FAIRMODE WG8 – Guidance Document on the estimation of spatial representativeness

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Version 4, 03/03/2025

This Guidance Document summarizes the work carried out so far within the FAIRMODE WG8 community in relation to the issue of spatial representativeness of air quality sampling points. It builds on and replaces the previous WG8 guidance document on this issue and provides a range of recommendations for the estimation of spatial representativeness of sampling points. The document also includes a number of annexes with contributions and examples from different monitoring networks and organisations following extensive testing of the spatial representativeness methodology during the last few years.

The revised EU Ambient Air Quality Directive (EU) 2024/2881 (AAQD) includes a number of key criteria for determining spatial representativeness area of sampling points (AAQD, Annex IV Point B.5), which are largely based on the methodology and recommendations that have been developed within FAIRMODE for estimating spatial representativeness. This document is intended to give more details and important background information on the methodology and recommendations, as well as examples on the application of these criteria.

In its current version, this guidance does not identify the best ways of reporting representativeness area of sampling points under the Implementing Provisions on Reporting (IPR), but the recommendations and experiences gained within FAIRMODE WG8 can provide an important input to the upcoming review of the IPR.

Recommendations on spatial representativeness estimation

Context

The assessment of the spatial representativeness (SR) of sampling points 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, the AAQD requires that the spatial representativeness area (SRA) of each sampling point is clearly defined (obligatory in all zones which exceed the relevant assessment threshold). The SRAs of sampling points is also requested to be reported under the current 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 suitability 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. Interpretation of measurement data
2. Assessment of population exposure based on monitoring data
3. Estimation of exceedance areas based on monitoring data (in case of no up-to-date modelling data available), for further analysis in air quality planning
4. Monitoring network design and evaluation of compliance with siting criteria
5. 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 spatial representativeness area (SRA) 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 SRA. Such an SRA serves many purposes of the application domains mentioned above. The SRA naturally links the observed concentrations in a monitoring station to an exposed population (application 1, 2 and 3) or an area or road link in exceedance of a limit value (application 3). 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 and thus give important input on the potential to optimise / ensure the completeness of a network during the regular reviews of network layouts that are required by the AAQD (application 4). Finally, the spatial extent of the SRA can be used to select the relevant monitoring stations for a model validation or data fusion/assimilation exercise (application 5). The spatial extent of the SRA should not be smaller than the spatial resolution of the model for a meaningful comparison.

Recommended methodology for SRA estimation

The aim of the FAIRMODE WG8 exercise on SR 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. Based on joint efforts over recent years, the WG8 community have developed such a methodology to practically delineate the SRA of a sampling point. Various modelling teams have evaluated and rigorously tested this methodology for different monitoring stations in Europe, covering the whole spectrum of rural, urban background and traffic sites and for the main pollutants in the AAQD (including PM10, PM2.5, NO_2 and O_3).

The key elements of this methodology were included in the revised 2024 AAQD and the FAIRMODE recommendations given below have been somewhat adapted (compared to previous versions of this guidance document) to ensure alignment with the language of the AAQD and the approach to SR assessment that is prescribed therein.

Definition: Spatial representativeness means an assessment approach whereby the air quality metrics observed at a sampling point are representative for an explicitly delineated geographical area to the extent that air quality metrics within that area do not differ from the metrics observed at the sampling point by more than a pre-defined tolerance level.

Associated key criteria: The approach for determining the SRA of sampling points is based around a number of key criteria:

- The geographical area may include non-contiguous domains but shall be limited in its extension by the borders of the air quality zone (with the exception of assessment, e.g. in rural background, which is not conducted in relation to air quality zones and for which different limits need to be applied).
- The recommended tolerance level and minimum tolerance levels / lower cut-offs define the width of the concentration interval for which concentrations are considered similar. The minimum tolerance level depends on the pollutant.
- The annual average of the observed pollutant concentration shall be used as the air quality metric for a specific year, although other metrics may be considered, e.g. percentiles.
- If assessed via modelling applications, a fit-for-purpose modelling system shall be used and modelled concentrations shall be used at location of the sampling point to prevent systematic model-measurement biases from distorting the assessment. The spatial resolution of the model shall correspond to the monitoring site type (e.g. for SRAs of traffic sites, a high resolution / street canyon model is appropriate).

Further description, recommendations and references to examples on application of these criteria:

- **A non-contiguous definition is adopted for the SRA**. This means that the SRA of a sampling point can cover different sub-areas separated by areas of high or low concentration that are not included in the SRA (i.e. the SRA of a sampling point does not have to be fully joined together). This recommendation is grounded in the logic provided by the AAQD which states that sampling points shall, where possible, also be representative of similar locations not in the immediate vicinity. Various examples of non-contiguous SRAs can be found in the appendices to this document, e.g. Fig. C2 in Appendix 1, Figures 6 – 13 in Appendix 3 and Figure 3 in Appendix 4.

- **Air quality zones as defined under the AAQD are used as maximum geographical limits for SRAs, where relevant.** The use of a non-contiguous approach makes it necessary to set appropriate maximum geographical limits to ensure that SRAs do not become unreasonably large. Since the majority of measurements carried out under the AAQD are related to air quality zones, it is recommended to use these zones as the primary approach for limiting the spatial extent of SRAs. For such measurements, SRAs shall not include areas outside of the air quality zone in which the monitoring site is located. If relevant and deemed appropriate, it is also possible to apply a more stringent approach and limit SRAs to areas smaller than the air quality zone. This can be relevant for large air quality zones where the SRA can be limited to a specific subzone or a particular city/urban area. Examples indicating cases where it could be considered appropriate to limit SRAs to a specific city/urban area can be seen in figures 2 – 5 in Appendix 3. In these examples, SRAs for urban background stations extend large distances away from the cities in which they are located, including into rural areas which are likely to be better represented by rural background stations in the region.

- **Need for alternative maximum geographical limits for certain measurements.** Testing within FAIRMODE has shown that the zone-based approach described above can be problematic for certain measurements that are not carried out in relation to air quality zones. This applies in particular to regional background stations, where the required station density according to the AAQD has no relation to air quality zones. Applying zone-based limitations for SRAs of regional background stations can therefore create apparent "gaps" in the monitoring network, which are largely due to different zone designs rather than an actual lack of data / coverage in rural areas of a country (see various examples provided in Appendix 7). There is currently no consensus within FAIRMODE on a one-size-fits-all solution for defining maximum geographical limits for regional background stations. It is instead recommended that Member States and their competent authorities should have some flexibility to choose appropriate maximum geographical limits based on their own conditions. The use of different NUTS units may be relevant in some countries (see example in section 2.2. of Appendix 6), while in others the use of topographical and climatological zones (see example in Appendix 5) may be more appropriate. Where Member States choose to apply alternative maximum geographical limits (instead of zones) it is important that this choice is well documented, with a detailed justification. In any case, and regardless of the choice of geographical limit, an absolute maximum radius of 200 km from the station is recommended for all SRAs.

- **Annual mean concentration values are used primarily as similarity criterion**. This means that SRAs are to be defined based on annual average concentrations at the sampling point's location. However, there may also be circumstances where it is relevant to assess SRAs considering other metrics such as percentiles (see further below). The vast majority of the examples presented in the appendices of this document are SRAs that have been estimated using annual average concentrations.

- **The similarity criterion is applied with a tolerance level**. Following extensive testing within FAIRMODE (see appendices), it is recommended to use a tolerance level of ±15 % to define the concentration interval to be used for all types of measurement stations.[1]

- **Pollutant-specific minimum tolerance levels / concentration intervals.** In lower concentration ranges a percentage criterion, which is proportional to the concentration itself,

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[1] This recommendation has evolved from a previous FAIRMODE recommendation to use tolerance levels of ±10 % for rural and urban background stations and ±20 % for traffic or industrial stations. While initial testing indicated that varying tolerance levels depending on station type could be appropriate, further testing identified potential issues, for example that it could potentially cause problems when the station type is not clearly defined (e.g. traffic versus urban background site) and that it might be irrelevant / inappropriate for some pollutants (e.g. $PM_{2.5}$ where differences between traffic and urban background concentrations can be relatively small). The use of varying tolerance levels also adds an additional layer of complexity in the methodology, which is a clear disadvantage.

is not appropriate since it can lead to SRAs that are unreasonably small. Therefore, in addition to the relative tolerance levels, it is recommended to set minimum absolute tolerance levels / concentration intervals so that the width of the concentration interval used for delineating SRAs is not smaller than this value. This is important for areas with the lowest concentration ranges and is thus especially relevant for rural stations. The following minimum tolerance levels / concentrations intervals are recommended:

- PM10, NO_2, O3: ± 2 µg/m^3
- PM2.5, SO_2: ± 1 µg/m^3
- CO: ± 0.025 mg/m^3
- B(a)P: ± 0.2 ng/m^3

Further testing is needed before minimum values can be recommended for benzene and metals (As, Cd, Ni and Pb).

Examples illustrating cases where the minimum tolerance level / concentration interval is applied, rather than the relative tolerance level (±15 %), can be seen in figures 3, 5 and 11 in Appendix 3 and figures 4 and 5 in Appendix 6.

- **Modelling applications should be used to estimate SRAs**. Air quality models represent our best possible understanding of sources, boundary conditions, dispersion characteristics and chemistry regimes. Obviously, care should be taken that fit-for-purpose modelling systems are applied in this process. The spatial resolution of the model shall correspond to the monitoring site type. This also assumes that the model bias at the location of the station is small (see further below).

- **Use modelled values rather than measured values.** Given a fit-for-purpose modelling system is applied, the modelled concentration at the location of the station, rather than the measured values, should be used to determine the similarity criterion to be applied for a specific sampling point. This avoids bias related anomalies in the SR area delineation.

Formula and examples on calculating the concentration interval to be used for estimating SRAs:

The following formula can be used to determine the lower and upper bound of the concentration interval that is to be used for estimating SRAs in accordance with the relevant criteria set out above (i.e. the uniform tolerance level of ±15 % and pollutant-specific minimum tolerance levels):

$$\left[\min\left(C - cut\_off,\ C \times \left(1 - \frac{15}{100}\right)\right); \max\left(C + cut\_off,\ C \times \left(1 + \frac{15}{100}\right)\right)\right]$$

Where C is the modelled concentration at the sampling point location and cut_off is the minimum tolerance level for the pollutant that is being assessed.

The following two examples illustrate one case where the uniform tolerance level of ±15 % determines the width of the concentration interval to be used for estimating the SRA and one case where the pollutant-specific minimum tolerance level determines the width of the concentration interval:

- **Sampling point for NO_2 with a modelled annual mean concentration of 34.80 µg/m^3.** Using the pollutant-specific minimum tolerance level for NO_2 of ±2 µg/m^3, the resulting interval would be 32.80 – 36.80 µg/m^3. Using the uniform tolerance level of ±15 % the resulting interval would be 29.58 – 40.02 µg/m^3. Since the concentration interval using the uniform tolerance level is larger than the minimum permitted concentration interval using the pollutant specific minimum tolerance interval, an interval of 29.58 – 40.02 µg/m^3 should be used for estimating the SRA of the sampling point.

- **Sampling point for PM2.5 with a modelled annual mean concentration of 5.19 µg/m^3**. Using the pollutant-specific minimum tolerance level for PM2.5 of ±1 µg/m^3, the resulting interval would be 4.19 – 6.19 µg/m^3. Using the uniform tolerance level of ±15 % the resulting interval would be 4.41 – 5.97 µg/m^3. Since the concentration interval using the uniform tolerance level is smaller than the minimum permitted concentration interval using the pollutant specific minimum tolerance interval, an interval of 4.19 – 6.19 µg/m^3 should be used for estimating the SRA of the sampling point.

Further refinements on SR methodology choices

Obviously, the rather simple methodology presented above contains certain shortcomings and can be further refined. There may be cases where it is appropriate to apply additional criteria in order to further improve estimations of a sampling point's SRA. The following additional criteria have so far been identified by the WG8 community and can be applied on a voluntary basis:

- Extend the concentration metric (annual mean) that the similarity criterion is based upon to other metrics relevant in the AAQD, e.g. percentiles, or to seasonal averages. Some examples of the estimation of SRAs using percentiles have already been produced by the WG8 community and can be found in the appendices, for example in Fig. B2, B4, B7 and C4 in Appendix 1.
- Extend the similarity criteria with source information to arrive at source-specific criteria (e.g. consider different types of industrial or traffic sources which, by chance, produce similar concentrations). This could be relevant in the context of source apportionment (WG1) and air quality planning (WG9). For further examples and reflections related to source-specific criteria, see Appendix 5, section 2.6 of Appendix 6, and page 23 of Hooyberghs et al. (2020)[2].

There also remain some open issues that have been identified and that require further testing and discussion within the FAIRMODE community:

- Investigate the temporal (inter-annual and long-term) variability of SRAs which can be driven by meteorological influence or emission trends. Testing for street canyon stations in Berlin indicates that SRAs remain relatively stable over time (see section 3 of Appendix 6), whereas testing of a street canyon station in Brussels indicates the opposite, i.e. that SRAs can very considerably over time (see section 3.1 of Appendix 7). Testing carried out in the Friuli Venezia Giulia region in Italy, suggests that inter-annual variability could be pollutant-dependent, since they found larger variability in SRAs for PM10 than for NO_2 (see Appendix D of Appendix 1).

