (averaged) population exposure and/or exposure reduction targets.
- Forecasting and public information purposes: Providing current and short term forecast of air quality levels and development/application of Air Quality Indexes.
- Source apportionment purposes: Identification of air pollution sources, quantification of their contributions to provide a knowledge basis for planning mitigation strategies.
- Planning purposes: Development and assessment of plans and measures to improve and ensure good air quality to meet air quality standards

FAIRMODE recommends to make modelling mandatory for air quality planning, exposure calculations and short term forecast. Modelling should be strongly encouraged for monitoring network design, exceedance indicator estimates and near-real-time mapping, source apportionment and estimates of long-range transport and to define zones & agglomerations.

Knowledge of emissions from all sectors are a necessary input to enable the use of modelling for all four air quality applications above, as these activities are highly dependent on the anthropogenic activities distribution and the accuracy of the emission data. Therefore, the FAIRMODE recommendations also include a chapter on

(1) http://fairmode.jrc.ec.europa.eu/
(2) https://ec.europa.eu/environment/air/quality/aqd_fitness_check_en.htm

how to secure the compilation of emission data with sufficient level of detail to enable modelling results of appropriate quality for the above-mentioned air quality management purposes.

The main reasons to recommend an enhanced use of models in the revised AAQDs are: 1) the evidenced robustness of current modelling estimates for specific purposes, 2) the greater availability of modelling based information in most of Europe, 3) the need for more robust assessment of the spatial variability of the air quality situation and identification of hot spots which is not attainable cost-effectively based only on observations, 4) the recognition that air quality standards are to apply everywhere and not only at sampling points which requires the assessment of the spatial representativeness of monitoring results, 5) the fact that models are instrumental to plan and evaluate different control options.

Key implications for the review of the AAQDs

The enhanced use of modelling for air quality management has key implications that need to be considered in the review of the AAQDs. These are the six identified aspects to be considered according to FAIRMODE

1) The specification for which purposes and under what circumstances modelling results are to be used for air quality assessment applications
2) The identification for a common methodology to ensure the evaluation of the quality of modelling results
3) The revision of the monitoring network requirements to enable also model validation purposes.
4) The identification of synergies and complementarities between emissions reported to international conventions (i.e. NEC/CLRTAP) and emissions used in AAQDs context
5) The need to recognise FAIRMODE network activities in parallel to AQUILA network activities in the legislation because this would facilitate the implementation of modelling applications across Europe.
6) The reference in the IPR decision and in general commission guidance documents to FAIRMODE guidance documents to support air quality modelling applications.

Specific recommendations per air quality modelling applications:

Air quality assessment

1. Use of the Modelling Quality Objective (MQO): FAIRMODE proposes to use the MQO (Janssen et al. 2022) as a quality control mechanism to determine whether an assessment is "sufficient" for application in the context of the AAQDs.
2. Fitness-for-purpose criteria related to spatial resolution: FAIRMODE proposes, as a general guidance, the spatial scale(s) of the modelling system to be such that all observations of concentration levels within the scope and relevant time aggregation of the application can be reproduced with acceptable quality. This recommendation is further refined according to the various modelling application purposes:
    - modelling data for assessment, including as supplementary information to observations;
    - modelling for the calculation of specific exceedance situation indicators;
    - modelling to provide understanding of the current and future situation;
    - modelling assessment to serve as starting point for air quality planning and
    - modelling for forecast.
3. Identification of sampling points spatial representativeness (SR): FAIRMODE proposes an SR assessment methodology following a discontinuous approach to delineate an SR area. The simple and robust model-based assessment method identifies the annual averaged concentration fields within a given margin of tolerance as SR area. Thus, enhancing the ability to interpret measurement data in a spatial context supporting e.g. the identification of hot spots and areas in risk of exceedance.
4. Exceedance situation indicators (ESI): ESIs are currently to be reported under the e-Reporting system once an exceedance of the limit values is recorded at a monitoring station. ESIs are useful both for planning purposes and for flagging exceedance situations. FAIRMODE proposes to define an ESI for planning purposes, to be assessed as the starting point for the planning process, rather than an annual reporting

obligation as it is now. The planning ESI should be assessed based on comprehensive modelling results and should give a detailed spatially explicit picture of the extent of the exceedance situation, both in terms of area and population exposed to high concentration values. The planning ESI should be reported together with the air quality plan. In addition, FAIRMODE proposes to revise the definition of the ESI used for exceedance flagging applications in view of its actual robustness as indicator. The proposal is to define an Exceedance flagging indicator (EFI) that could be considered as a first qualitative estimate of the severity of the observed exceedance. The EFI should be a simple classed based (e.g. 4 grades) system, reflecting on the robustness of the indicators, easy to estimate based on expert judgement.

5. Modelling supported by (low-cost) sensors: to improve the overall quality of assessment methods FAIRMODE recommends to further develop QA/QC procedures for low-cost sensors, to develop methodologies to exploit sensor networks as a whole and to integrate the measurement data in modelling systems.
6. Regarding modelling applications for forecasting, relevant to short-term planning and to inform the public, FAIRMODE recommends the mandatory use of models (statistical or deterministic) for this type of applications. In addition, it proposes to introduce a requirement to test additional features of the modelling system related to high episodes when forecasting applications are evaluated.

Source apportionment

1. Use and limitations of source apportionment methods: For the specific purpose of providing information of direct relevance to support the design of air quality plans and assess their potential benefits, FAIRMODE has the following recommendations: (a) Emission sensitivity-based approaches are suited and recommended for identification and quantification of emission sources because they directly reflect the impact of emission reductions. However, for non-linear species their applications are limited in terms of emission reduction strength, hence the need to carefully assess their range of applicability. (b) Mass-transfer methods based on tagging species algorithms are suited to identify sources but not suited to quantify their impact on pollution, unless pollutants are involved in linear processes. These methods can be used to complement emission sensitivity-based approaches (c) Mass-transfer methods based on receptor models are suited for the identification and quantification of pollution sources but only for pollutants involved in linear processes. (d) Incremental approaches are not recommended for air quality planning applications.
2. Use of benchmarking methodologies: FAIRMODE recommends applying proven benchmarking methodologies (where available) to ensure fit-for-purpose and reliable quality when performing source apportionment applications.
3. Nomenclature for classifying emission sources: FAIRMODE recommends adopting the nomenclature used under the NEC Directive for reporting emissions as basis for the source apportionment activities under the AAQDs.

Air quality plans

1. Use of models: FAIRMODE recommends to identify models as the recommended mandatory tool for designing air quality plans and assessing ex-post their effectiveness.
2. Harmonization: to facilitate exchange of best practices, FAIRMODE recommends to harmonize the way in which plans are reported and to review the required information to be reported.
3. Guidance: more guidance and recommendations are needed, to help design effective air quality plans.
4. Benchmarking: models should be benchmarked using FAIRMODE methodologies or equivalent, especially before being used for air quality planning.

Recommendations regarding emissions for local/urban applications

1. High-resolution emission metadata requirements: FAIRMODE proposes to specify requirements for documenting the high-resolution emission data that is used as input for local/urban air quality assessments and air quality planning under the AAQDs and link those to the information provided under national emission compilation in lower resolution scale prescribed under the National Emissions reduction Commitments (NEC) Directive[3].
2. Guidance to compile high resolution emissions: FAIRMODE can provide guidance on high-resolution emission inventory compilation and proposes a cooperation process with the Task Force on Emission Inventories and Projections for the development of user-checked methods to secure consistency with the national emission estimates compiled under the NEC Directive.
3. Use of benchmarking for quality assessment of emissions: FAIRMODE proposes to introduce benchmarking activities to establish the validity of the high-resolution emission data used for local/urban air quality assessments and air quality planning.
4. Nomenclature for classifying high-resolution emission sources: FAIRMODE recommends adopting the nomenclature used under the NEC Directive as a minimum disaggregation level for reporting high-resolution emissions by sector, as basis for the local/urban air quality assessments and source apportionment activities under the AAQDs.

