FAIRMODE WG8 – Guidance Document on the estimation of Spatial Representativeness and of Exceedance Situation Indicators

Authors: Stijn Janssen, Leonor Tarrason, Matthew Ross-Jones on behalf of the WG8 community
Version 3: including output of the discussion during the Technical Meeting in Oslo, 18 October 2022
Date: 21/02/2023

This Guidance Document summarizes the recent work of the FAIRMODE WG8 community. It provides recommendations for the estimation of Spatial Representativeness of monitoring stations and the estimation of the Exceedance Situation Indicators, both relevant parameters when reporting under the Ambient Air Quality Directives (AAQD). Note that this guidance focuses on the methodologies to be used for estimation of these parameters and provides recommendations on their estimation. In its current version, this guidance does not identify the best ways of reporting those methodologies and their results under the Implementing Provisions on Reporting (IPR).

The recommendations on spatial representativeness have to some extent been taken into account in the EC proposal for the new AAQD. The recommendations on the Exceedance Situation Indicators can serve as a basis for the upcoming review of the IPR.

I. Recommendations on Spatial Representativeness estimation

Context

The assessment of the spatial representativeness (SR) of monitoring stations has been discussed within the air quality community for a long time. SR is an essential indicator of any sampling point location and relevant for further interpretation of its measurement data in the context of the EU AAQD. It also plays a crucial role in the characterization of exceedance situations, the evaluation of modelling results and in the design and evaluation of the monitoring network. Therefore, SR is requested to be reported under the IPR and the related e-Reporting system under Data Flow D.

FAIRMODE has been involved in the discussion of SR assessment since the early days, given the potential role of modelling in this assessment process and the relevance of SR in any process where observations from monitoring stations are combined with modelling (validation, data fusion or data assimilation…).

For a better understanding of the concept of SR, it is essential to clearly specify the various application domains of SR. These include:

1. Assessment of population exposure based on monitoring data
2. Assessment of exceedance situations based on monitoring data
3. Monitoring network design
4. Use of monitoring data for model validation and data fusion/data assimilation

Spatial Representativeness Area

Over the last years progress has been made within the FAIRMODE community by putting forward the concept of a SR area of a monitoring station. In such an area, concentrations are similar to the ones observed in the station and as a result, the station is representative for the situation in that SR area. Such a SR area serves many purposes of the application domains mentioned above. The SR area naturally links the observed concentrations in a monitoring station to an exposed population (application 1 and 2) or an area or road link in exceedance of a limit value (application 2). It can also help to assess the (spatial) overlap in a monitoring network or identify blank spots in the air quality zone which are not sampled yet or identify redundancies in the network layout (application 3). Finally, the spatial extent of the SR area can be used to select the relevant monitoring stations for a model validation or data fusion/assimilation exercise (application 4). The spatial extent of the SR area should not be smaller than the spatial resolution of the model for a meaningful comparison.

Recommended methodology for SR area estimation

Based on joint efforts, the FAIRMODE WG8 community developed a methodology to practically delineate a SR area of a monitoring station. The aim of the exercise was to come forward with a simple, robust and transparent approach that can be easily applied all over Europe and that captures the essential and scientifically sound elements of SR in the context of the AAQD.

Definition: The spatial representativeness area around a monitoring station is defined as an explicitly delineated geographical area for which the observed air quality metric at the monitoring station does not vary more than a pre-defined tolerance level.