[2] Hooyberghs, H., Tarrason, L., Janssen, S. and Soares, J., (2020). Assessing the spatial representativeness (SR) of air quality sampling points – Sensitivity and feasibility tests for a tiered approach – Final Report for the European Commission, ED 11492. Available at: https://fairmode.jrc.ec.europa.eu/document/fairmode/WG1/20201221_ENV_comments_SR5_Task1_FINAL_clean.pdf

- At present, there has not been sufficient testing of sampling points in industrial locations, around ports and airports or in domestic heating hotspots. Further testing of the recommended methodology is needed in these locations to investigate the need for potential additional criteria that may be relevant for application in such environments.
- Further investigate the impact of model bias at the location of the station. What is an acceptable bias in this context? In any case, the MQO and related MPC should be fulfilled.
- Is there a need for clear recommendations regarding model calibration via data fusion and what is the impact of calibration on the estimation of SRAs? Some initial testing of the impact of different bias correction on SRA estimates has been done by FAIRMODE WG4 (see appendix 2), but it was clear from the results that further work is needed. Testing carried out by Germany (see section 2.5 of Appendix 6) has indicated that the suitability of using results following data fusion may depend on the data fusion method that has been applied. For example, data fusion methods using interpolation techniques can lead to artificial patterns and have a large impact on the resulting SRAs, which does not seem appropriate. In such cases it may be preferable to instead use the raw model data in the assessment of SRAs. However, the use of simpler bias correction techniques, e.g. adjustment of the whole model domain by a single factor, can produce more realistic air pollutant concentrations without introducing artificial patterns and an over-dependency of the SRA on the correction method. It therefore seems reasonable to use corrected results rather than the raw model results, where such simpler techniques have been applied.
- How should SRAs be reported under the IPR? At present a shapefile (or similar geographical info) is requested in Member States' reporting according to 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 have actually reported the information to date. How can the reporting of SRAs be improved in the coming years with the revision of the IPR? The availability of this recommended FAIRMODE methodology, along with clearer requirements related to SR in the AAQD, should significantly increase the availability of information on the SRAs of sampling points within Europe's monitoring networks. Work is, however, needed in the coming years to ensure a simple and harmonised approach to reporting SRAs in the revised IPR reporting provisions. One issue that is clear from the testing and discussions carried out within FAIRMODE relates to the importance of providing detailed documentation together with the SRAs of sampling points. This is particularly important where the additional, voluntary criteria detailed under "Further refinements on SR methodology choices" above have been applied. FAIRMODE WG8 plan to develop a template to aid the harmonisation of this documentation for reporting purposes.

List of appendicies

APPENDIX 1

FAIRMODE WG8 – RECOMMENDATIONS ON SPATIAL REPRESENTATIVENESS ESTIMATION - ITALY

5/2/2024

This document provides the feedback from Italy to FAIRMODE WG8 Guidance Document using results from different applications related to WG8 proposed Checklist. This outcome is based on the discussions of a working group that brings together the Ministry of Environment, ENEA and several Italian Regional agencies (Regions are the administrative entities in legal charge for air quality assessment). In the following, comments are provided in the context of the New Air Quality Directive - Annex IV recommendations with respect to the spatial representativeness area of sampling points.

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Recommendations on Spatial Representativeness estimation

New AQD, Annex IV: *When defining the spatial representativeness area the following associated characteristics shall be considered:*

(a) the geographical area may include non-contiguous domains but shall be limited in its extension by the borders of the air quality zone under consideration;
(b) if assessed via modelling, a fit-for-purpose modelling system shall be used and modelled concentrations shall be used at station location to prevent systematic model-measurement biases from distorting the assessment;
(c) other metrics than absolute concentrations can be considered (e.g. percentiles);
(d) the tolerance levels and possible cut-offs for the different pollutants may change depending on the station characteristics;
(e) the annual average of the observed pollutant concentration shall be used as the air quality metric for a specific year.

Section Geographical Area

(a) *the geographical area may include non-contiguous domains but shall be limited in its extension by the borders of the air quality zone under consideration;*

Tests on Italian Regions showed that

- the contiguous and non-contiguous approaches give different results for NO_2, while results are more similar for PM10. Therefore, the geographical area may include non-contiguous domains for NO_2, while for PM contiguous areas may be adopted.
- The Air Quality Zones as boundaries are essential if the non contiguous approach is adopted. In fact, it limits the overlap between areas of representativeness. As a general remark, the zone is to be considered hierarchically superior to the spatial representativeness because, by definition, it is a part of the territory of a Member State delimited for the purposes of air quality assessment and management.
  However, limiting the extension of the SR area by the borders of the air quality zone could lead to a fictitious limitation of the SR area if the station is located nearby the edge of the zone.

Section Modelling

(b) *if assessed via modelling, a fit-for-purpose modelling system shall be used and modelled concentrations shall be used at station location to prevent systematic model-measurement biases from distorting the assessment;*

DIFFERENCES IN THE SR AREAS WITH AND WITHOUT BIAS CORRECTION (DATA FUSION, DATA ASSIMILATION)

This point probably needs to clarify technical aspects of the fitness for purpose: e.g, traffic stations require high resolution models including atmospheric chemistry and high resolution inventories, model calculation of SR areas gives different results with and without bias correction, bias correction may include assumptions (inputs) on the representativeness area of the station that would probably influence resulting representativeness areas (outputs), bias correction should be applied (or not) consistently at the station location and in the surroundings.

Section Metrics

(c) *other metrics than absolute concentrations can be considered (e.g. percentiles);*

DIFFERENCES IN THE SR AREAS USING ANNUAL MEAN VS RELEVANT PERCENTILE(S)

Different areas may be obtained for annual mean and relevant percentiles for each pollutant. However, this seems not operationally manageable under the e-Reporting system and for an air quality plan. The smaller SR area may be considered.

Section tolerance levels and cut-offs

(d) *the tolerance levels and possible cut-offs for the different pollutants may change depending on the station characteristics;*

DIFFERENCES IN THE SR AREAS WITH DIFFERENT TOLERANCE LEVELS:

(10 OR 15 % FOR BACKGROUND STATIONS, 15 OR 20 % FOR HOTSPOT/TRAFFIC STATIONS)

DIFFERENCES IN THE SR AREAS WITH DIFFERENT LOWER CUT-OFFS

A. *1 OR 2 µG/M3 FOR PM2.5?*
B. *2 OR 4 µG/M3 FOR NO_2?*
C. *2, 4 OR 6 µG/M3 FOR OZONE?*
D. *INPUT ON RELEVANT CUT-OFFS FOR SO2, BENZENE, CO, B(A)P & METALS?*

It is shown that the tolerance level strongly impacts on SR area definition, namely on trafic stations. Most stations reach the maximum area at tolerance between 10-20%. For NO_2 lower tolerances permit to define the area, while for PM higher tolerances are required. For sake of simplicity, a single tolerance level for all stations for every pollutant is preferred.
Some tests identified the most suitable lower cutoff values as 2 µg/m^3 for both NO_2 and PM10, and the most suitable value as 10%, in order to obtain a SR area involving the proper air quality zone for each background station-point.
According to other tests, aimed at both reducing interannual variability and avoiding the SR region to expand to the whole IPR AQ zone, the 20% tolerance seems reasonable for PM10 and NO_2, since smaller values would lead to a much larger interannual variability, while larger values would lead to a SR often coincident with the IPR AQ zone. On the other hand, for ozone annual average a smaller threshold (about 10%) for the relative tolerance could work better, avoiding the SR region to expand to the whole IPR AQ zone.

Section SRA with Annual Average

(e) *the annual average of the observed pollutant concentration shall be used as the air quality metric for a specific year.*

ANNUAL VARIATION IN SR AREAS

The interannual variability of SRA remains an open issue, for practical use in the context of the AAQD a fixed SR area may be appropriate. SRA should be updated with the same frequency of the Evaluation Programme (required by 2008/50/CE) is updated (i.e. at least every 5 years).

Other issues

-SRA and monitoring networks;

Though the SR definition may show redundancies in the existing monitoring network for reporting purposes, it should be considered the importance of a dense network to calibrate, validate and verify model outputs.

-use of MoNET

Monet proved to be a valuable tool for the evaluation of monitoring networks, not in terms of redundancies in measurement, but to focus on similarities and verification of air quality zones coherence. Furthermore, the tool is useful for highlighting local hot-spots.

Examples of good practices

Appendix A- Examples of good practices by ARPAE

The present work has been done in the framework of FAIRMODE WG8 activity and represents a case study of the spatial representativeness definition applied to Emilia-Romagna (Fig. A1).
Arpae (Regional Environmental Agency of Emilia-Romagna) participated in the activity of "Fine-tuning and further testing spatial representativeness methods" first step in November 2021 (https://fairmode.jrc.ec.europa.eu/document/fairmode/event/presentation/CT8/1_CT8_SR-Recommendations.pdf). Arpae has also participated in the second phase exercise aimed at studying tolerance levels depending on measurement errors (https://fairmode.jrc.ec.europa.eu/document/fairmode/event/presentation/CT8/20220303_3_CT8_Amorati_FAIRMODE_CT8_1_March2022.pdf). The results have been carried out by using Bonafè, G. (2020) R-script (https://github.com/jobonaf/spatial-representativeness/tree/main).

DATA & METHOD

Applied criteria

- Annual averaged ground level concentrations
- A deviation from the modelled concentration at the monitoring stations is allowed within a threshold or tolerance level of 20%.
- Variable tolerance is examined
- An absolute minimum 2µg/m³
- A non-contiguous approach is used to outline the SR area and comparison with contiguous approach
- Boundaries of the IPR Air Quality Zones as the maximal extent of the SR area

Data

- CTM: NINFA suite @ Arpae (CHIMERE + COSMO) 3x3 km^2
- CTM and KED (Kriging CTM + Observations)
- PM10 PM2.5 NO2
- Background station locations
- Reference year 2020

Output

- For every station location:
- a SR map
- a plot of the SR area, calculated varying the tolerance from 10% to 20% by step of 1%

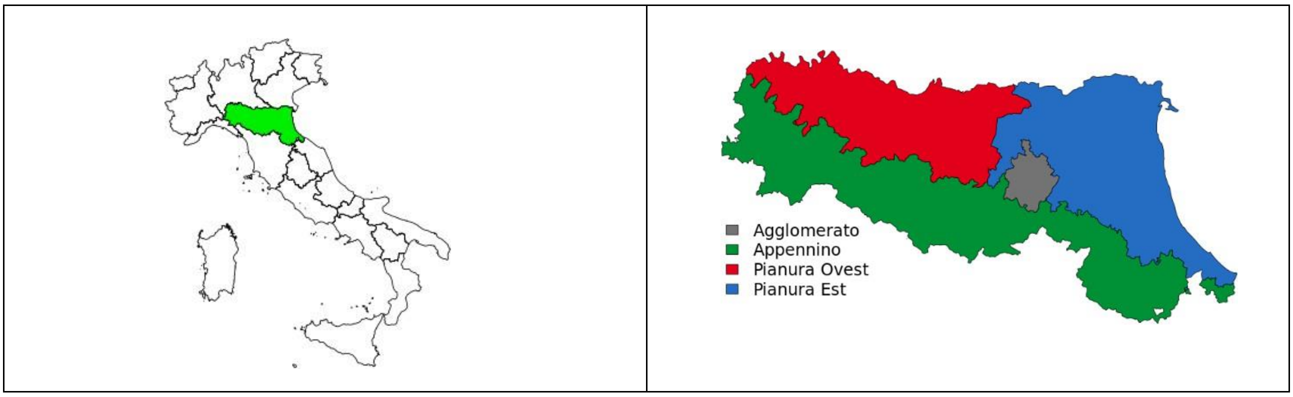


Fig. A1 – Emilia-Romagna Air Quality Zones.

RESULTS

In Fig. A2 PM10 Spatial Representativeness is obtained for each station location using CTM with 20% tolerance.