Quick guide

- FAIRMODE proposes a series of recommendations addressing assessment, emissions, source apportionment and planning in the context of air quality modelling applications related to the Ambient Air Quality Directives.
- FAIRMODE recommendations focus on fitness-for-purpose, quality control and necessary guidance to cover these aspects.
- The implications of the FAIRMODE recommendations on legislation and associated guidance are identified and shortly discussed.

([3]) https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2016.344.01.0001.01.ENG&toc=OJ:L:2016:344:TOC

1 Introduction – Policy context

The Forum for Air Quality Modelling (FAIRMODE) is a European network of air quality experts aimed at exchanging experiences and competence on the use of air quality models by the member states in the context of the application of the Ambient Air Quality Directives (AAQDs). Member States can designate one or more experts in the use and/or development of air quality models to be their representatives to FAIRMODE and contribute to the work plan of the Forum. FAIRMODE works by consensus, with the aim of strengthening and better focusing guidance to the use of modelling in the context of the AAQDs. The Ambient Air Quality Expert Group[4] approves the FAIRMODE work plan and supports the participation of relevant national/regional representatives to achieve the goals from the work plan. The objectives of the FAIRMODE network are presented in chapter 2.

The recommendations in this document are FAIRMODE's contribution to the on-going revision of the EU AAQDs (Directives 2008/50/EC and 2004/107/EC) initiated by the European Commission in 2020. These Directives set air quality standards and requirements to ensure that Member States monitor and/or assess air quality in their territory, in a harmonised and comparable manner. They also provide provisions for population exposure assessment, source apportionment, air quality planning and information sharing. The recommendations also address the Implementing Decision 2011/850/EC (IPR) and Commission Directive EU/2015/1480 amending several annexes to Directives 2004/107/EC and 2008/50/EC.

The Fitness check of the AAQDs evaluated the relevance, effectiveness, efficiency, coherence, and EU added-value of the AAQDs. In particular, the Fitness check addressed to what extent the AAQDs have successfully defined methods to monitor and assess air quality to ensure that representative and high-quality assessment regimes are in place in all Member States. The conclusion of the Fitness check was that while "*the AAQDs have been broadly fit for purpose, there is at the same time scope for improvements to the existing framework such that good air quality be achieved across the EU. In particular, it emerges from this Fitness check that additional guidance, or clearer requirements in the AAQDs themselves, could help to make monitoring, modelling and the provisions for plans and measures more effective and efficient.*

The recommendations are an update of those published in 2019 (Thunis et al. 2019). They draw from the experience of all Member States participating in FAIRMODE. The topics considered include assessment, high-resolution emissions, source apportionment and planning activities, following the current priority areas of work in FAIRMODE. The recommendations aim at supporting the strengthening of provisions on modelling and on planning. The implications of the proposed FAIRMODE recommendations for legislation and related guidance are summarised in Chapter 7.

(4) http://ec.europa.eu/transparency/regexpert

2 The FAIRMODE network: objectives

FAIRMODE is a Forum for Air Quality Modelling created for exchanging experience and results from air quality modelling in the context of the Ambient Air Quality Directives (AAQDs). Its purpose is to identify and promote the use of good practices of air quality modelling (assessment, management, information to the public and reporting to EEA (European Environment Agency) and EC (European Commission)) and to propose harmonized ways to assess the quality of model-based air quality applications by EU Member States (MS). Its main objectives are:

1. To provide a permanent European Forum for air quality modellers;
2. To study and set-up a system (protocols and tools) on the quality assurance of air quality model systems (the model, their input data and use) operating at different spatial scales from national to urban and local;
3. To provide guidance, support the standardization and evaluate the fitness-for-purpose of air quality models and input data, for assessing current and future air quality within the framework of implementing the EU's Air Quality Directives;
4. To support air quality management (at the national, regional and local level) in developing and implementing plans and measures to improve air quality with efficient modelling tools;
5. To promote capacity building activities aiming at ensuring an optimum use of the proposed common methodologies and guidance and to promote good practice among the EU Member States;
6. To make recommendations on future priorities, research activities and other relevant initiatives to secure Air Quality improvements.

BOX 1: FAIRMODE GUIDANCE DOCUMENTS RELATED TO MODELLING

FAIRMODE has issued guidance to support the use of modelling (all available on the FAIRMODE web pages):

- The application of models under the European Union's Air Quality Directive: A technical reference guide (EEA, Technical report No 10/2011)
- Guide on modelling Nitrogen Dioxide (NO_2) for air quality assessment and planning relevant to the European Air Quality Directive. ETC/ACM Technical Paper 2011/15
- European guide on air pollution source apportionment with receptor models, Report EUR 29816 EN, 2019
- How to start with PM modelling for air quality assessment and planning relevant to the Air Quality Directive. ETC/ACM Technical Paper 2013/11
- Guidance Document on source apportionment to support air quality management practices, a fitness-for-purpose guide, 2020
- Guidance Document on Modelling Quality Objectives and Benchmarking, 2020.

The structure of FAIRMODE reflects the main applications on the use of models in the context of the AAQDs. The recommendations presented below are organised around applications of assessment, including forecasting, emissions, source apportionment and planning. The Forum published a series of technical guides in relation to these topics (see Box 1).

3 Recommendations regarding assessment using modelling

3.1 Background

Under the AAQDs, EU Member States have obligations to assess and manage ambient air quality and report the results of those assessments and management on a regular basis. The data sharing obligations are thoroughly defined in the IPR Decision (2011/850/EU). The EEA, supported by their European Topic Centres, oversees the collection of air quality data according to the provisions in the AAQDs and the IPR Decisions and manages the technological infrastructure involved in the data exchange and processing (e-Reporting).

Whilst previous directives have based assessment and reporting largely on measured data, Directive 2008/50/EC[5] encourages the use of modelling in combination with monitoring networks in a range of applications. The AAQDs (and their related IPR) define or suggest a range of situations in which modelling can be applied for assessment, as follows:

a) Use of modelling results as supplementary information to observations (instead of — or in combination with — fixed measurements) in the assessment process;

b) Use of modelling results for the calculation of specific exceedance situation indicators (area of exceedance, length of road in exceedance, population in the exceedance area) as described in the IPR;

c) Use of modelling results to provide a comprehensive understanding of the current situation of the air pollution situation in an air quality zone of interest. This assessment can serve as starting point for the use of models for other applications in the context of the AAQDs, i.e. for source apportionment, to assess the effectiveness of measures, to perform future scenario simulations, etc.

d) Use of modelling results to forecast air pollution, the geographical area of expected exceedances of standards and/or information thresholds for following hours/day(s) and the reasons for changes.

In all cases (except for d), modelled data or related indicators are to be reported to the European Commission via the e-Reporting mechanism. The present document aims to provide some additional recommendations on all these points to support the review of the AAQDs.

3.2 Challenge / Issue

Modelling quality objectives are described in Annex I of the AAQDs along with the monitoring quality objectives. However, the guidance documents associated to the AAQDs and their related IPR are significantly vague with respect to the definition and quality objectives of the modelling methods that are to be used in air quality assessments.

Two questions thus arise and are the basis for the following recommendations

1) When is a modelling application fit-for-purpose?

2) When can it be applied for the situations listed above?

In order to be fit-for-purpose, a modelling application should be able to capture the magnitude and both the spatial and temporal variability of the environmental indicator under investigation. This ability is assessed by quantitatively comparing the model output of the application to observations. FAIRMODE proposes a standardized Modelling Quality Indicator (MQI, see Box 2), which can be used to evaluate the quality of a given modelling application.

(5) https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32008L0050&from=EN

BOX 2: MODELLING QUALITY OBJECTIVE (MQO) & MODELLING QUALITY INDICATOR (MQI)

The Modelling Quality Indicator (MQI) is a statistical indicator calculated on the basis of measurements and modelling results. It describes the difference between measurements and modelling results, normalized by measurement uncertainty and an empirical scaling factor. The Modelling Quality Objective (MQO) is the criterion that values of the MQI should fulfil. The CEN working group 264/43 is currently discussing whether and how modelling applications shall fulfil the MQO.