Associated characteristics: This definition comes with some associated characteristics:

- The geographical area may include discontinuous domains but shall be limited in its extension by the borders of the Air Quality Zone under consideration.
- The tolerance levels and possible cut-offs for the different pollutants may change depending on the station characteristics and should be provided by specific guidance from FAIRMODE.
- The annual average of the observed pollutant concentration shall be used as the air quality metric for a specific year

More concretely, this can be specified as:

- **A discontiguous definition is adopted for the SR area**. This means that the SR area can cover different sub-areas separated by areas of high or low concentration not included in the SR area (i.e. the SR area of a sampling point does not have to be fully joined together). This is in line with the AAQD logic for a sampling point to be representative of similar locations not in their immediate vicinity.
- **The Air Quality Zones as defined under the AAQD are used as boundaries for the SR area**. Such boundaries are essential under a discontiguous approach and follows the assessment logic under the AAQD and the IPR. If relevant and deemed appropriate, the SR area can be smaller than the Air Quality Zone. This can be relevant for large Air Quality Zones where the SR area can be limited to a specific (rural) subzone or a particular city/urban area. But it cannot include areas outside of the given Air Quality Zone.
- **Annual mean concentration values are used as similarity criterion**. This means that SR areas are only defined for annual averaged situations. This restriction can be extended at a later stage (see further below).

- **The similarity criterion is applied with a tolerance (or threshold) level**. The recommended tolerance level may change depending on the station characteristics and WG8 proposes a tolerance level of:
    - ± 10% for rural and urban background stations
    - ± 20% for traffic or industrial stations

  In addition to the relative tolerance levels, a lower absolute cut-off value of 2 µg/m³ is recommended to be used for the lowest concentration ranges. So the tolerance level is never smaller than this lower cut-off value. This is especially relevant for rural stations. The tolerance levels have been tested for NO_2, PM10, PM2.5 and O_3.
- **Model simulations are used to evaluate the similarity criterion** (i.e. annual mean concentrations). Air quality models represent our best possible understanding of (local) sources, boundary conditions, dispersion characteristics and chemistry regimes. Obviously care should be taken that fit-for-purpose modelling systems are applied in this process. This also assumes that the model bias at the location of the station is small (see further below).
- Given a fit-for-purpose modelling system is applied, the modeled concentration at the location of the station is used in the similarity criterion rather than the measured values. This avoids bias related anomalies in the SR area delineation.

Various modelling teams of the FAIRMODE WG8 community have evaluated and tested the methodology for different monitoring stations in Europe, covering the whole spectrum of rural, urban background and traffic sites and for the pollutants PM10, PM2.5, NO_2 and O_3. Based on the findings of this WG8 exercise, the proposed methodology is deemed appropriate for practical use in the context of the AAQD.

Further refinements on SR methodology choices

Obviously, the rather simple methodology presented above contains certain shortcomings and can be further refined. Open issues or refinements already identified by the WG8 community are:

- Further discuss and test the split in tolerance level (10% vs 20%) for different station types. The split can be seen as an additional layer of complexity in the definition. It could potentially cause problems when the station type is not clearly defined (e.g. traffic versus urban background site) or might be irrelevant for some pollutants (traffic site for $PM_{2.5}$ vs NO_2). These are arguments to adopt a single tolerance level of e.g. 15% for all station types, so further testing is needed to investigate the impact of different approaches on monitoring networks across Europe.
- Test alternatives for the lower cut-off value (now 2 µg/m³) for various pollutants. First feedback from the WG8 community is that 2 µg/m³ might be too large for some pollutants.
- Extend the annual mean similarity criterion to other aggregation times relevant in the AAQD (e.g. percentiles) or to seasonal averages.
- Extend the similarity criterion with source information to arrive at source specific SR areas. This could be relevant in the context of source apportionment (WG1) and air quality planning (WG9).
- Investigate the inter-annual variability of SR which can be driven by meteorological effects or long(er) term emission trends.
- At present, SR of industrial stations was only poorly analyzed and should be further investigated. In situations where important point sources are relevant average values can be inappropriate and the influence area of the important source(s) must be isolated and evaluated separately.