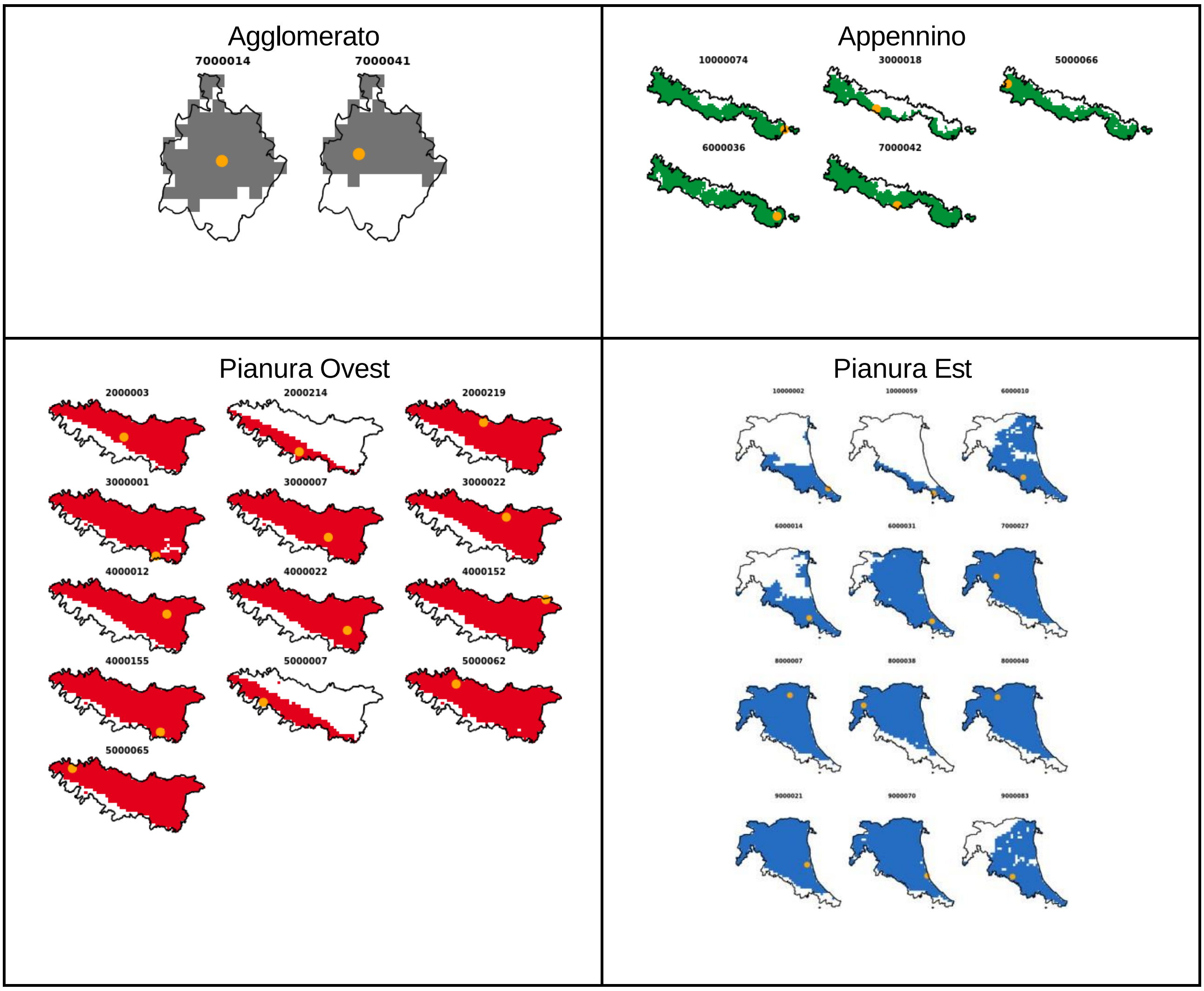
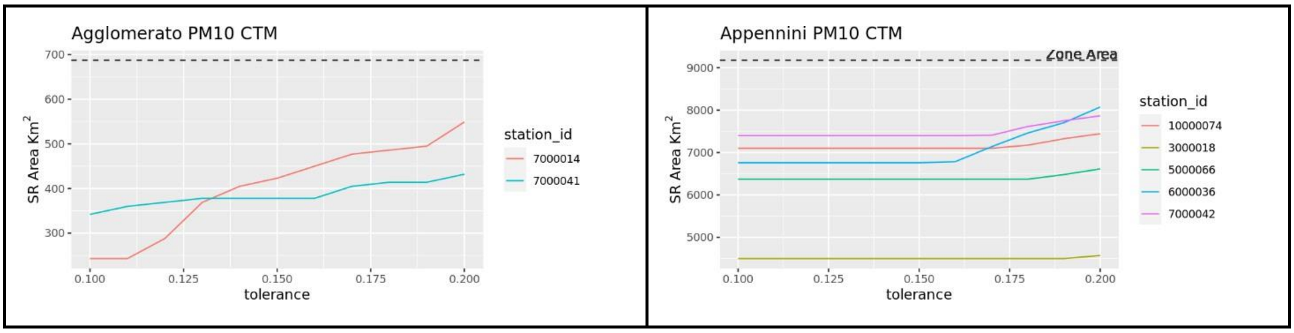


Fig. A2 – PM10 SR based on CTM and 20% tolerance.

In Fig. A3 the PM10 SR area is computed for each station by varying the tolerance from 10% to 20%.



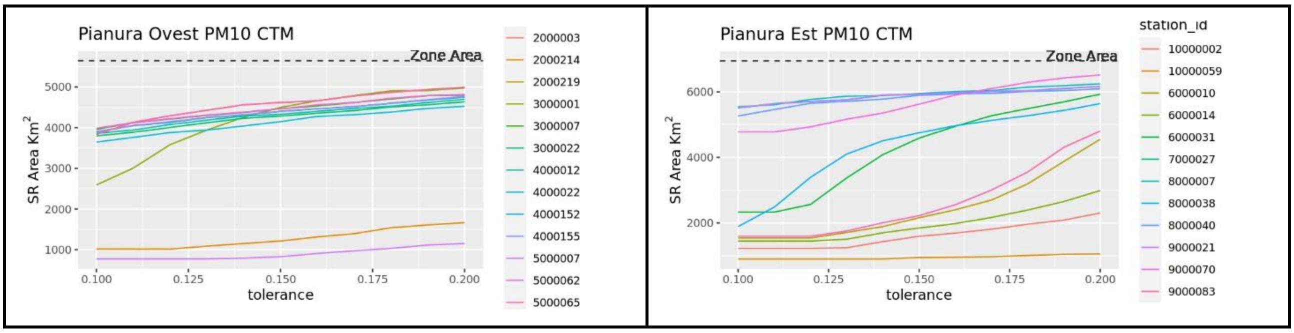


Fig. A3 – PM10 SR based on CTM varying the tolerance from 10% to 20%.

In Fig. A4 PM2.5 SR is obtained for each station location using CTM with 20% tolerance.

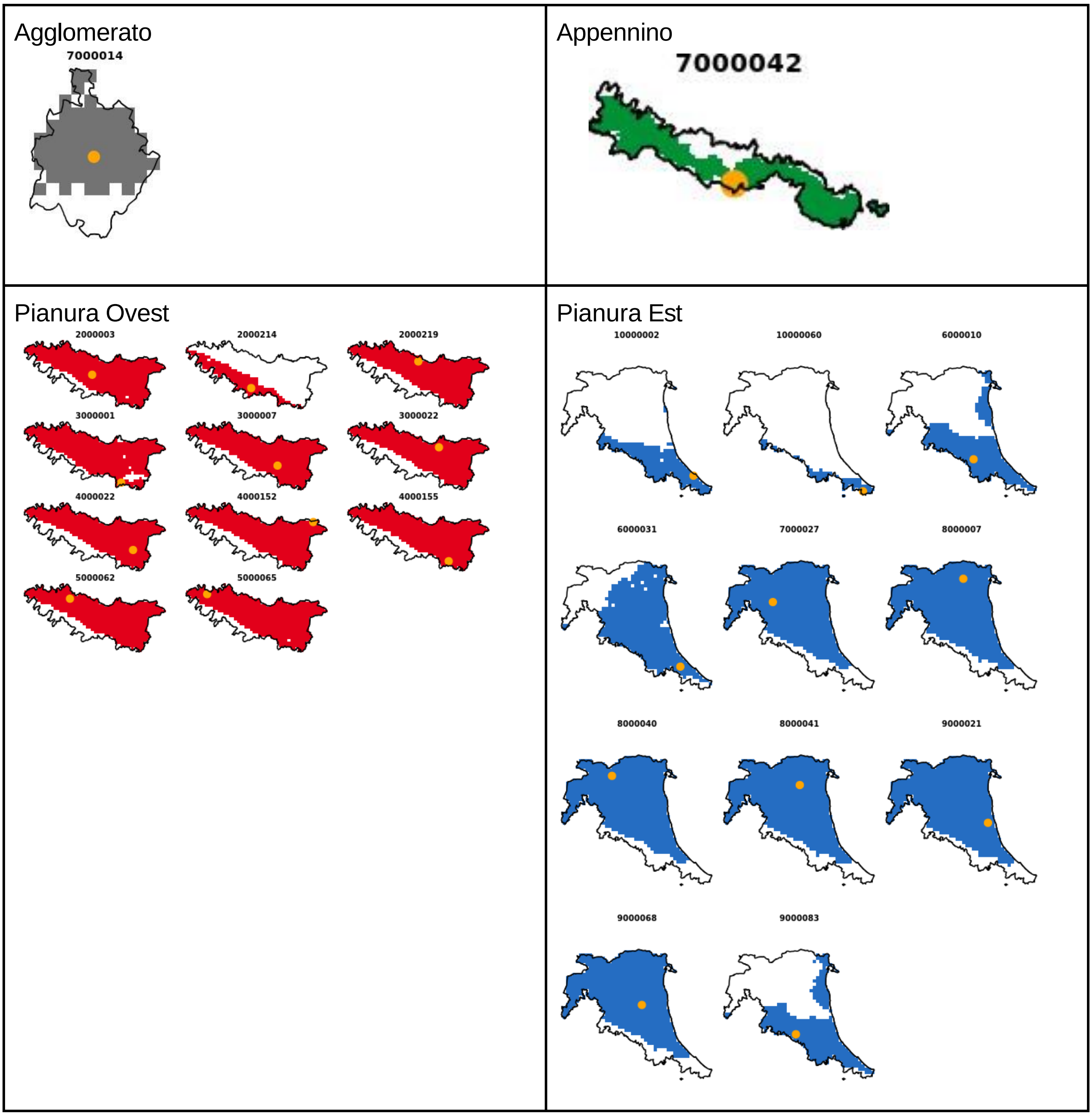


Fig. A4 – PM2.5 SR based on CTM and 20% tolerance.

In Fig. A5 the PM2.5 SR area is computed for each station by varying the tolerance from 10% to 20%.

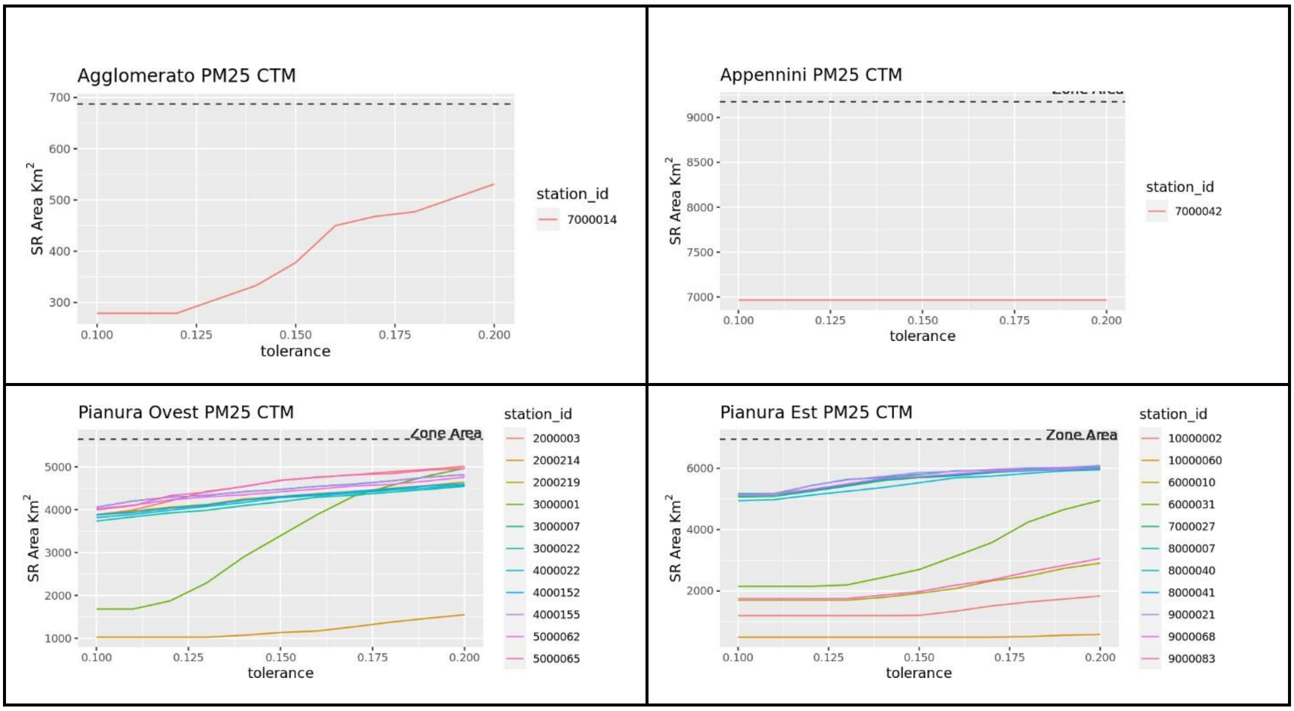


Fig. A5 – PM2.5 SR based on CTM varying the tolerance from 10% to 20%.

In Fig. A6 NO_2 SR is obtained for each station location using CTM with 20% tolerance.