While the temporal resolution of indicators is set by the requirements in the AAQDs (specific annual averaged values or percentiles have to be reported), the spatial resolution of the indicator is not well defined. However, this spatial variability can differ significantly per pollutant and has major implications on the minimum spatial resolution that should be covered by the modelling system. As a consequence of this dependency, the minimum spatial resolution can differ per pollutant.

Clearly, when results have to be reported at a spatially detailed level (e.g. at road level), the type of modelling has to be fit-for-purpose, and should match the requested level of detail. Up to now, very little guidance exists on how to define the fit-for-purpose resolution or spatial scale of a modelling system in order to match the level of detail required by the application.

Assuming fit-for-purpose and high quality models are at hand, it is recognized that they can play an important role to complement information retrieved from fixed monitoring networks, indicative sampling campaigns and lately also low cost sensor observations. This comprises an evaluation of the monitoring network itself, assessment of the spatial representativeness of sampling sites and estimation of exceedance situation indicators.

3.3 Recommendations

1. Use of the MQO: The standardized Modelling Quality Objective (MQO), as defined by FAIRMODE, proposes metrics to quantify how well the results from a modelling application are in agreement with observations. It should be used as a quality control mechanism to assess whether a modelling-based assessment is of sufficient quality for application in the context of the AAQDs. These applications encompass:
    a) Modelling as complementary information to observations in the assessment process;
    b) Modelling to estimate the exceedance situation indicators;
    c) Modelling of short-term air quality forecasts (note that a specific Modelling Quality Objective for forecast is established);
    d) Modelling in support of planning, where the model should be proved of sufficient quality (through the use of the MQO) before being used for planning.

    Note that assessing the fitness for purpose of a given modelling application would require additional (to the MQO) Quality Assurance steps that cover all aspects of the modelling application.
2. Fit-for-purpose modelling systems are most often a combination of various modelling tools designed for different spatial extents. The composition of the modelling chain should depend on the type of application. Regional scale models should reasonably cover the entire zone or country. Urban-scale models should be used in cities and local-scale models should be used for hotspots and street canyons. It is recommended to carefully couple the various essential and relevant building block in a modelling system, e.g. with respect to double counting of emissions, chemistry regimes, boundary conditions, etc. It should be noted that a priori the fitness-for-purpose criteria does not rule out any specific modelling technique (e.g. deterministic dispersion modelling of various kinds, machine learning or statistical models…).
3. Fitness-for-purpose criteria related to spatial resolution: To reduce the ambiguity of the spatial scale in the fitness-for-purpose definition, FAIRMODE proposes, as a general guidance, that the spatial scale(s) of the

modelling system should be such that all observations of pollutant concentration levels within the scope of the application can be reproduced within the margin of tolerance of the MQO:

a. A modelling application which produces data used as supplementary information to observations should be consistent with the type of station and pollutant that is supplemented. This means that, for rural stations, regional scale model results with a coarser spatial resolution can be sufficient, whereas for traffic stations and traffic related air pollutants more detailed street level models have to be applied. The MQO should be evaluated by making use of all observations from monitoring stations (including specific campaigns if they meet the Data Quality Objective (DQO)) that are supplemented by the modelling application.

b. A modelling application that is used to assess exceedance situation indicators (area of exceedance, length of road in exceedance, population in the exceedance area), should be able to describe pollutants concentration levels in the area or air quality zone of interest. So, an appropriate model resolution should be selected and all available observations (meeting the DQO) in the investigated area should be included in MQO evaluation.

c. When modelling is performed as a starting point for planning under the AAQDs, the ambition should be to reproduce what is observed in the atmosphere within the air quality zone under investigation. Therefore, it is recommended that all observations in the air quality zone are used in the MQO evaluation of the assessment results. This will ensure that the starting point of the plan reproduces (most of) the complex structures and gradients as described by observations. Obviously, stations that have been used in the modelling application as boundary condition or for data fusion should be excluded in the MQO evaluation.

4. Spatial representativeness (SR): FAIRMODE has evaluated and tested a methodology to assess SR of monitoring stations. The methodology is based on modelling results and put forward the concept of an SR area. The method follows a discontinuous approach to delineate an SR area within the boundaries of the air quality zone. The simple and robust modelling-based assessment method identifies the annual averaged concentration fields within a given margin of tolerance as SR area. The identified methodology to assess SR area could be improved in future on various aspects: take into account indicators other than the annual mean (i.e. percentiles of the daily indicators), include seasonal or source related elements in the SR assessment…

5. Exceedance situation indicators (ESI): ESI are to be reported under the e-Reporting system once an exceedance of the limit values is recorded at monitoring stations. In order to facilitate, simplify and harmonise the assessment and reporting obligations, FAIRMODE proposes to distinguish between planning ESI and flagging ESI. The planning ESI is to be assessed and reported as the starting point of the planning process. The planning ESI should be assessed based on comprehensive modelling results and should give a detailed and spatially explicit picture of the extent of the exceedance situation, both in terms of area and population exposed to high concentration values. The planning ESI should be reported together with the air quality plan.

   In addition, an Exceedance flagging indicator (EFI) could be introduced. The purpose of the EFI is to provide a first qualitative estimate of the severity of the observed exceedance. The EFI should be a simple (e.g. class or grade based) indicator, easy to estimate, potentially even based on expert judgement. This is because the current ESI has associated significant variability and uncertainty ranges that can be better assessed following a class or range approach. Such a "lighter" EFI could then replace the current annual reporting obligation under Data Flow D.

   Detailed guidance on how to estimate the exceedance flagging and situation indicators is provided in the CT8 Guidance Document on *Exceedance indicators and Spatial Representativeness*[6].

6. Low-cost sensors are an emerging technology that opens opportunities for additional information to be used in assessments. However, proper attention should be given to the QA/QC process. Therefore:

   a. FAIRMODE recommends, in addition to using individually calibrated low-cost sensors, to calibrate/validate groups of low-cost sensors in a network setting. A network calibration, where multiple sensors can be dealt with in batch, can extract useful information from sensors where the individual quality of the sensors is limited or unknown.

(6) https://fairmode.jrc.ec.europa.eu/activity/ct8

b. FAIRMODE recommends to further develop a QA/QC procedure for low-cost sensor networks to guarantee sufficient added value of the measurement technology. Within a few years, (low cost) sensors in a sensor network are expected to be qualified as indicative measurements for specific pollutants under the AAQDs.

c. FAIRMODE recommends, once the QA/QC procedure is developed, to integrate sensor data in modelling results via data fusion or data assimilation techniques to improve the overall quality of the air quality assessment methodologies.

7. Regarding modelling applications for forecasting, relevant to short-term planning and information to the public, FAIRMODE recommends the mandatory use of models (statistical or deterministic) for this type of applications. In addition, FAIRMODE works and discussions led to a scientific consensus on the additional features to be assessed when a forecasting application is evaluated. The proposed methodology is provided in the revised Guidance Document on Modelling Quality Objectives and Benchmarking (Janssen et al. 2022). Member States and scientific community are encouraged to use the proposed methodology to assess the quality of modelling applications for forecasting purposes

3.4 Implications

The adoption of the proposed recommendations would have consequences:

- As the MQO allows the comparison of modelling results throughout Europe, it is important to select a set of parameters in the MQO that are supported by the whole air quality community as its definition is likely to be embedded in a CEN standard. Future discussions within FAIRMODE will focus on the conditions of applications of the MQO as well as on appropriate additional Quality Assurance steps for MS.

- For assessment specifically aimed at urban environments, modelling systems down to street level have to be applied (although some exceptions may apply to secondary pollutants, e.g. ozone; part of PM). In these urbanized situations, regional scale models like CTMs will be insufficient to capture the observed spatial gradients in hot spot locations, and consequently they are not fit-for-purpose in local environments like street canyons. If the modelling assessment is not able to sufficiently reproduce the fine scale concentration patterns of a pollutant from the ambient atmosphere observations, it means that the modelling system is not 'fit-for-purpose' for assessment of that pollutant in that location and at that scale. More elements should be added to the modelling system to capture the observed variations, or another modelling system should be considered. It should be noted that a mismatch could also be related to insufficient quality of the input data (emissions, meteorology, boundary conditions, etc.), and not necessarily to the type of model used in the application.