- Investigate the impact of the model bias at the location of the station. What is an acceptable bias in this context? Is there a recommendation regarding model calibration via data fusion and what is the impact on the SR assessment? In any case, the MQO and related MPC should be fulfilled.
- How should the SR areas be reported under the IPR and e-Reporting? At present a shapefile (or similar geographical info) is already requested in the IPR, along with a text description and a URL to more detailed documentation. These elements are "Mandatory (where available)" but very few Member States actually report the information. How do deal with this situation? Can e-Reporting request for shape files of the SR area per monitoring station, per pollutant?

II. Recommendations on the estimation of Exceedance Situation Indicators

Context

The Implementing Provisions on Reporting (IPR) under the Ambient Air Quality Directive (AAQD) request information on the attainment of environmental objectives. The information is required in the form of Exceedance Situation Indicators (ESI) and such indicators are to be reported under Data flow G of the e-Reporting. More precisely, the IPR Guidance document states: "*When environmental objectives have been exceeded, estimates of the total area, population and road length exposed to levels above the environmental objective shall be reported for each zone as a whole. Associated geometry information (GIS data) shall also be provided. References to the assessment methods observing the exceedances shall also be given e.g. the fixed or indicative measurements, modelling or objective estimation used. Assessment methods are reported within Data flow D.*" Thus, the information on total area, population, and road length above the limit value are the core of the Exceedance Situation Indicators (ESI) that are further considered in this document. Note that ecosystem exceedance indicators have not been included in the WG8 analysis yet.

A number of questionnaires and surveys carried out in the context of the review of the Ambient Air Quality Directives have indicated that Member States are in need for more guidance to arrive at a transparent, robust and comparable definition of these indicators and a recommended methodology to be used for their estimation.

The estimation of the ESI's has been discussed and evaluated within the FAIRMODE community under WG8 as part of the work plan for 2020-2022. The findings and recommendations from the benchmarking activities carried out under FAIRMODE WG8 are summarised in this note and form the basis for the current recommendations on the definition and estimation of the three above-mentioned Exceedance Situation Indicators.

Purpose of the Exceedance Situation Indicators

As mentioned in the IPR Guidance document, the purpose of the ESI is to provide information on the attainment of environmental objectives, or phrased differently, about the extent and severity of the observed exceedance.

The basis for the assessment of exceedances are observations at specific monitoring sampling points[1]. They provide the evidence that the concentration level is above the environmental objective at the position of the station/sampling point. In such a situation the exceedance indicator is used to complement this observation with additional information about the extent and impact (e.g. on population) of the exceedance situation. Apart from the compliance purpose, the exceedance situation indicators are also used for health impact assessments and as information for the planning purposes.

Current definition of ESI: area, population, road length and ecosystem

There are currently four different exceedance situation indicators defined under the AAQD/IPR.

1) **The area of exceedance** is the most robust and simple ESI, both in definition and assessment methodology. The indicator is expressed as a surface in m² or km². It is recommended that this indicator is the leading ESI. It is currently an ambiguous indicator in that it is not fully clear whether this area refers to the representative area of the monitoring sampling point(s) or to an area in the entire air quality zone. It is proposed to link the definition of this indicator to the whole air quality zone (or subzones at e.g. city level if relevant).
2) **The population in the area in exceedance indicator** currently refers to the population in the area where exceedances are observed but the actual interpretation varies amongst Member States. The indicator is expressed as number of residents. For this indicator to be useful also for health impact assessments and to guide the design of air quality plans, it is recommended to link it to the Area ESI by adding information on population data and to inform about the population affected in the area of exceedance.
3) **The road length indicator** is very much connected to exceedances observed in traffic stations. Despite its seemingly simple definition, the estimation can be sensitive to the assessment methodology (e.g. which road link network is used). The indicator is expressed as a length in m or km. Within the WG8 community there is no consensus yet about the usefulness of this indicator.
4) **The ecosystem indicator** is defined in the IPR but is not considered in this version of the guidance yet.