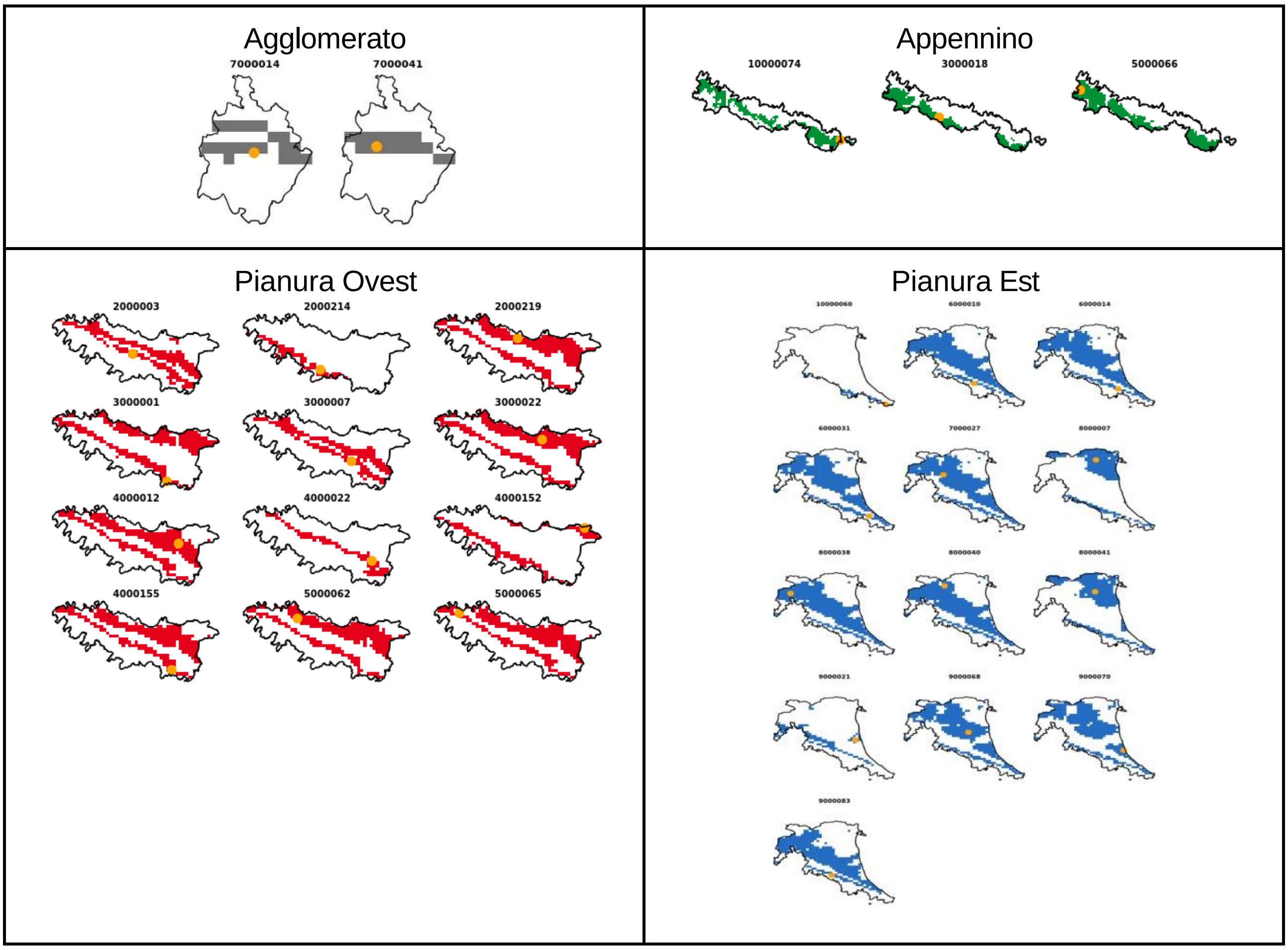


Fig. A6 – NO_2 SR based on CTM and 20% tolerance.

In Fig. A7 the NO_2 SR area is computed for each station by varying the tolerance from 10% to 20%.

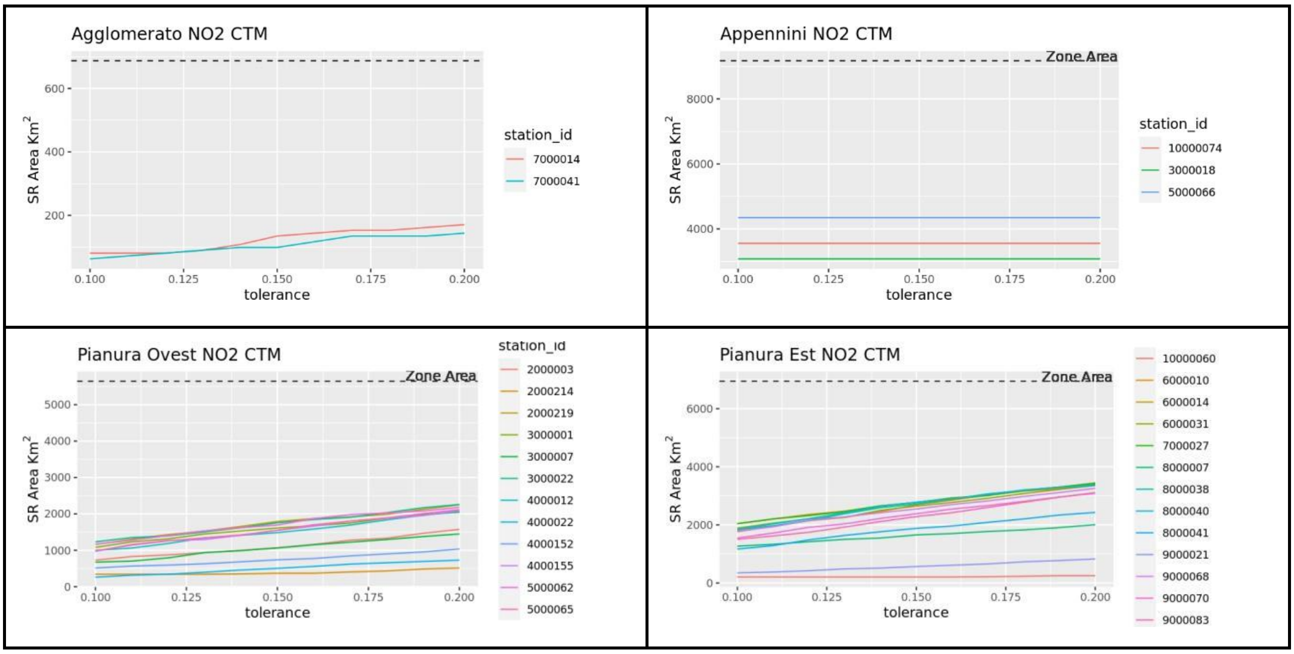
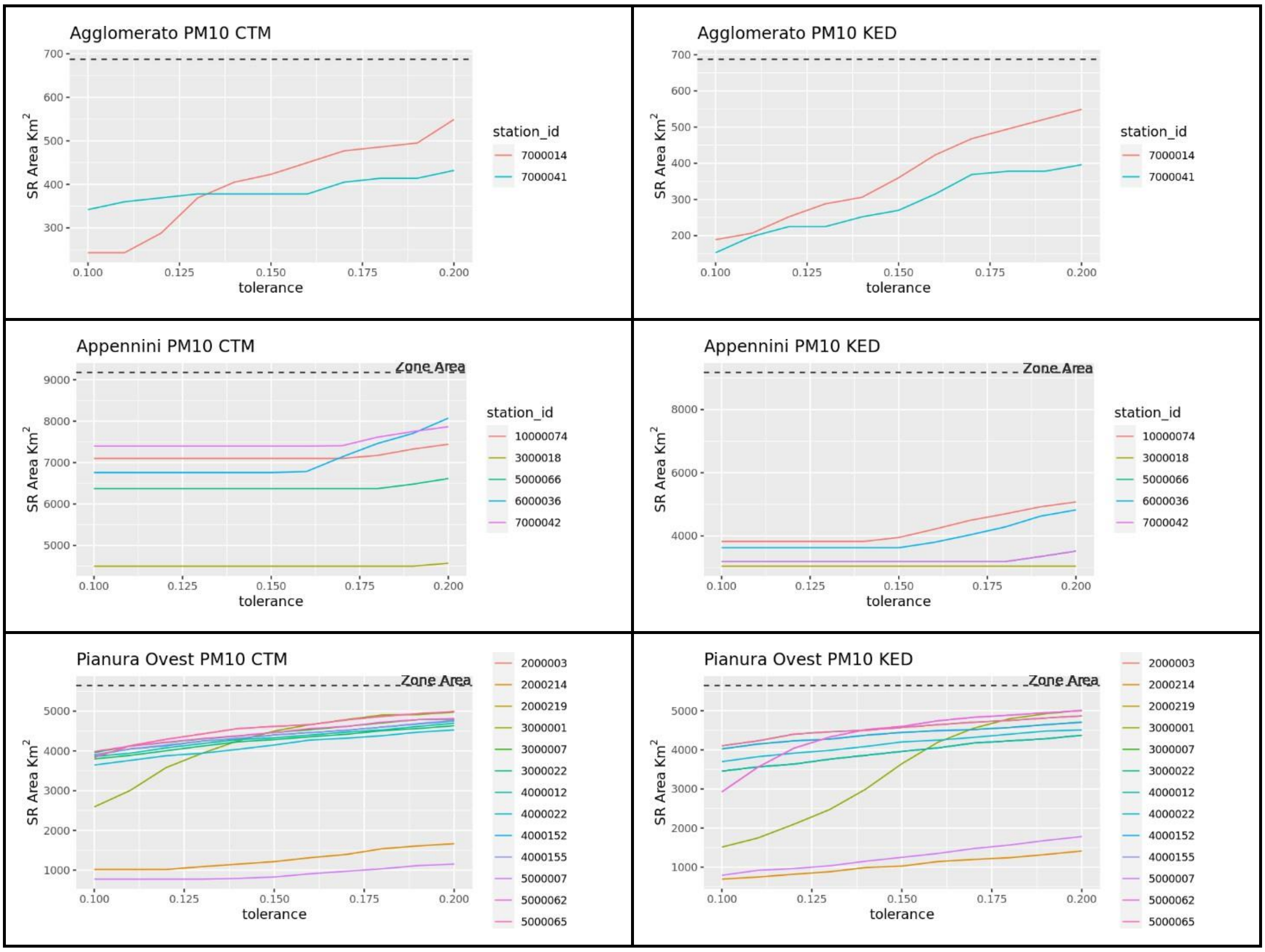


Fig. A7 – NO_2 SR based on CTM varying the tolerance from 10% to 20%.

In Fig. A8 a comparison is presented of PM10 SR area derived using CTM itself or data fusion Kriging with External Drift. CTM is the field to define the External Drift for observation interpolation.



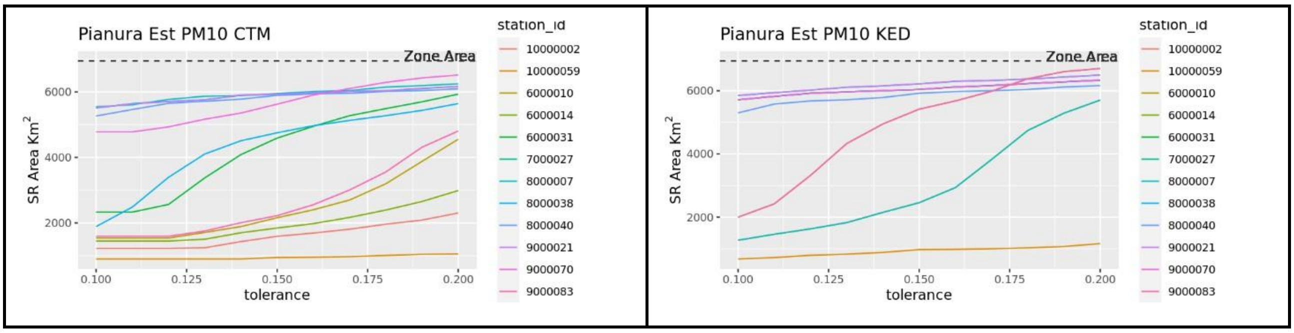


Fig. A8 – PM10 SR: CTM vs KED.

A comparison between SR areas obtained considering contiguity or non-contiguity criterium is conducted for PM10 and NO_2 (Fig. A9). The results for the eastern air quality zone are shown as example.

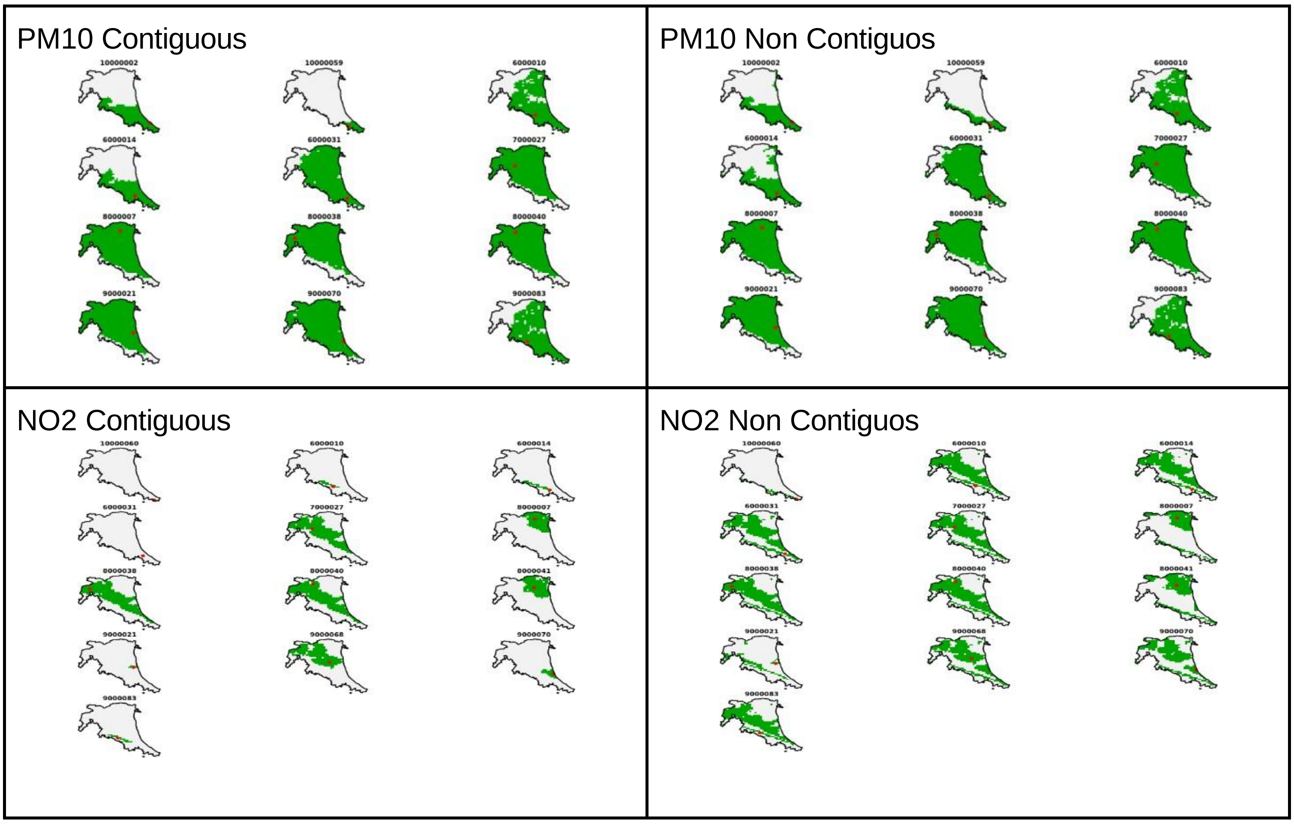


Fig. A9 – PM10 (top) and NO_2 (bottom) SR: contiguous vs non-contiguous criterium.