- Various (sub)models in a modelling chain still need validation, but most probably the concept of the (IPR) "station type/classification" should be sufficient to select appropriate stations for such a partial validation of the modelling chain.

- In exceptional situations, monitoring stations can be disregarded from model application when stations micro-environment is too complex to be captured in a model. However, in reporting the results of the assessment, it should be clearly described the regions/situations where the modelling system (including input data such as meteorology, terrain data or emissions) may not be 'fit-for-purpose'. No formal assessment in the context of the AAQDs/IPR is possible in this region/situation with such a modelling system.

- The proposed methods for the estimation of the exceedance situation indicators and the spatial representativeness of monitoring stations will result in a more robust, transparent and harmonized assessment process. This, in turn, allows for a better comparison of exceedance situations over air quality zones, regions and Member States.

4 Recommendations regarding source apportionment

4.1 Background

The identification and quantification of the sources responsible for the air pollution situation is a prerequisite for planning activities. Hence, reliable and quantitative information on the origin of pollution and on pollution sources is required by the AAQDs (Annex XV), as well as in the IPR guidance documents, with a view of supporting the design of air quality plans and explaining the origin of exceedances. This information regarding the identification and quantification of the sources of air pollution, both in terms of their sectorial and spatial origins, constitutes an essential step of the air quality management process.

Different approaches (see Box 3) are available to provide this information, but not all methods are suited to support air quality planning. Therefore, the limitations and range of applicability of each approach should be properly defined. Although FAIRMODE provided support[7] on specific aspects, guidelines are generally lacking.

BOX 3: WHAT IS SOURCE APPORTIONMENT?

Source apportionment (SA) is defined as the practice of deriving information about the influence of emission sources on ambient air pollution levels. It includes among others:

- Emission sensitivity-based methods (brute force, potential impact, etc.) where source contributions are obtained by differencing two source-oriented model simulations performed with the full and a reduced emission source. This approach is applied to determine the contribution from both sectorial and spatial sources.
- Mass-transfer methods designed to estimate the mass of a pollutant transferred from the emission sources to the ambient concentrations (receptor or source-oriented tagging models). It is applicable to determine sectoral (receptor and source-oriented models) and spatial (source oriented models) contributions to concentrations.
- Incremental methods (or "Lenschow" approaches) based on spatial gradients of concentration, calculated as the difference between concentrations measured at different types of stations e.g. rural background, urban background. They are based on the assumption that source contributions can be derived from the difference between the concentrations. This approach is based on the assumptions that: a) the regional contribution is constant outside and inside the urban area, and b) the urban area does not contribute to the regional background. This approach is only applicable to determine contributions from different spatial sources (e.g. city vs regional background) to concentrations.

4.2 Challenge / Issue

Different source apportionment approaches lead to results that generally differ among themselves and can subsequently lead to inadequate conclusions about the responsibility of certain sectors and raise misleading prospects about the efficiency of mitigation strategies. The lack of guidance on what methods to use to support air quality planning and under which circumstances these can be used is a main challenge that FAIRMODE has been addressing. Specifically, the following issues were explored:

- Technical guides and proposed QA/QC steps are not always applied in source apportionment studies.
- The validity of the assumptions underpinning the incremental or Lenschow approach (Lenschow et al. 2001) (i.e. spatially homogenous background and background location not influenced by the source under consideration) is difficult to assess. Experience shows that this approach lacks robustness and often leads to important under- or over-estimation of the contributions from different sources.
- The nomenclatures of the emission sources used in different source apportionment studies, both with receptor and source-oriented models are not always consistent.

(7) https://fairmode.jrc.ec.europa.eu/activity/ct1

- Information about the range of applicability of a given source apportionment approach is generally lacking.
- Information is often lacking to ensure that source apportionment outputs are comparable.

4.3 Recommendations

1. Use and limitations of source apportionment methods: For the specific purpose of providing information of direct relevance for air quality plans and assess their impacts, both an identification of the sources and a quantification of their impacts is necessary. FAIRMODE has the following recommendations:

    a) Emission sensitivity-based approaches are suited and recommended for identification and quantification of emission sources in the context of air quality planning applications because they directly reflect the impact of emission reduction. However, for non-linear species their applications are limited in terms of emission reduction strength, hence the need to carefully assess their range of applicability.

    b) Mass-transfer methods based on tagging species algorithms are suited to identify sources but not suited to quantify their impact on pollution unless pollutants are involved in linear processes. These methods can be used to complement emission sensitivity-based approaches.

    c) Mass-transfer methods based on receptor models are suited for the identification and quantification of pollution sources but only for pollutants involved in linear processes.

    d) The incremental approach is not recommended for air quality planning applications. This is because the increment is defined as a spatial gradient which differs from a source apportionment unless the background concentrations are spatially homogenous, and the background location is not influenced by the source. The validity of these two assumptions cannot be assessed with the method itself.

2. Use of benchmarking tools: To perform source apportionment applications, we need to select an approach that is of reliable quality concerning: a) the source apportionment (SA) method (mass-transfer or emission sensitivity), b) the air quality model used for the scenario runs and c) the emission scenario development methodology. In order to check a) the SA method and b) the selection of air quality model, we recommend applying the FAIRMODE source apportionment benchmarking technical guides and to promote the use of methodologies that have been tested with the FAIRMODE performance assessment methods for this type of applications (e.g. DeltaSA, see box 4 below).

BOX 4: DELTA SA

The DeltaSA (Delta Source apportionment) tool is an R-package and a Java on-line tool developed at the EC-JRC to support and benchmark source apportionment applications. Its key functionalities support two critical tasks: the assignment of a factor to a source in factor analytical models (source identification) and the model performance evaluation. The source identification is based on the similarity between a given factor and source chemical profiles from public databases. The model performance evaluation is based on statistical indicators used to compare model output with reference values generated in inter-comparison exercises.

3. Nomenclature for classifying emission sources: Following the recommendations for emissions, we recommend to adopt the nomenclature used under the NEC Directive for reporting emissions as basis for the source apportionment activities under the AAQDs. In this way, better consistency between the different Directives and higher level of transparency would be ensured, harmonising with the classification of emission sources at macro sector level given as the GNFR and NFR Nomenclature For Reporting. In the case of receptor models, guidance needs to be developed in order to harmonize the nomenclature to classify emission sources with the above.

4.4 Implications

The implications of adopting the general source apportionment recommendations would be as follows:

- With respect to source apportionment, Member States should report the source contributions at a given site at which an exceedance was observed using the most suitable approach without an “a priori” imposition of the Lenschow approach, which lacks general validity (see recommendation 1d). Suitable approaches should be fit for purpose (recommendation 1) and their performances and uncertainties be tested with FAIRMODE benchmarking tools and technical protocols where available (recommendation 2).
- The classification of sources should be adapted according to recommendation 3 in 4.3.
- Additional information should be provided with the SA output to ensure that the adequate SA methodology is used for the desired scope. Additional metadata (type of approach used, range of applicability, spatio-temporal averages applied at the receptor, spatio-temporal characteristics of the source, etc.) should be reported in this context to ensure relevance and comparability of the information (see proposal in Section 7.2.3).

5 Recommendations regarding planning

5.1 Background

As stated in Article 23 of the AAQD 2008/50/EC, "Where, in given zones or agglomerations, the levels of pollutants in ambient air exceed any limit value or target value … Member States shall ensure that air quality plans are established for those zones and agglomerations in order to achieve the related limit value or target value …".

Air quality planning is therefore required when air pollution in a given zone exceeds the limits set in legislation; and suggested when future emission projections (i.e. due to energy policies) are not sufficient to expect a fulfilment with those limit values.