Proposed modified definition of Exceedance Situation Indicators

In order to facilitate, simplify and harmonise the assessment and reporting obligations of these Exceedance Situation Indicators, FAIRMODE proposes to distinguish between the two objectives of the indicators. We recommend to establish first an Exceedance Flagging Indicator useful to flag the exceedance and then define an Exceedance Situation Indicator related to health impacts and relevant to guide the planning process.

- The **Exceedance Flagging Indicator** (EFI) is primarily a flagging indicator in the compliance checking process. It helps to evaluate the severity of the exceedance in an air quality zone that contains a sampling point with a measured exceedance. This is a *qualitative* indicator to flag the severity of the exceedance. Given its qualitative nature, it is proposed that such an indicator is class based, categorising the exceedance situation in a limited range (e.g. 4, see

[1] At present, only a few Member States report exceedances based on model simulations.

further) of classes according to its severity in terms of population exposed. Such type of indicator could be assessed rather quickly with limited efforts in a first attainment evaluation.

- The **Exceedance Situation Indicator** (ESI) is primarily a health related indicator that provides *quantitative* and spatially explicit information. This is a quantitative indicator that identifies all the areas and the number of resident in the air quality zone exposed to concentrations above the limit values. These so-called hot spots areas can be very local or, in some cases, cover large part of the Air Quality Zone (e.g. for O3 or PM). This type of indicator should be used as a basis for the design of an Air Quality Plan and should be coupled to a source apportionment analysis for a better understanding of the reasons behind the explicit exceedance situation.

Proposed Estimation Methodology

The purpose of the indicators mentioned above has an impact on the methodology used to estimate these quantities. The overall recommendation for the estimation of the EFI's and ESI's is to keep it simple. This is the only guarantee to arrive at a robust, transparent and harmonized set of indicators. The recommendation is to separate the definition of the indicators on the basis of their purpose but maintaining an alignment between the two to secure consistency across the different air quality assessments. Finally, it is important to mention that definition of the EFI's and ESI's should work for all pollutants.

- **Compliance Purposes:** The qualitative **Exceedance Flagging Indicator (EFI)** is expressed in classes that provide an indication of the severity of the exceedance in the air quality zone. The EFI is an estimate of the total population in the Air Quality Zone exposed to concentrations above the limit value. The definition is given in the scheme below [REALITY CHECK NEEDED - FEEDBACK REQUIRED ON THE RANGES DEFINING THE CLASSES]:

Class	Residents in exceedance in the AQ Zone	Description of the exceedances
1	< 100	Very Limited
2	100 – 1.000	Limited
3	1.000 – 100.000	Extensive
4	> 100.000	Widespread

The simple definition of the EFI allows for a rather straightforward estimation of the exceedance situation in the zone. The severity class of the exceedances can be assessed based on expert judgement or simple (low Tier) assessment methods based on proxy data, measurement campaigns or existing model simulation. In this process, only a "rough" estimate (class 1 to 4) has to be identified. It is expected that this EFI assessment process is light and doesn't result in addition administrative burden.

- **Planning and health impact purposes:** The quantitative **Exceedance Situation Indicator** (ESI - Area and Population) is a more refined, quantitative and spatially explicit indicator. The indicator is more precise and can serve as the starting point for an Air Quality Plan. This ESI should be based on spatially explicit modelled concentration maps or detailed (indicative) measurement campaigns.

  For the ESI, the Area can be derived based on a concentration map and comprises all areas in the AQ zone above the limit value. For the Population indicator, a static map (for the time

being) can be used in overlay with the Area shape to arrive at the number of people living in the Area of exceedance. The Area indicator is a shape, the Population indicator a number. The usefulness of the road length indicator should be further evaluated. In some Member States it has demonstrated its merits, other experts have doubts about the robustness of the indicator.

As a general observation it can be stated that an "on/off" threshold exceedance indicator is not ideal for air quality planning and policy development. By definition, such an exceedance indicator can be (very) sensitive to small changes in assessment technique. It is considered useful to complement this on/off indicator with full range concentration maps to give a more comprehensive picture of the exceedance situation at hand.