CONCLUSION

- Most stations have a wide SR area in flat areas for PM
- For NO_2 the SR areas are generally smaller
- For NO_2 the contiguous/non-contiguous approach has an impact
- The use of data fusion (kriging with external drift) has little impact. More investigation required

Appendix B- Examples of good practices by ARPA LOMBARDIA

Arpa Lombardia conducted a preliminary study, in early 2024, on PM10 and NO_2 background and traffic stations of the regional monitoring network (Fig. B1).

This preliminary study does not include a sensitivity analysis of the relative and absolute criteria. Further tests will be conducted to investigate better the sensitivity with other cut off/range values.

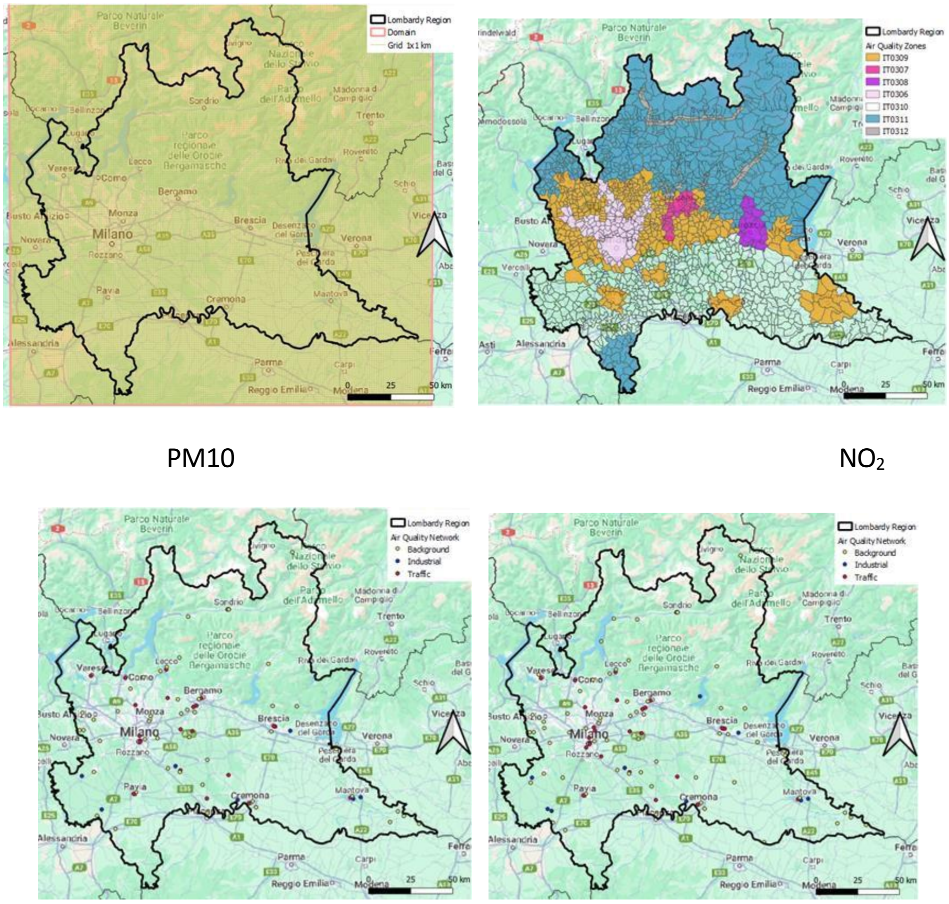


Fig. B1 – Lombardia Region (top left), Air Quality Zones (top right), and Air Quality Monitoring Network for PM10 (bottom left) and NO_2 (bottom right).

DATA AND METHOD

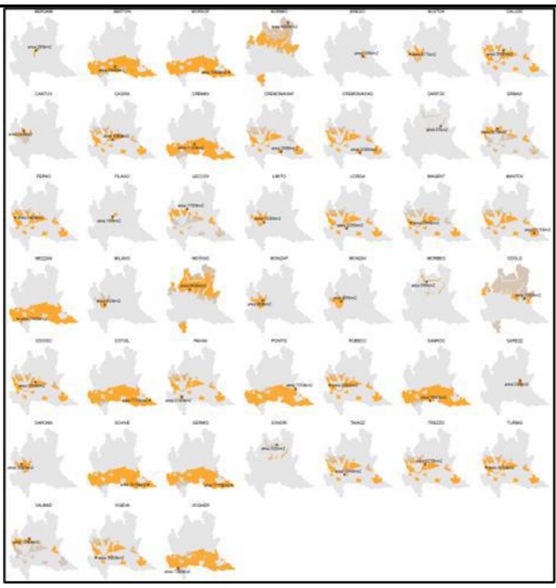
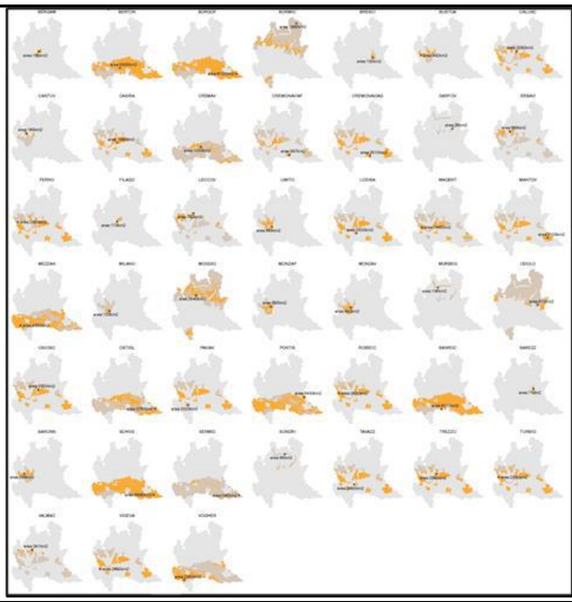
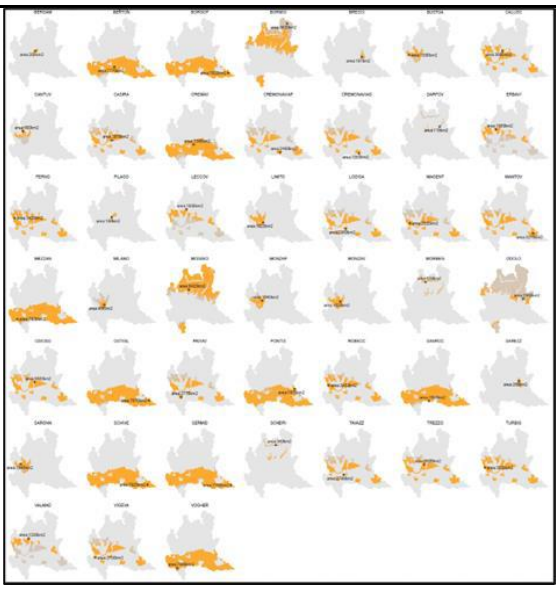
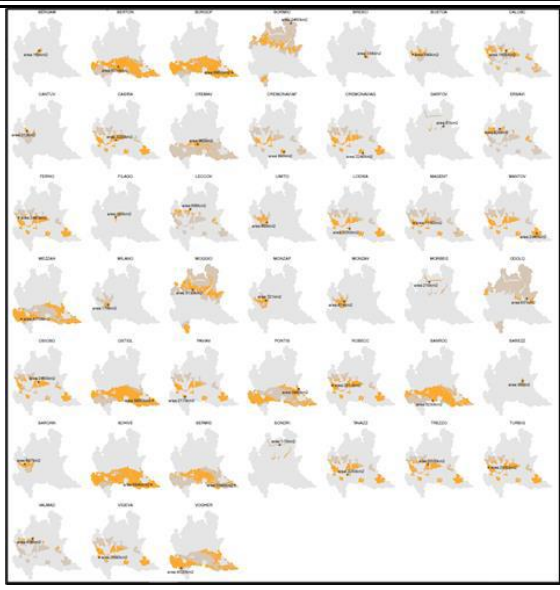
The results have been carried out by using Bonafè, G. (2020) R-script (https://github.com/jobonaf/spatial-representativeness/tree/main).

- Zones: Air Quality Zones non-contiguous and SR limited to AQ zone
- Pollutants: PM10 and NO2 considered separately
- Model data used: 2020-2021-2022 (https://www.arpalombardia.it/documenti-e-report?tema=Aria&sottotema=Modellistica)
- Metrics: absolute annual mean and percentiles (90.4° PM10 and 99.8° NO2) concentrations
- Type of models: Eulerian model with a resolution of 1 Km domain centred on Lombardy Region
- Bias treatment:
  1) adjustment: ARPMEAS data fusion (Corrective Successive Method) with air quality measurements (yearly assessment)
  2) Without adjustment: WRF-FARM (chemistry-transport model)
- Similarity criterion based on simple definition with symmetric cut-off:
  1) Relative: concentration in range cstation ± 20%
  2) Absolute: concentration in range cstation ± 2µg/m3

3) Uncertainty-dependent threshold: concentration in range cstation ± U95 (cstation) as described in the Guidance (Janssen et al., 2022) and implemented in R package dartle (Bonafè, 2020)

RESULTS

In Fig. B2 and B3 PM10 SR are presented based on FARM (with bias) and ARPMEAS (with data fusion) data, respectively. Only background stations (without distinction of rural, suburban, urban) are taken into account.

	Yearly average	90.4° Percentile
2020		
2021		

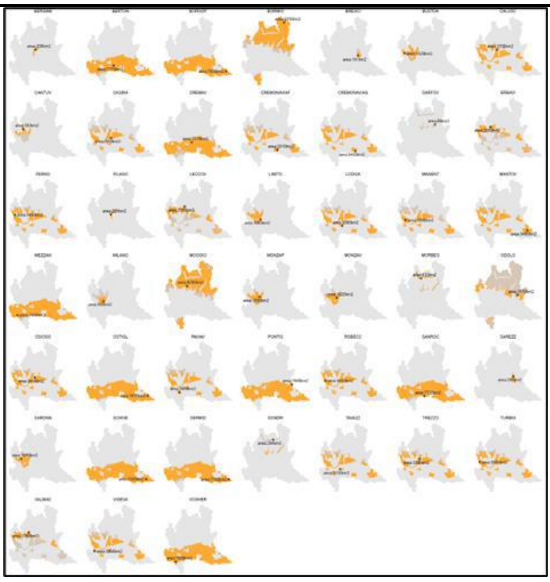
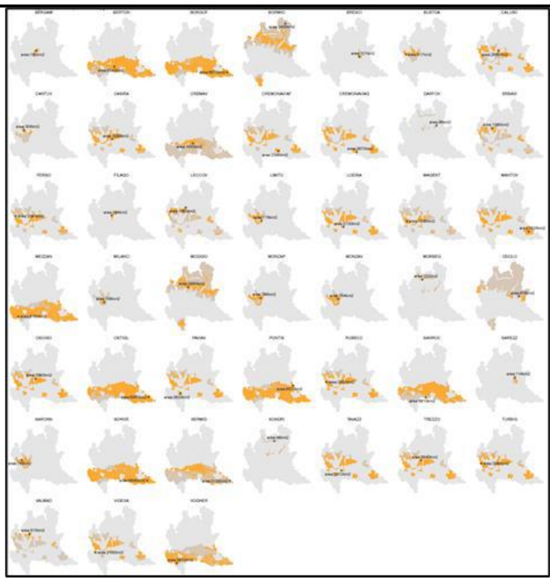
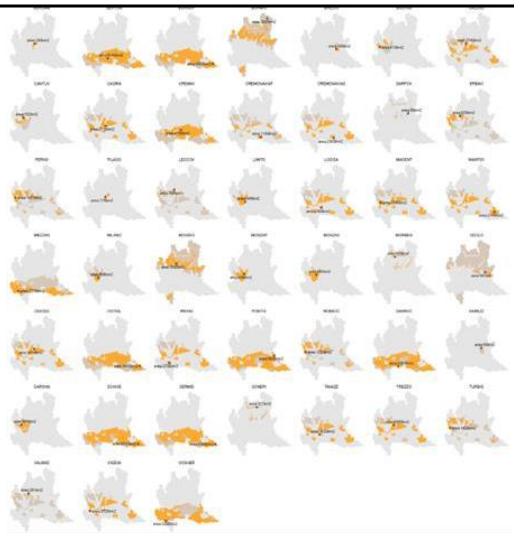
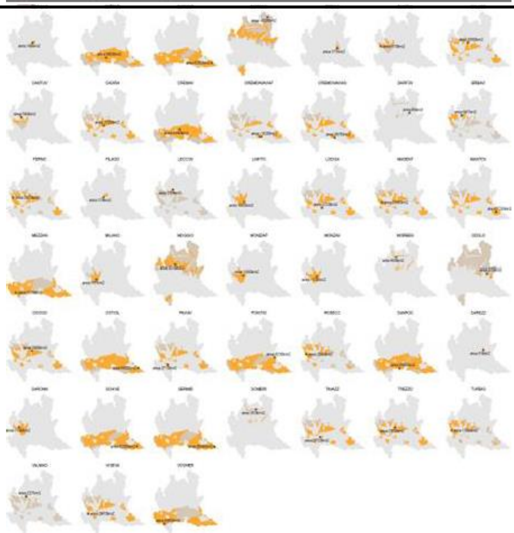
2022		

Fig. B2 – PM10 SR based on FARM.