In terms of air quality plans, both long-term (related to long-term measures like the replacement of boilers) and short-term action plans (related to temporary measures triggered by forecasted exceedances, like limiting local traffic circulation) are considered. The impact of the measures can be evaluated in terms of long- (e.g. yearly averages) or short-term (e.g. number of hours/days in exceedance) air quality indicators.

In any case, designing air quality plans is a complex task, involving, among others, the following sub-tasks:

1. identify and quantify the sources that contribute to air pollution (both for long-term and short-term periods);
2. identify possible mitigation measures to be applied to each of these sources; and
3. evaluate the effectiveness of such mitigation measures.

In addition to source apportionment (sub-task 1), modelling can support air quality planning activities for sub-tasks 2 and 3 above.

5.2 Challenge / Issue

The European Court of Auditors raised the issue[8] that air quality plans were not designed as "effective monitoring tools" because their measures were poorly targeted and could not be implemented quickly for the areas where the highest concentrations were measured.

Even when air quality plans are defined according to the requirements of the AAQDs 2008/50/EC and the 'Commission Implementing Decision 2011/850/EU' (also known as IPR), challenges remain to ensure their proper implementation and evaluation.

These challenges are related to:

- Ensuring a proper validation of modelling applications to be used to design these plans, e.g. taking into account the dynamic response of models to changes in emissions;
- Fostering the development and implementation of data assimilation / data fusion techniques to improve the base case results using the most advanced approaches, and understanding how to use these methods to assess emission reduction scenarios;
- Lack of guidance to choose the appropriate type of models (in terms of scale, input data needs, chemistry mechanism involved, etc.) for the specific needs and context of the air quality plan;
- The availability and completeness of data needed to design air quality plans (e.g. on effect of measures, on activity levels and/or emission factors, on costs and efficiency of measures acting on emissions, etc.);
- The difficulty to assess and prioritize measures in terms of cost-effectiveness, political and public acceptance, etc;

(8) https://www.eca.europa.eu/Lists/ECADocuments/SR18_23/SR_AIR_QUALITY_EN.pdf

- The uncertainty associated to the model responses to emission reductions. The variability of model inputs such as emissions, meteorology and diversity of model setups is a source of model response variability;
- The need to ensure coherence between the National air pollution control programmes (NAPCP) in the frame of the NEC directive and air quality plans.
- The lack of harmonization in reporting as well as the lack of guidance on how to report the required information that prevents an efficient exchange of best practices.

5.3 Recommendations

Given the challenges listed above, the following recommendations are made:

1. Use of air quality models should be mandatory when designing and assessing air quality plans. In some cases, plans are still designed based only on emission inventories or concentration data from the routine monitoring networks, which is neither sufficient to capture the processes of dispersion of pollutants nor the processes involving secondary pollutants and other complex processes occurring in the atmosphere.
2. Modelling applications should be tested/validated through the recommended FAIRMODE benchmarking procedures (MQO, QA/QC for the modelling application…).
3. Foster the exchange of information among Member States by harmonizing practices, so that they can be replicated in different contexts.
4. Develop guidance for air quality plans preparation. As in the case of the NAPCP in the frame of the NEC directive, a more structured approach for the design of air quality plans is needed and coordinated with other policies (on emissions, climate, energy, noise…).
5. Take into account existing air pollution management plans that have been implemented in the past and test their robustness and suitability.
6. Use emission inventories and other input/initial data tested/validated through the FAIRMODE tools

5.4 Implications

The implications of adopting the general planning recommendations would be as follows:

- With respect to air quality plans, Member States should apply air quality models to, first, assess the spatial extent of an exceedance and the main sources that should be mitigated (source apportionment), and, secondly, to evaluate the efficiency of the mitigation measures proposed/designed.
- Member States should assess the quality of their modelling applications in the context of air quality plans. They should be benchmarked with recommended FAIRMODE approaches (e.g. MQO, QA/QC indicators) and possibly inter-comparison exercises performed in the scope of FAIRMODE to ensure the confidence and suitability of the model results.
- Member States should follow guidance to prepare an air quality plan; this guidance should follow a structured and integrated approach, based on past experiences and measures adopted).

6 Recommendations regarding high-resolution emissions

6.1 Background

The methods to monitor and assess air quality with the help of air quality models require good quality input data on emissions, boundary conditions and meteorology. In order to ensure the representativeness and the quality of the assessment results required by the AAQDs, further focus is to be placed on the compilation of high-resolution input data. This applies, in particular, to emission data that needs to be compiled at high spatial (horizontal and vertical) and temporal resolution. The different modelling applications under the AAQDs require emissions at different spatial and temporal resolution to cover regional, urban/local, street/microscale applications. For the latter, high-resolution emission data is necessary. However, neither the AAQDs nor the IPR guidance documents provide any identification of the methods to be applied in the compilation of high-resolution emission data to be used as basis for modelling air quality assessments at different urban/local and microscales. Also, no reference is made as to how the quality of emission data used as input for air quality modelling is to be assessed.

6.2 Challenge / Issue

National emission data reporting is addressed in the National Emission reduction Commitments (NEC) Directive (2016/2284/EU). Reporting under the NEC Directive is harmonized with EMEP emission reporting under the LRTAP or Air Convention[9]. The EEA is responsible for the reporting of the EU inventory under the Air Convention. The methods mandated for the compilation of the EMEP and NECD emission data are specified in the EMEP/EEA emission inventory Guidebook (EMEP 2019). The EMEP/EEA guidance on methods for emission compilation is organized by three different levels or tiers of increasing complexity, from Tier 1 that is based on statistical activity rate and default emission factors; Tier 2 that includes more specific information regarding for instance fuel or technology types; to Tier 3 that involves higher level of detail to describe and quantify emission processes. The EMEP/EEA Guidebook also includes guidance on the spatial disaggregation of emissions down to 0.1° x 0.1° long-lat, the resolution requested for the reporting of the official EMEP emissions (ECE/Ab.AIR/122/Add.1, decision 2013/4).

Since the focus of the NEC Directive is on national emission totals, its emission data compilation requirements do not take into account the needs for high-resolution emission data that is required for air quality modelling applications under the AAQDs. The requirements on emission data from NEC Directive and the guidance under EMEP/EEA are too coarse—both spatially and temporally—to respond to the needs of highly resolved high-resolution emission data needed to fulfil assessment requirements under the AAQDs.

The experience gained in FAIRMODE with emission benchmarking, the understanding of practices to compile urban emissions and results from the EEA´s Air Implementation Pilot ([10]) revealed the existence of a large gap between national and local/urban inventories. A higher level of disaggregation of emission information is necessary for urban/local scale air quality applications in the AAQDs, and this requirement is not necessarily solved by downscaling highly aggregated national emission data to high resolution, because the downscaling process introduces additional uncertainties. Greater consistency and coherence between high-resolution and national inventories compilation practices need to be ensured (taking account of the different scales), as well as an alignment of nomenclatures. Box 5 provides an overview of the different emission inventories currently available. While the European scale national emissions (either official or expert estimates) are too coarse to support urban air quality modelling applications under the AAQDs, high-resolution expert emission estimates do not consistently cover the whole of Europe.

([9]) https://www.unece.org/env/lrtap/welcome.html.html

([10]) https://www.eea.europa.eu/publications/air-implementation-pilot-2013; https://www.eea.europa.eu/publications/europes-urban-air-quality

BOX 5: EMISSIONS OFFICIAL VS OTHER EMISSION ESTIMATES

- The EMEP and NECD emission inventories are the official national emission data and are reported under the CLRTAP and the NEC Directive. The EMEP/NECD emissions are reported in 0.1x0.1° resolution and are compiled following the EMEP/EEA emission Guidebook.
- Expert estimates at national/European scale are compiled by various methods, notably CAMS/MACC (in 0.1x0.05° resolution) are estimates compiled under Copernicus, based on the EMEP/NECD data and expert knowledge on emissions.
- High-resolution emission inventories compiled by experts or authorities under the AAQDs for elaboration of management plans and other modelling applications, generally following non-harmonized methodologies and nomenclatures.