For the ESI, a comprehensive estimation approach is required based on fit for purpose modelling systems. According to recent FAIRMODE recommendations[2], the selection of a modelling system should be based on the concentration patterns that are observed in the real atmosphere and are most probably pollutant dependent. If strong concentration gradients are expected and/or recorded in measurement stations or monitoring campaigns, a modelling system should be setup that is capable to capture these gradients. The modelling system should at least meet the FAIRMODE Modelling Quality Objective.

Street canyons in an urban environment play an important role in the concentration patterns of some pollutants. For urban Air Quality Zones, proper accounting of the canyons seems indispensable for an assessment of the traffic related hot spot locations. A remaining open issue is the use of street canyon concentration increments in population exposure. If residents live in front of a street canyon, are they exposed to facade or backyard concentrations? This is still considered as an open issue which requires further analysis in cooperation with the health community.

Further refinements on EFI and ESI methodology choices

The methodology presented above requires further refinements to be implemented in practice. Some of the refinements are given below. Also a number of open issues and shortcomings have been identified which require further testing and fine tuning. Open issues or refinements already identified by the WG8 community are:

Reporting of the indicators

Up to now, the ESI's are required via Data flow G of the e-Reporting system when an exceedance is observed and reported. The ESI's are also requested in Data Flow I of the e-Reporting system, but this is not an explicit requirement in the IPR decision (2011/850/EU). In our view, both the EFI and the ESI require an appropriate but independent reporting.

The **EFI** could remain under data flow G. Since it doesn't necessarily require new detailed modelling but could build upon e.g. existing modelling results it can be estimated rather quickly and reported when measurement data is provided, annually before 30th September (for the previous year's data). The reporting of the EFI comprises an expert judgement process that should be properly documented.

[2] FAIRMODE recommandations: https://publications.jrc.ec.europa.eu/repository/handle/JRC114599

The **ESI** requires more in depth analysis and could be reported under Data Flow I as starting point for the planning process. Reporting of these ESI's should be accompanied by adequate documentation of the analysis conducted. Elements of Data flow D (D1b meta information of models) could be used as inspiration to accommodate this specific reporting of related model data under Data Flow I.

At present, information about the air quality plan under Data Flow I has to be reported 2 years after the exceedance. It remains to be discussed if this timing is appropriate for the reporting of the ESI or if it could/should be reported at an earlier stage.

Requirements for time resolution

The time aggregation of the environmental objective (limit or target value) is given by the AAQD and defines the required time aggregation of the indicators.

Not necessarily the same time resolution is requested for the model output. E.g. in some cases daily limit values or percentiles can be estimated based on modelled annual concentration levels. Specific attention is required to demonstrate the validity of these relations.

Requirements for input data

For the time being, population exposure could be based on static population data sets. A fully dynamic population exposure assessment (e.g. including commuting patterns) is out of scope although it can be expected that a static approach may lead to an underestimation of the number of people affected (exceedances more common in city centers where people commute to work, shop… but where much fewer people live).

It is recommended that the resolution of population data is aligned with the model resolution.

Static population data in the ESI can be complemented by information about sensitive groups such as hospitals, elderly homes, kindergarten… In any case this is valuable information as starting point for the development of the air quality plan.

Link between EFI/ESI and measurements

The trigger for EFI/ESI reporting is an observed exceedance in a monitoring station. Therefore, the spatial representativeness of the monitoring station gives an indication about the exceedance and can be used in the estimation process of the EFI/ESI.

In order to identify the areas with the highest concentrations in the AQ Zone, it is proposed by AQUILA to supplement fixed measurements by modelling techniques or indicative measurements for situations where the observed concentrations are above the Upper Assessment Threshold (UAT). When the exceedance is caused by a known point source, there might be limited need for such an additional explorative assessment exercise.