	Yearly average
2020	
2021	

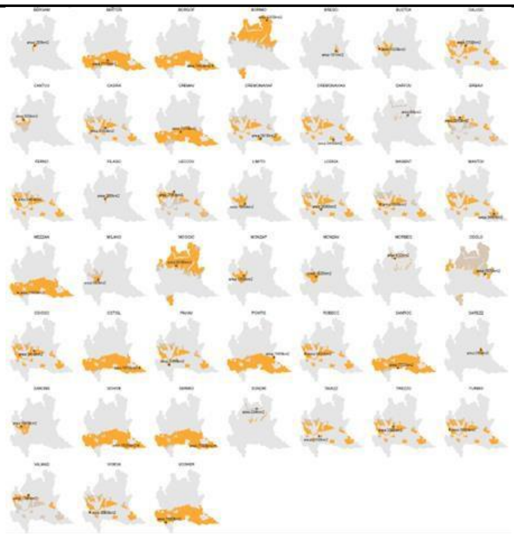
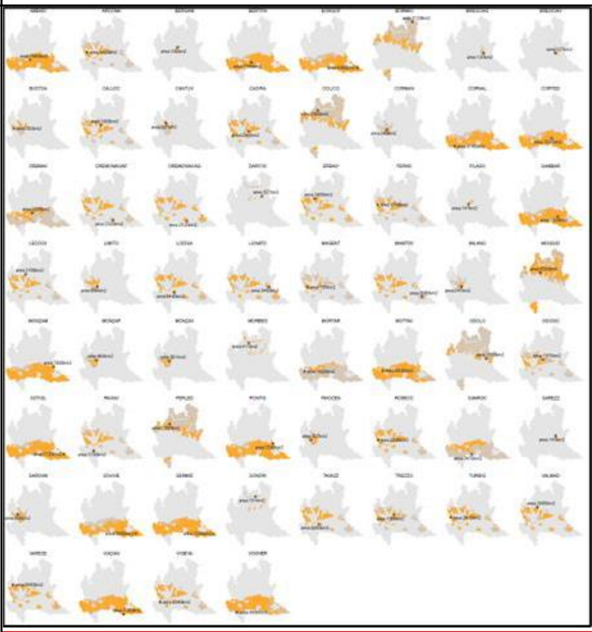
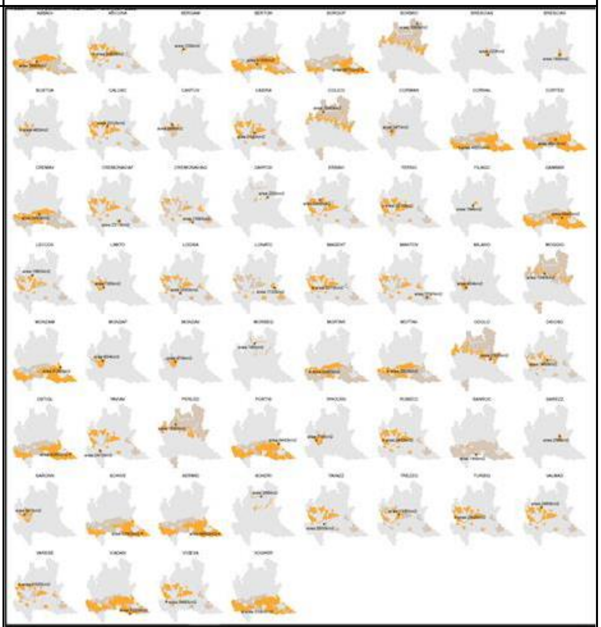
2022	

Fig. B3 – PM10 SR based on ARPMEAS.

The results, focusing on PM10 and exclusively on background stations, reveal that in general:

- The representativeness area is smaller for percentiles compared to the average.
- The representativeness area is smaller for ARPMEAS (without bias) in comparison to FARM (potentially caused, for example, by the interpolation radius or the radius of influence of the stations).

In Fig. B4 and B5 NO_2 SR are presented based on FARM (with bias) and ARPMEAS (with data fusion) data, respectively.

	Yearly average	99.8° Percentile
2020		

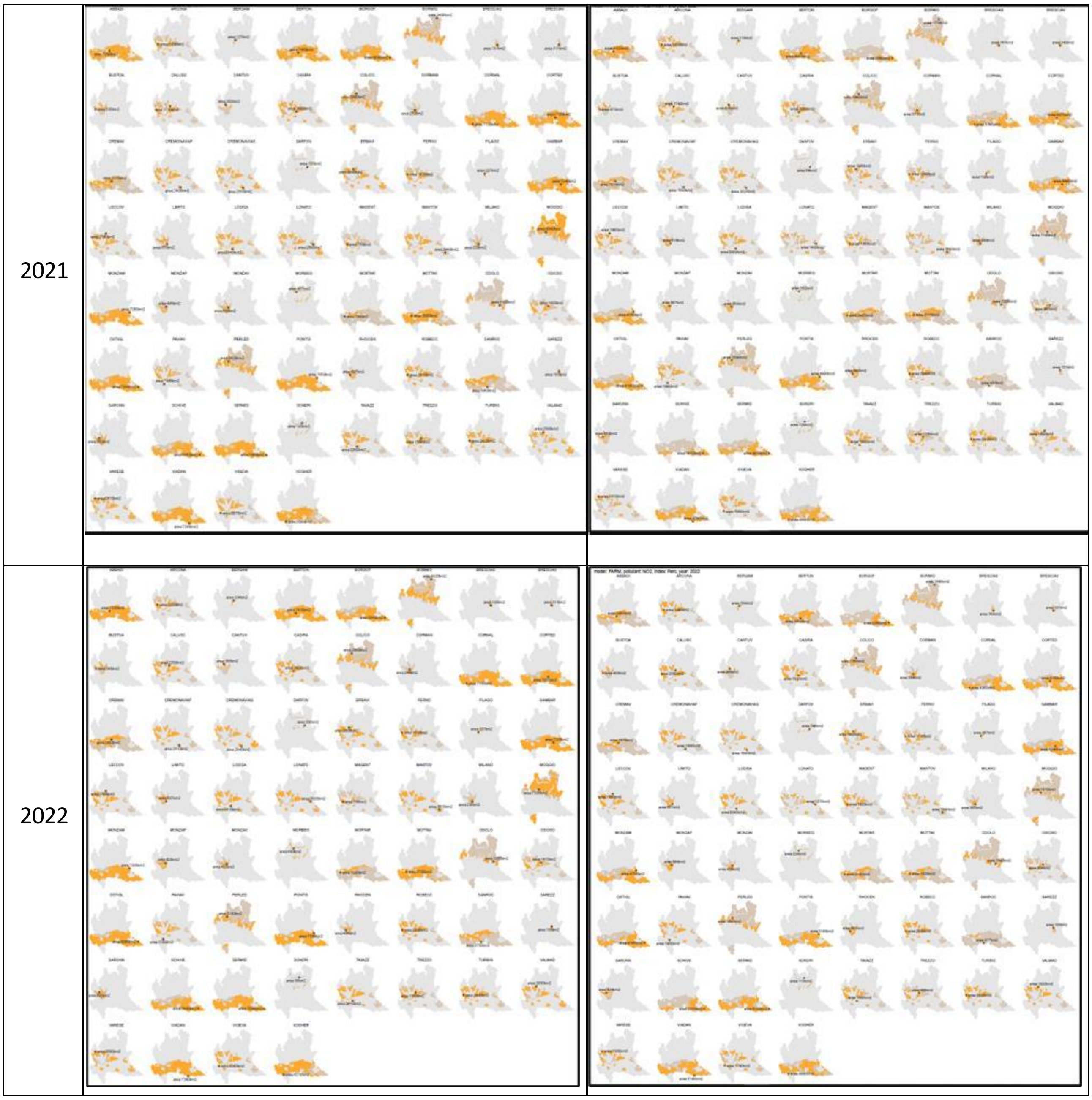


Fig. B4 – NO_2 SR based on FARM.

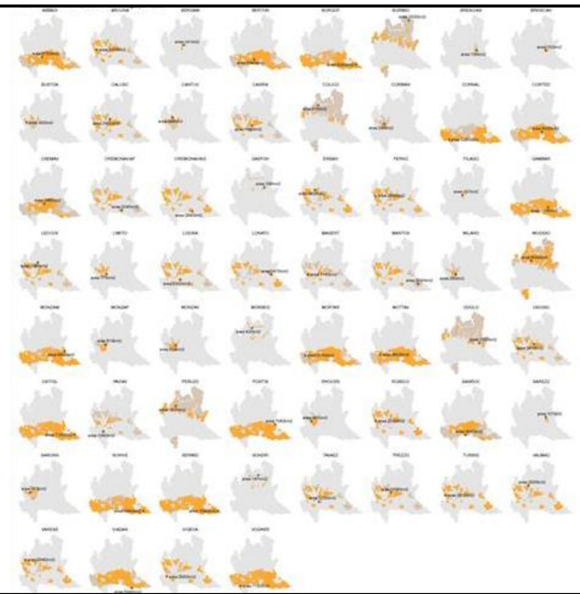
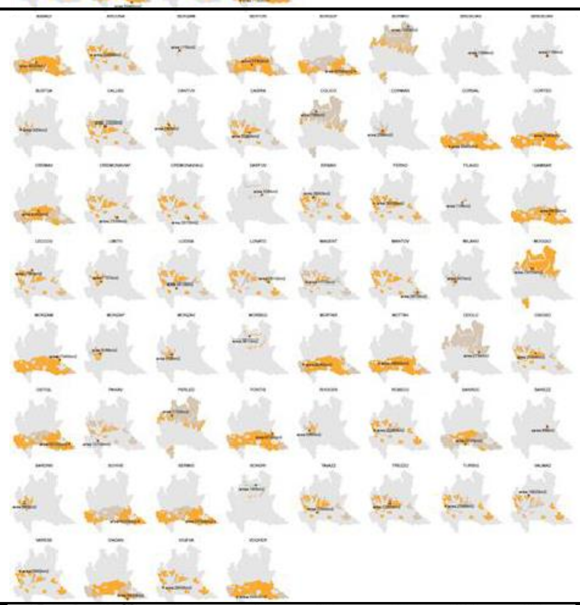
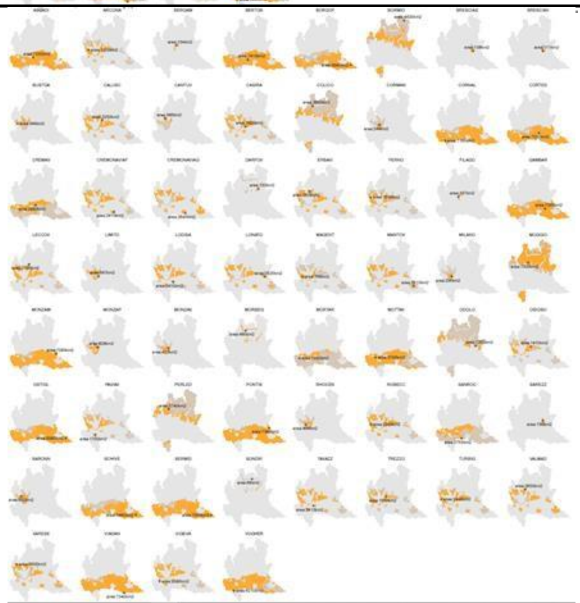
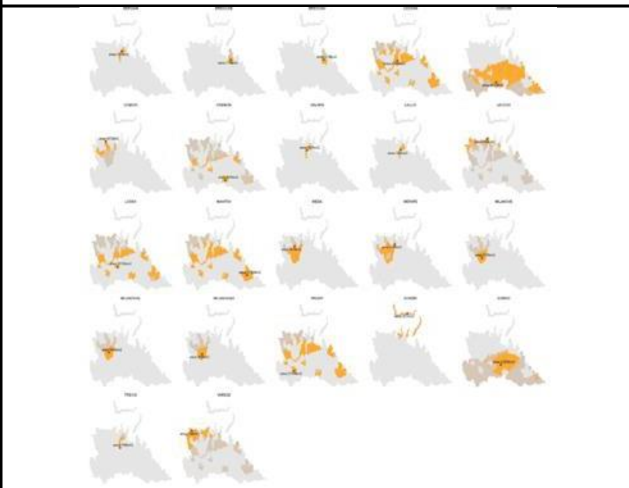
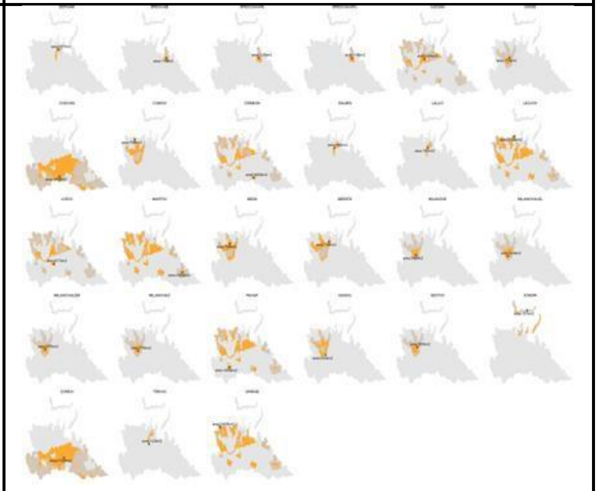
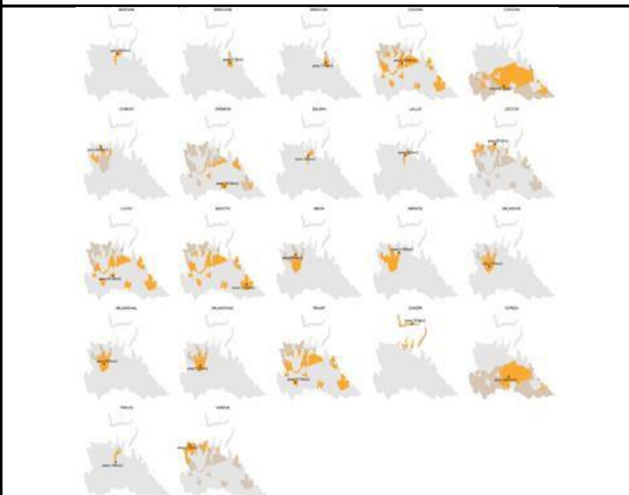
	Yearly average
2020	
2021	
2022	