6.3 Recommendations

The main recommendation from FAIRMODE is to provide guidance so that emission inventories used in modelling to support air quality management applications under the AAQDs are appropriate to ensure the quality of the modelling results. It also proposes that emission data is clearly documented to enable the transparency and comparability of the results across Europe and to allow better alignment with the official emissions reported under the NEC Directive.

1. High-resolution emission documentation requirements (metadata): When high-resolution modelling applications are carried out under the AAQDs and reported thereof, FAIRMODE recommends to document what high-resolution emission data is used as input for air quality modelling and what methods (i.e., bottom-up, hybrid or downscaled) were used for the compilation of the high-resolution emission information. The current practice to compile and report national emission data is not appropriate to ensure the highly spatially and temporally disaggregated air quality assessments required under the AAQDs. Despite on-going methodological improvement, some emission processes are currently missing in the national data. For instance, Member States are not requested to include particle resuspension sources (traffic-related) in their official national emission inventories, even though these could dominate local/urban PM emissions in some countries. A better alignment between NEC/CLRTAP and AAQDs in some key areas should be attained. FAIRMODE can assist in the specification of the necessary metadata information on high-resolution emission data.
2. Guidance to compile high-resolution emissions: Create a new emission guidance document on high-resolution emission compilation. The current EMEP/EEA emission inventory Guidebook provides guidance for the spatial disaggregation of emission data, but the methodologies proposed do not always ensure appropriate results for high-resolution emission estimation, especially when generalised instead of local data are used. For example, spatial proxies used to generate the gridding of residential wood combustion emissions may largely vary between countries due to local factors (e.g., legal restrictions, social customs) and subsequently urban and rural population distribution maps cannot be applied in a generalized way. FAIRMODE can contribute to the development of guidance for the compilation of high resolution emission inventories, along with the development of time variations profiles for each sector and further refined information on emission speciation (e.g., NMVOC).
3. Use of benchmarking for quality assessment of emissions: Introduce benchmarking activities (analogous to those carried out within FAIRMODE) as a system to evaluate the quality of emission data used for air quality assessments. The benchmarking of emission inventories in selected cities that has been performed in the framework of FAIRMODE during the past years has highlighted large inconsistencies between local bottom-up urban emission inventories and regional emission inventories and contributed to the improvement of both types of emission inventories. It is recommended to promote the use of the FAIRMODE benchmarking tools (Delta-tool, composite mapping tool, etc.) to reduce the gaps between local and regional emission inventories, to spot the main inconsistencies and to evaluate the quality of emission data.
4. Nomenclature for classifying emission sources: We recommend adopting the nomenclature used under the NEC Directive as a minimum disaggregation level for reporting emissions by sector, as basis for the urban emission assessment and source apportionment activities under the AAQDs. This nomenclature is the NFR-UNECE. For uses in high-resolution AQ modelling, the spatial aggregation for gridding (GNFR – Gridded

Nomenclature For Reporting)[11] is a good starting point, although further disaggregation to the NFR level may be necessary in specific modelling applications (e.g., GNFR: I non-road mobile machinery, which includes a large variety of emission sources that require different treatment, such as recreational boats and construction machinery).

6.4 Implications

The adoption of these recommendations would have significant implications for the compilation and quality control of emission data, and for the resources in terms of input data acquisition and processing used for emission data compilation.

- Member States would need to include detailed metadata information on the geographical and temporal distribution of high-resolution emissions in their reporting under AAQDs and the e-Reporting chain.
- It is advised to co-ordinate efforts at national level on high-resolution emission compilation and put more focus on the compilation of high-resolution emission data following bottom-up approaches.
- The IPR and e-Reporting guidelines would need to adopt the nomenclature for reporting emission by sector consistently across the AAQDs and NEC Directives, so that the request to report urban emissions adopts the GNFR/NFR nomenclatures used in the NEC Directive.
- Guidance documents for the compilation of high-resolution emissions will need to be elaborated, preferably linked to the EMEP/EEA emission inventory guidebook.

The implications for the revision of the legal provisions under the AAQDs and related guidance are summarised in section 7.2.5.

(11) https://www.eea.europa.eu/publications/emep-eea-guidebook-2019/part-a-general-guidance-chapters/7-spatial-mapping-of-emissions/view

7 Impact on legislation and associated guidance

In this chapter we identify the necessary revisions to the text of the AAQDs and to the IPR Decision and related guidance documents. We have also made an effort to identify how existing or planned guidance documents from FAIRMODE can contribute.

7.1 Recommended revisions to the AAQDs

The recommendations in the previous chapters reflect a consensus within the FAIRMODE network that has been consolidated through extensive discussions at plenary and technical meetings since 2017. In this section, we detail how these general recommendations might impact legislation, in particular the AAQDs and IPR.

7.1.1 Scope for modelling applications

On the scope for modelling in the AAQDs, FAIRMODE recommends the following:

- Clarify and extend the range of possible use of modelling methods, regardless of the upper or lower assessment thresholds (Art 6.2, 6.3 and 6.4), provided a quality assurance framework comparable to the one already defined for measurements is included. FAIRMODE recommends to use modelling for following applications:
    - Assessment purposes: Assessment of air quality levels, identification of hotspots, estimation of the extent of exceedances and of the (averaged) population exposure and/or exposure reduction targets.
    - Forecasting and public information purposes: Providing current and short term forecast of air quality levels and development/application of Air Quality Indexes.
    - Source apportionment purposes: Identification of air pollution sources, quantification of their contributions to provide a knowledge basis for planning mitigation strategies.
    - Planning purposes: Development and assessment of plans and measures to improve and ensure good air quality to meet air quality standards
- FAIRMODE recommends to make modelling mandatory for air quality planning, exposure calculations and short term forecast. Modelling should be strongly encouraged for monitoring network design, exceedance indicator estimates and near-real-time mapping, source apportionment and estimates of long-range transport and to define zones & agglomerations.
- Support the use of modelling in the establishment of zones and agglomerations (art. 4). Article 4 can be rephrased to allow Member States to combine results from previous measurements, previous measurement campaigns and modelling applications when they are to establish zones and agglomerations throughout their territory. This is especially relevant because the established zones and agglomerations represent the basis for all air quality assessment and air quality management purposes.
- Support the use of modelling in the review of monitoring site selection (annex III.D) and monitoring network design. The site-selection procedures can be facilitated with the use of modelling by providing information on the representativeness of the monitoring site. In addition, there is a need to revise site selection requirements to secure that there is a minimum number of sampling points to allow model validation in the specific zone and agglomeration. These two aspects should be considered in a possible revision of Annex III.
- Revise the possibility of reducing the required minimum number of fixed sampling points when supplementary techniques of assessment are allowed. The current text of the AAQDs allows for a reduction of the number of fixed measurements when indicative measurements or modelling approaches are used instead. However, an extended use of modelling also requires a better assessment of the quality of the modelling applications, namely though model validation with the use of measurements. The revised text of the AAQDs should allow for the revision of the minimum number of fixed measurements to secure enough measurements to be used for model validation purposes. Therefore, any reduction of the required minimum number of sampling points should be revised to consider the potential risk of such a rule would it drastically limit opportunities for modelling validation. Art 7.3, Art 10.3, Art 14.2.

7.1.2 A formal role for modelling (and FAIRMODE)

FAIRMODE recommends that each Member State (MS) should identify the main (national) reference institution related to air quality modelling applications, which will be encouraged to engage with the FAIRMODE network (in case they are not doing so yet). The role of national FAIRMODE reference institutions shall be clearly stated since this will be an important step to ensure that all the recommendations will be followed in the most adequate way/process.

7.1.3 Modelling Quality Objective (MQO)

Model Quality Objectives (MQO) are mentioned in Annex I: "Data Quality Objectives". FAIRMODE recommends using the standardized Modelling Quality Objective (MQO), as defined by FAIRMODE. This would imply the following changes to Annex I.

- Remove information related to model uncertainties in Annex table.
- Update (as proposed below) the existing definition of the overall model uncertainty (intended here as; model + input + configuration).

The modelling quality objective will be evaluated in accordance with the forthcoming principles of CEN WG264/43 (Ambient air — Definition and use of modelling quality objectives for air quality assessment) and/or EUR 30264 EN (FAIRMODE Guidance Document on Modelling Quality Objectives and Benchmarking), with parameters as specified in the Table below.

The modelling quality indicator (MQI) is defined as an average indicator of the measured-modelled concentration deviations scaled by the measurement uncertainty. It shall be interpreted as being applicable over the whole range of concentration. For a given monitoring station, the MQI applies to an entire assessment year, based on either short-term (hourly, 8h daily maximum average or daily) or long-term (annual) modelling results, according to the formula:

$$MQI_{long} = \frac{|\bar{O} - \bar{M}|}{\beta U(\bar{O})} \qquad \text{with } U(\bar{O}) = U_r(RV)\sqrt{\frac{(1-\alpha^2)}{N_p}\bar{O}^2 + \frac{\alpha^2 RV^2}{N_{np}}}$$

$$MQI_{short} = \frac{\mathrm{RMSE}}{\beta RMS_U} \qquad \text{with } RMS_U = U_r(RV)\sqrt{(1-\alpha^2)(\bar{O}^2 + \sigma_o^2) + \alpha^2 RV^2}$$

where $\bar{O}$ and $\bar{M}$ are the average measurement and model data, respectively. RMSE represent the root mean square error of the measured-modelled pairs. All other parameters are set in the Table below.

The MQO shall be calculated as the 90th percentile of all individual MQI values, over the assessment period considered. All fixed measurements available in the region of assessment and meeting the Data Quality Objective shall be used. For modelling hourly/daily output, both the short-term and long-term MQO shall be fulfilled.

$$MQO_{short} = MQI_{short,90th} \leq 1.00$$

$$MQO_{long} = MQI_{long,90th} \leq 1.00$$

Guidelines for conditions of applications and reporting of MQO shall be published by the Commission/FAIRMODE.

Table 1: Uncertainty parameters required for defining the MQO.

	β	U(RV)	RV	*a*	N_p	N_{np}
NO_2 hourly	2	0,24	200 µg/m³	0,20	1	1
NO_2 annual					5,2	5,5
O_3 maximum 8h daily average	2	0,18	120 µg/m³	0,79	1	1
O_3 annual average					11	3
PM_{10} daily	2	0,28	50 µg/m³	0,25	1	1
PM_{10} annual					20	1.5
$PM_{2.5}$ daily	2	0,36	25 µg/m³	0,50	1	1
$PM_{2.5}$ annual					20	1.5

Source: JRC, 2022

Note: β is a parameter that determines the stringency of the MQO. Its value shall be published by the Commission/FAIRMODE

7.2 Recommendations related to IPR decision

7.2.1 Estimation of Exceedance Situation Indicators

FAIRMODE recommends the development of a new 2 stages approach for the estimation and reporting of the exceedance situation indicators, since the current timing of the reporting under IPR is posing challenges for many MS. A first qualitative Exceedance Flagging Indicator can be easily assessed and expresses the severity of the exceedance in the air quality zone. This information could be reported under data flow G on the attainment of environmental objectives. The second quantitative Exceedance Situation Indicator requires a more comprehensive assessment approach and is used as the starting point of the air quality planning process. Reporting could take place under data flow H-K. A full description of the proposed methodology is given in the Guidance Document on *Exceedance indicators and Spatial Representativeness*[12].

7.2.2 Spatial Representativeness of monitoring stations

The methodology proposed by FAIRMODE CT8 on the assessment of a spatial representativeness area of a monitoring station should be referred to in the IPR. The methodology is based on modelled annual averaged concentrations varying within a specific margin of tolerance. The spatial representativeness area is defined according to a discontinuous approach within the boundaries of the air quality zone. The full description of the proposed methodology is given in the CT8 Guidance Document on *Exceedance indicators and Spatial Representativeness*.

7.2.3 Source apportionment

In this section, suggestions are made to update the reporting of information on source apportionment (data flow I) under the IPR to improve consistency and ensure comparability. It includes additional metadata fields (type of approach used, range of applicability, spatio-temporal averages applied at the receptor, spatio-temporal characteristics of the source, etc.) and ensure the consistency of the requested information with the emission classification proposed in section 4.3. A flexible, comprehensive and consistent interface to report

[12] https://fairmode.jrc.ec.europa.eu/activity/ct8

emission sources should be developed under IPR. An example of the proposed entries for data flow I can be detailed as follows:

1. *Code(s) of exceedance situation (link to Data Flow G)*
2. *Reference year*
3. *Time period over which the source is active (year, season…)*
4. *Indicator (concentration, exposure…)*
    a. *Pollutant*
    b. *Time average (day, year…)*
    c. *Spatial average (monitoring station, city, street…)*
5. *Local: definition of the area considered (e.g. city extension)*
6. *Local: SA method (sensitivity, tagging…)*
7. *Local: total*
8. *Local: traffic (GNFR F)*
9. *Local: industry (GNFR A, B, D)*
10. *Local: agriculture (GNFR K, L)*
11. *Local: commercial and residential (GNFR C)*
12. *Local: shipping (GNFR G)*
13. *Local: off-road mobile machinery (GNFR I)*
14. *Urban background: Definition of the area considered*
15. *Urban background: SA method*
16. *Urban background: total*
17. *Urban background: traffic*
18. *Urban background: industry including heat and power production*
19. *Urban background: agriculture*
20. *Urban background: commercial and residential*
21. *Urban background: shipping*
22. *Urban background: off-road mobile machinery*
23. *Regional background: SA method*
24. *Regional background: total*
25. *Regional background: from within Member State*
26. *Regional background: transboundary*
27. Regional background: natural
28. Total (all scales): transport
29. Total (all scales): industry
30. Total (all scales): agriculture
31. Total (all scales): residential and commercial
32. Total (all scales): shipping
33. Total (all scales): *off-road mobile machinery*

More details are provided in the FAIRMODE guidance on source apportionment[13].

7.2.4 Planning

We suggest setting up a group of experts with the aim of revising the information reported on air quality plans under the IPR (known as data flows H, I, J, K, with related meta data). We think there is scope to streamline these requests, making the data flow easier for reporting entities, and at the same time more useful for other actors willing to design air quality plans. The final aim of these data flow would be to facilitate exchange of best practices among peers.

7.2.5 High resolution emissions

FAIRMODE proposes to specify requirements for documenting the high-resolution emission data that is used as input for local/urban air quality assessments and air quality planning under the AAQDs and link those to the information provided under national emission compilation in lower resolution scale prescribed under the National Emissions reduction Commitments (NEC) Directive. This is to ensure enhanced transparency and

([13]) https://fairmode.jrc.ec.europa.eu/activity/ct1

comparability of the air quality results reported under the AAQDs. FAIRMODE is currently developing a system for compiling metadata documenting the emission data used as input in air quality modelling applications that can be useful for this purpose.

FAIRMODE also recommends the elaboration of guidance for the compilation of high-resolution emission inventories to be used as basis for air quality modelling applications under the AAQDs. FAIRMODE can provide guidance on high-resolution emission inventory compilation and can host a co-operation process for the development of user-checked methods to secure consistency with the national emission estimates compiled under the NEC Directive. FAIRMODE proposes to introduce benchmarking activities to establish the validity of the high-resolution emission data used for local/urban air quality assessments and air quality planning. FAIRMODE recommends adopting the nomenclature used under the NEC Directive as a minimum disaggregation level for reporting fine scale emissions by sector, as basis for the local/urban air quality assessments and source apportionment activities under the AAQDs.

7.2.6 Modelling quality objective (MQO)

Following the recommendation in 7.1.3, the IPR guidance should be updated so that the quality objectives for modelling are no longer inserted as free text that refers to a generic document, but with fields specific in relation to the MQO.