Fig. B5 – NO_2 SR based on ARPMEAS.

The results, focusing on NO_2 and exclusively on background stations, indicate the following general observations:

- The representativeness area is more fragmented and smaller compared to PM10.
- The representativeness area is less influenced by interannual variability for FARM in comparison to ARPMEAS.

In Fig. B6 PM10 and NO_2 SR are presented for traffic stations (without distinction of rural, suburban, urban) based on ARPMEAS data.

	Yearly average PM10	Yearly average NO2
2020		
2021		

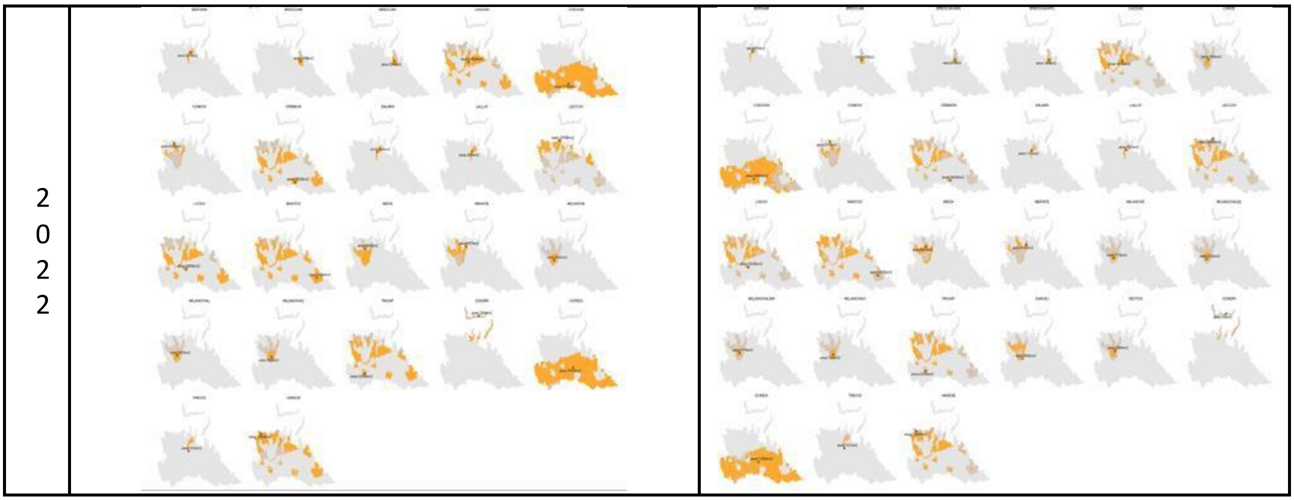


Fig. B6 – PM10 and NO_2 SR based on ARPMEAS.

The results, focusing on traffic stations, indicate the following general observations:

- The representativeness area for NO_2 is more fragmented and smaller compared to PM10.
- The representativeness area is in general less extended compared to background stations.
- The spatial representativeness coverage is in general different with traffic stations from background (less redundant).

NETWORK COVERAGE AND REDUNDANCE

According to FARM, concerning PM10, the network appears to be redundant in the plain and clustered in the mountains. However, focusing on NO_2, the network seems to be redundant in the plain but not in the northernmost part of the Region. In general, NO_2 exhibits a less redundant network compared to PM10.

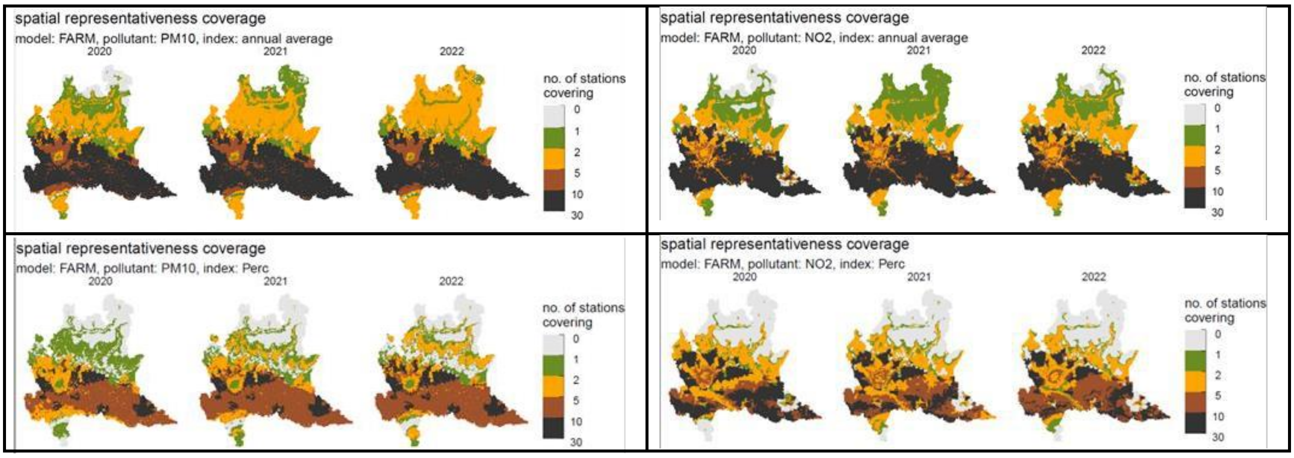


Fig. B7 –Maps of the spatial coverage for PM10 (left) and NO_2 (right) monitoring network, based on annual average (top) and percentiles (bottom).

CONCLUSION

It is essential to note that the model employed has a resolution of 1 km x 1km, heavily impacting the results. The model cannot assess changes in the spatial distribution of air pollutants at a smaller and more detailed level. Additionally, the assessment of the representativeness of the traffic stations depends on the choices made during the design of the air quality network. If stations are strategically placed to monitor specific hotspots, a model with a of 1 km x 1 km resolution may not accurately reflect the true representativeness of the station. As mentioned earlier, the analysis of the representativeness of traffic stations, although smaller than that of background stations, appears inadequate in capturing the real variability of pollutants concentrations, especially for primary pollutants (or NO2).

On the other hand, network design typically aims to focus on general population exposure, even in hot spot situations. Therefore, employing the guideline approach with models featuring a resolution of 1 km x 1km may be appropriate even though it might not capture the finest variabilities.

Appendix C- Examples of good practices by LaMMA-ARPAT

LaMMA-ARPAT participated in several WG8 Exercises on Spatial Representativeness.

In the following a short summary is provided of LaMMA-ARPAT contribution during FAIRMODE WG8 workshop on spatial representativeness, which took place on 14/12/2023.

WG8 methodology was applied to Tuscany Region (Fig. C1), focusing mainly on urban and rural background stations and using results from WRF-CAMx modelling system with 2 km resolution and no bias adjustment.

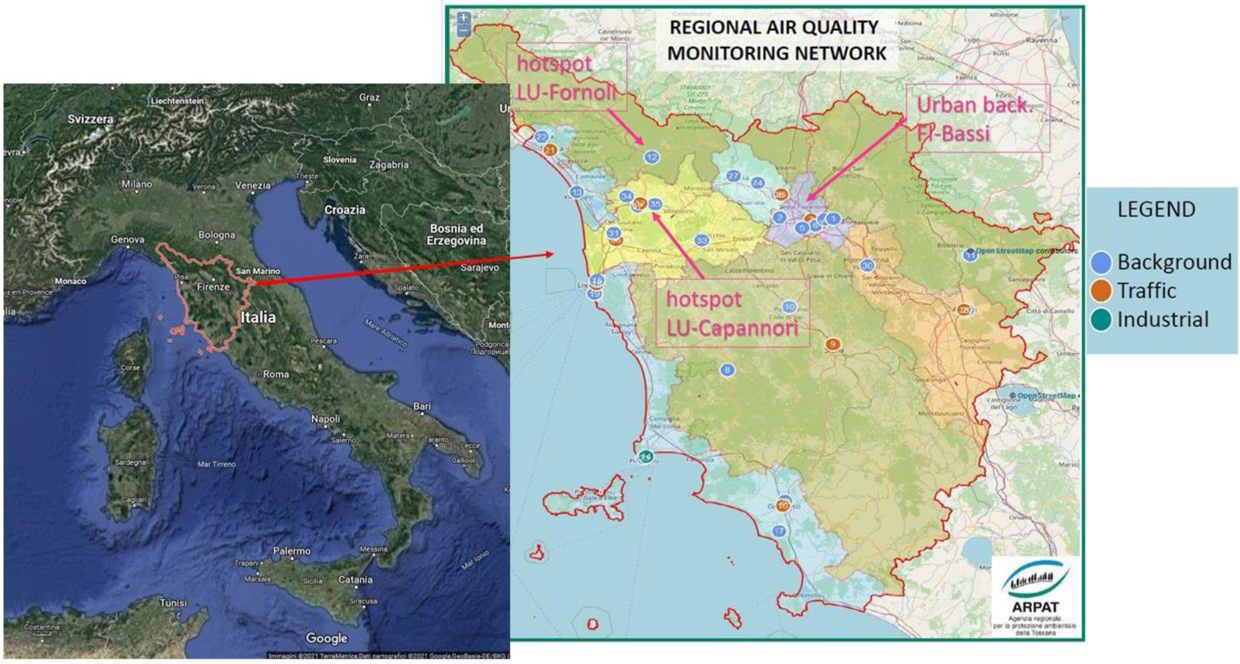


Fig. C1 – Tuscany Region and Regional Air Quality Monitoring Network.

DATA & METHOD

• Pollutants: PM10 and NO_2
• Model: WRF CAMx (eulerian model) annual mean concentrations at 2km resolution and no bias adjustment (see https://www.lamma.toscana.it/camx-info-sul-modello-previsionale for details).
• Model data used: modelled concentrations at station location for 2015 and 2017 (as in previous works) but also for additional available years: 2019, 2020, 2022.
• Metrics: Annual Mean, 90.4^{th} percentile
• Considered location points: background stations (urban and rural types and two hotspots)
• Different lower cutoff values evaluated: 2 or 4 $\mu g/m^3$ for PM10 and NO_2

• Different tolerance levels values evaluated: 10%, 15 %, 20% for background stations
• Comparison with SR evaluations by means of the current SR methodology used in the Tuscany Region based on daily mean values (https://www.regione.toscana.it/-/elenco-pubblicazioni-inerenti-la-rappresentativita-spaziale-delle-stazioni-di-rilevamento-della-qualita-dell-aria-in-toscana; Vitali et al. 2013; Piersanti et al., 2015)

RESULTS

The analysis for PM10 shows similar SR areas pattern using different tolerance levels and cutoff values (Fig. C2). Concerning SR areas variations with annual average (Fig. C3), the changes that can be seen in different years seem to be due to differences in the emission inventory rather than meteorology. Indeed, the same emission inventory is used for 2015 and 2017 and a different one for 2019 and 2020.