7.3 Summary table

These FAIRMODE recommendations mentioned above and their related changes in legal provisions, related guidance needs and links to other directives activities are summarised in the Table below for assessment, source apportionment, planning and high-resolution emissions.

Table 2: Summary of potential changes in legal provisions and guidance

FAIRMODE RECOMMENDATIONS			
On MODELLING APPLICATIONS	Related changes in Legal provisions	Related Guidance needs	Links to other directives
Clarify and extend the range of possible use of modelling methods, regardless of the upper or lower assessment thresholds	Revise AAQD articles 6.2, 6.3 and 6.4 in order to clarify for what applications modelling is mandatory and in which cases modelling can complement measurements and how.	General guidance on the use of modelling for air quality applications need to be developed to support this change in the legal provisions	N/A
Use of FAIRMODEs Model Quality Indicators (MQI) as basis for a Model Quality Objective (MQO) to provide a transparent and comparable quality assurance framework, like the one already defined for measurements	Revise the definition of MQI and MQO in Annex I of the AAQD to align with FAIRMODEs MQI definitions	Revise the IPR guidance document for reporting Modelling Quality Indicators in dataflow D (3) to correctly link and to refer to FAIRMODE MQI/MQO guidance documents.	N/A
Support the use of modelling in the establishment of zones and agglomerations.	Revise AAQDs Article 4 to allow Member States to combine results from measurements and modelling applications when they are to	Guidance is needed to relate the use of zones and agglomerations as basis for all air quality assessment and air quality	

	establish zones and agglomerations throughout their territory.	management purposes.	
Support the use of modelling in the review of monitoring site selection and monitoring network design.	Revise the formulation of AAQDs Annex III.D, to allow for the use of modelling to evaluate the spatial representativeness of the monitoring network and to revise site selection requirements to secure that there is a minimum number of sampling points to allow model validation in the specific zone and agglomeration.	Guidance needs to be developed to indicate how site-selection procedures can be facilitated with the use of modelling, by linking to guidance developed by FAIRMODE on the representativeness of the monitoring sites.	N/A
Model validation purposes should be considered when determining the minimum number of monitoring sampling points.	Revise AAQDs text in Art 7.3, Art 10.3, Art 14.2.to secure that any reduction of the required minimum number of sampling points should consider the potential risk of such a rule would it drastically limit opportunities for model validation purposes	Guidance on the use of models requires a better assessment of the quality of the modelling applications, namely though model validation with the use of measurements. FAIRMODE and CEN are currently providing guidance on The minimum number of fixed measurements to secure enough measurements to be used for model validation purposes.	N/A
Prescribe the use of modelling as mandatory for forecasting activities	Revise the text of the AAQD Annex XVI on public information to refer to mandatory modelling (deterministic or statistic)	General guidance on the use of models should also cover the forecasting application. And encourage the use of the FAIRMODE proposed methodology to assess the quality of modelling applications for forecasting purposes	NA
On ASSESSMENT PURPOSES	Related changes in Legal provisions	Related Guidance needs	Links to other directives
Enhanced use of models to facilitate the assessment of exceedance and exposure indicators.	Revise the formulation of average exceedance and exposure indicators in Article 11, 12 of the Commission's Implementing Decision 2011/850/EU (IPR decision) linking to the	Provide adequate links in IPR guidance document to the FAIRMODE Guidance documents, dataflows G, H, I, J, K will all be affected by the new guidance.	N/A

	new guidance from FAIRMODE.		
Use a tiered approach to determine the spatial representativeness of monitoring sampling points.	No changes needed	The current methodology proposed by FAIRMODE on the assessment of a spatial representativeness area of a monitoring station should be referred to in the IPR guidance	N/A
On SOURCE APPORTIONMENT	Related changes in Legal provisions	Related Guidance needs	Links to other directives
Enhance the use of modelling in source apportionment applications, with respect to identification of natural sources, winter salting and sanding and long-range transport transboundary contributions	Open for use of models to support source apportionment in AAQDs Article 20, Article 21, and Article 25 Revise the text of Commission's Implementing Decision 2011/850/EU (IPR decision), article 8 to enhance the use of models for source-apportionment applications	Guidance documents currently in use (SEC(2011) 207 and 208) do not reflect the maturity of modelling for use in source apportionment. These documents need now to be revised to allow for optimal use of state of art measuring methodologies and modelling techniques.	N/A
Provide guidance on the use and limitations of source apportionment methods and use of benchmarking tools	No changes needed	Revise existing guidance on source apportionment to available FAIRMODE documents on source apportionment approaches and promote use of a harmonised nomenclature to report source apportionment.	Need to ensure consistency between NEC and AAQDs reporting in terms of source apportionment
On AIR QUALITY PLANNING	Related changes in Legal provisions	Related Guidance needs	Links to other directives
Prescribe the use of modelling as mandatory for the elaboration of air quality plans for both long-term and short-term planning	Revise the text of AAQD Article 23 and Article 24 to indicate that modelling is mandatory for these applications	New Guidance on the development of air quality plans needs to be developed, including best practices and the use of benchmarking tools.	Requirements on the use of air quality modelling for planning purposes applies also to planning activities under the NEC directive
Provide harmonised comparable guidance on how to report air quality plans	Revise AAQD Annex XV according to new guidance Revise Commission's Implementing Decision 2011/850/EU (IPR decision) Article 13 and	Guidance needs to be developed on how to report data and metadata on air quality plans to secure comparable traceable documentation across Member States.	Guidance to be developed ensuring consistency between NEC and AAQDs reporting – specially with respect to NAPCP reporting

	Annex II – parts H, I and J according to new guidance		
On HIGH RESOLUTION EMISSIONS	Related changes in Legal provisions	Related Guidance needs	Links to other directives
Provide guidance on high resolution emission compilation	No changes needed	Guidance documents to support high resolution emission compilation are currently developed under FAIRMODE following GNFR nomenclature and promoting the use of benchmarking	Establish cooperation with experts in charge of the EMEP/CORINAIR emission Guidebook to secure consistency between national emission reporting under NECD and high-resolution emission estimates used under AAQDs
Introduce requirement for reporting high resolution emission metadata to document the emission data used in modelling applications under the AAQDs.	Commission's Implementing Decision 2011/850/EU (IPR decision) to be revised to secure that information on emission input to air quality modelling is provided	IPR guidance document to be revised to adjust to documentation requirements proposed by FAIRMODE following the GNFR and NFR nomenclatures High resolution emission metadata requirements are under development in FAIRMODE emission composite mapping	Documentation of high-resolution emissions used for air quality modelling to be linked to the information provided in the Informative Inventory Reports (IIR) under NEC Directive

Source: JRC, 2022

8 Conclusions

This document is FAIRMODE's contribution to the on-going revision of the EU AAQDs initiated by the European Commission. It provides strategic and technical recommendations where the scientific consensus within FAIRMODE indicates that robust conclusions can be drawn and identifies how and where to include these recommendations in the AAQDs, the IPR Decision and supporting Guidance documents.

The main recommendation from FAIRMODE is to secure and enable an extended use of modelling for air quality applications, in particular in the assessment of air quality levels, forecasting, source apportionment and planning purposes. The recommendations also include a chapter on how to secure the compilation of emission data with sufficient level of detail to enable modelling results of appropriate quality for the above-mentioned air quality management purposes. Recommendations are detailed for each of these modelling applications. The implications of the FAIRMODE recommendations on legislation and associated guidance are identified and shortly discussed.

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List of abbreviations and definitions

AAQDs	Ambient Air Quality Directives
CEN	European Committee for Standardization
CTM	Chemistry Transport Model
DQO	Data Quality Objective
EC	European Commission
EC-JRC	Joint Research Centre of the European Commission
EEA	European Environment Agency
EU	European Union
GNFR	Gridded Nomenclature For Reporting
IPR	Implementing provision Rules
MQI	Modelling Performance Indicator
MQO	Modelling Quality Objective
NECD	National Emission Ceiling Directive
PM	Particulate matter
PPM	Primary Particulate Matter
RM	Receptor model
SA	Source Apportionment
WG	Working Group

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