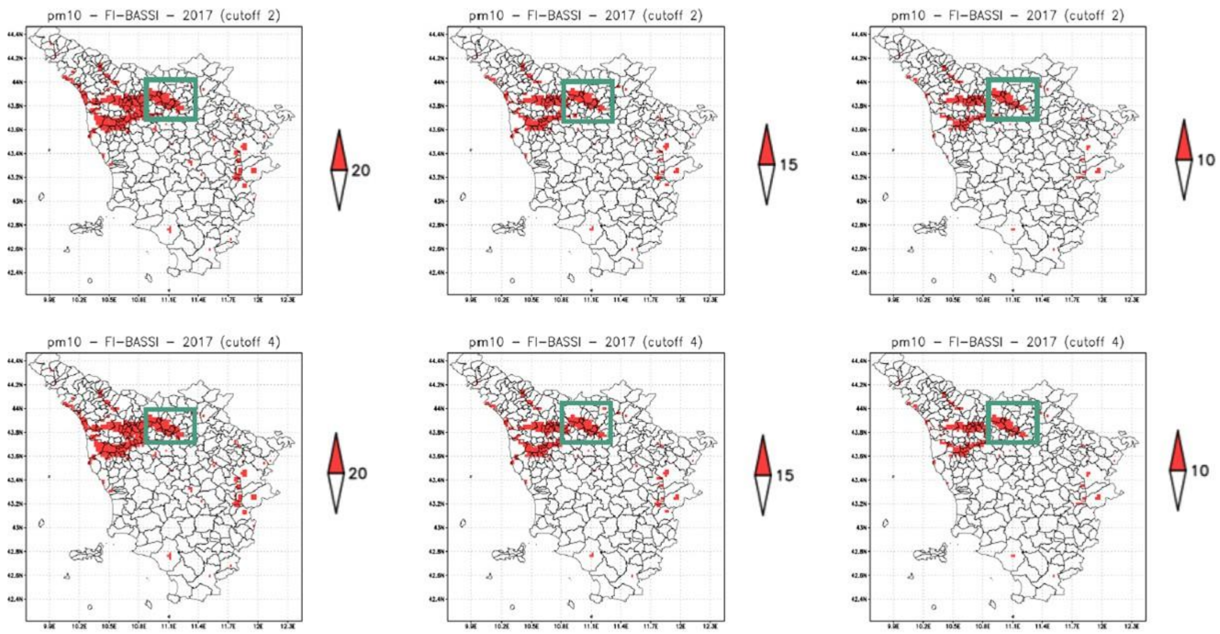


Fig. C2 – PM10 Spatial Representativeness (red pixels) of FI-BASSI monitoring station using different threshold (20%, 15% and 10%, from left to right) and cutoff (up: 2 µg/m^3; bottom: 4 µg/m^3) values.

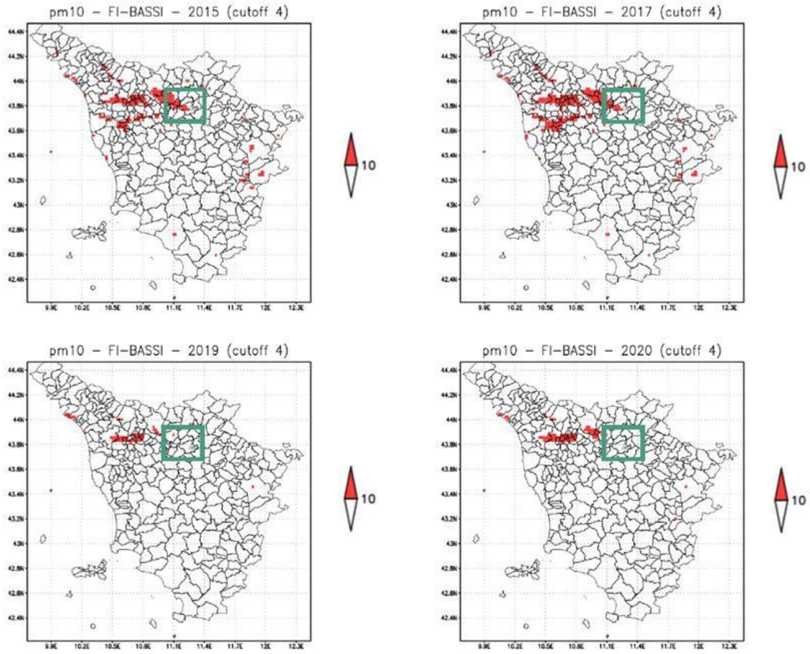


Fig. C3 – PM10 Spatial Representativeness (red pixels) of FI-BASSI monitoring station referring to different meteorological years.

Concerning NO_2, using different cutoff values (2 μg/m^3 or 4 μg/m^3) result in differences in spatial coverage, especially in the south inner part of the region and the upper part of the Apennines, characterized by lower concentration estimates.

Finally, the analysis conducted in Tuscany region identify the most suitable lower cutoff values as 2 μg/m^3 for both NO_2 and PM10. For the tolerance level the most suitable value turned out to be 10%, in order to obtain for each background station a SR area involving the proper air quality zone. For the traffic stations any significant differences are shown by using different tolerance values.

The proposed FAIRMODE SR methodology was applied both using the absolute concentration and the 90.4th percentile for the PM10 and NO_2. This percentile corresponds to the 35th higher value, and for PM10 it can be compared with the tolerance daily level: if the 90.4th percentile is greater than 50 μg/m^3 we are in the case of exceedance. In Fig. C4 results outcomes are shown for PM10 SR at FI-BASSI.

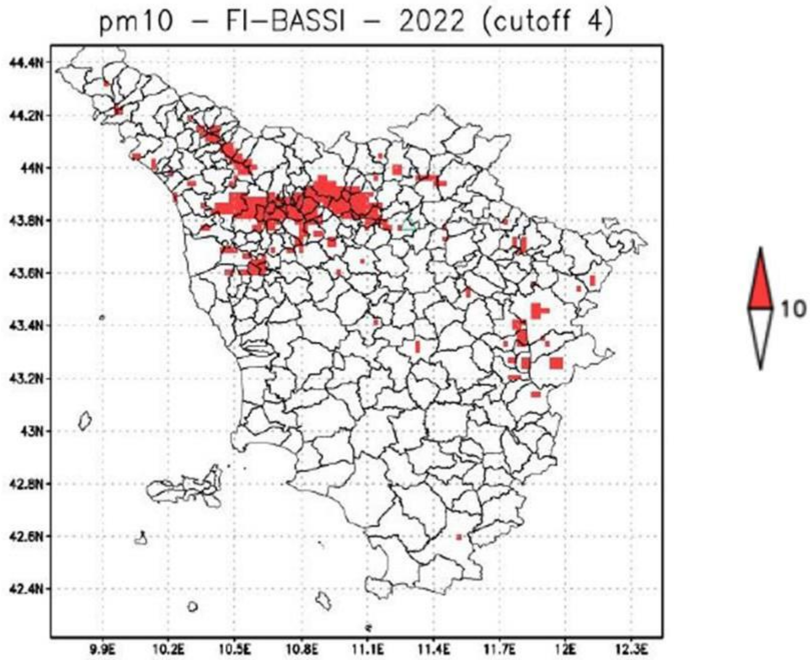


Fig. C4 – PM10 Spatial Representativeness (red pixels) of FI-BASSI monitoring station based on 90.4th percentile.

Using the percentile instead of the annual mean gives a SR more similar to the current SR evaluation adopted in Tuscany Region, based on hourly data. Furthermore, the preliminary analysis indicates that the use of percentiles gave less overlapping areas with different exceedance statuses (Fig. C5).

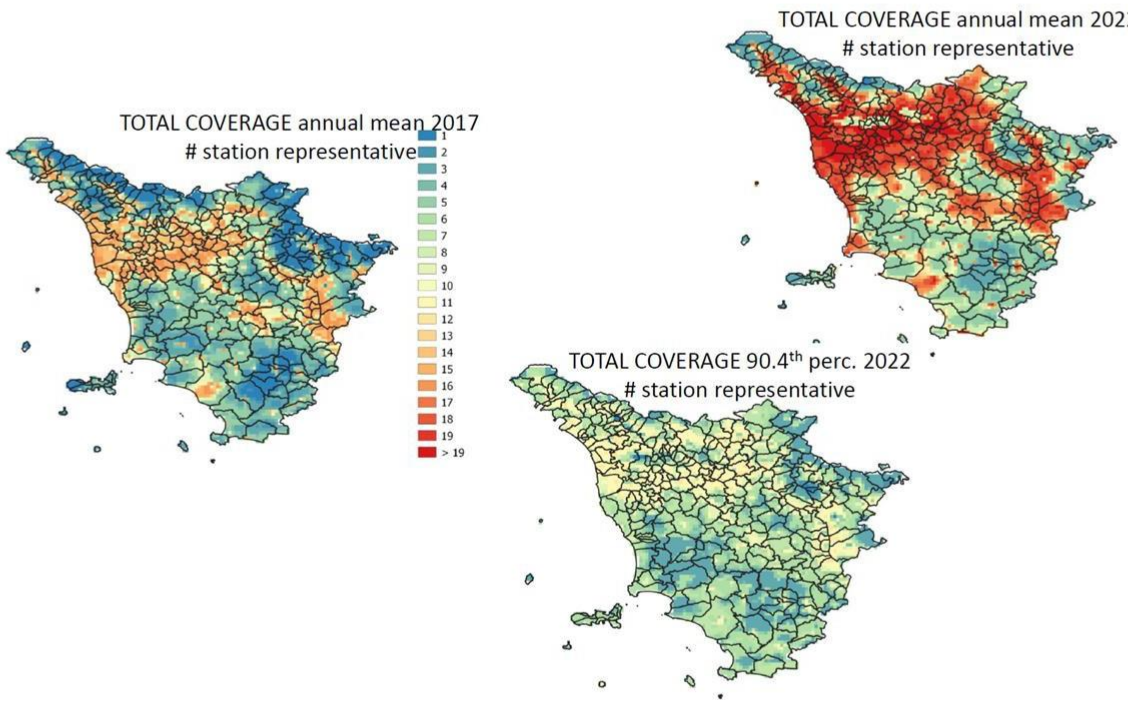


Fig. C5 – PM10 Total Monitoring Network coverage for different years (2017 on the left and 2022 on the right) and for different metrics used in SR evaluation (annual mean on the right top, 90.4th percentile on the right bottom).

Other percentiles or percentiles combinations (IQ distance?) could be feasible, but they were not tested yet.

If annual means are used, the resulting SR gives indications on this metric; but for some pollutant there are other indicators, of mid or short-term exposure, that must be considered. In Tuscany region there is a complex orography and for PM10, also if the situation on the basis of the annual mean is quite homogeneous, the behavior on a daily basis can be quite different. See, as example, the graphs in Figure C6 showing annual means and number of exceedances of PM10 in 2023.
Using a tolerance level of 10% on an annual mean of 20 µg/m3 (station 12), it means that 18 or 22 would be the same. So, the station 12 (1 exceedance) would be the same as station 4 (17 exceedance); indeed, the number of exceedances can be seen as an example of the different behaviour on a daily basis.

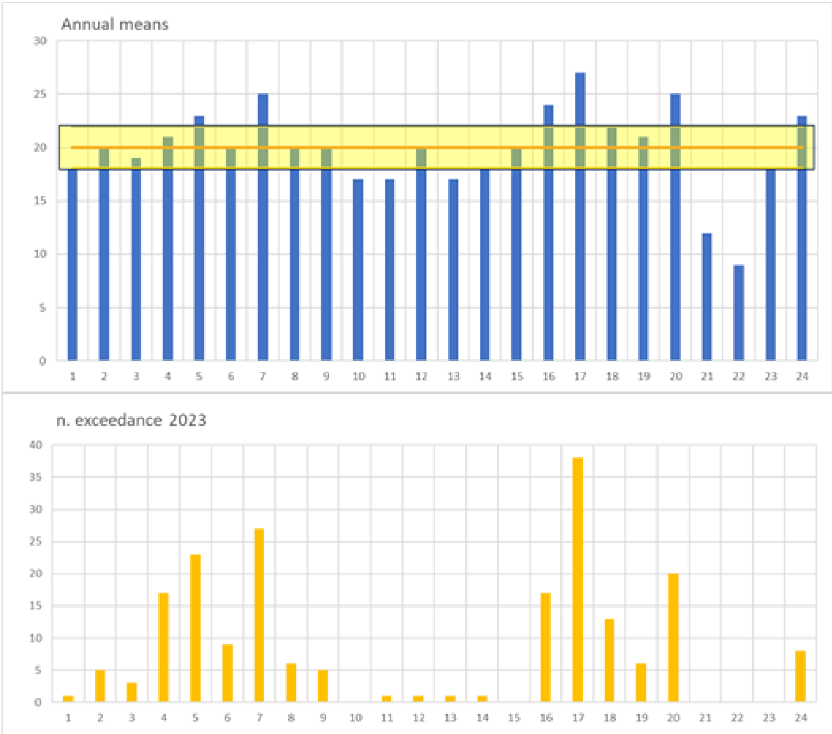


Fig. C6 – Annual mean concentration values and number of exceedances of PM10 in 2023.

So, an important issue identified by the analysis is how to handle cases where stations with overlapping SR areas have different exceedance statuses (i.e. one station exceeds the limit value, while the other station does not). For example, according to the new directive (COM/2022/542) setting the limit value for PM10 annual mean concentration at 20 µg/m^3, FI-FIGLINE monitoring station in 2022 exceeds the limit value (annual mean: 22 µg/m^3), while AR-ACROPOLI station does not (annual mean: 20 µg/m^3); anyway according to WG8 SR definition their SR areas overlap. FI-BOBOLI and FI-BASSI SR areas overlap too, but their annual mean values, respectively 19 µg/m^3 and 21 µg/m^3, indicate different exceedance statuses. It is worth noting that, in the latter case, using 90.4th percentile for SR assessment SR areas do not overlap.

An analysis of two hotspot stations for PM10 (Fig. C7) confirmed that these stations have a very local representativeness, regardless both the cutoff and threshold values.

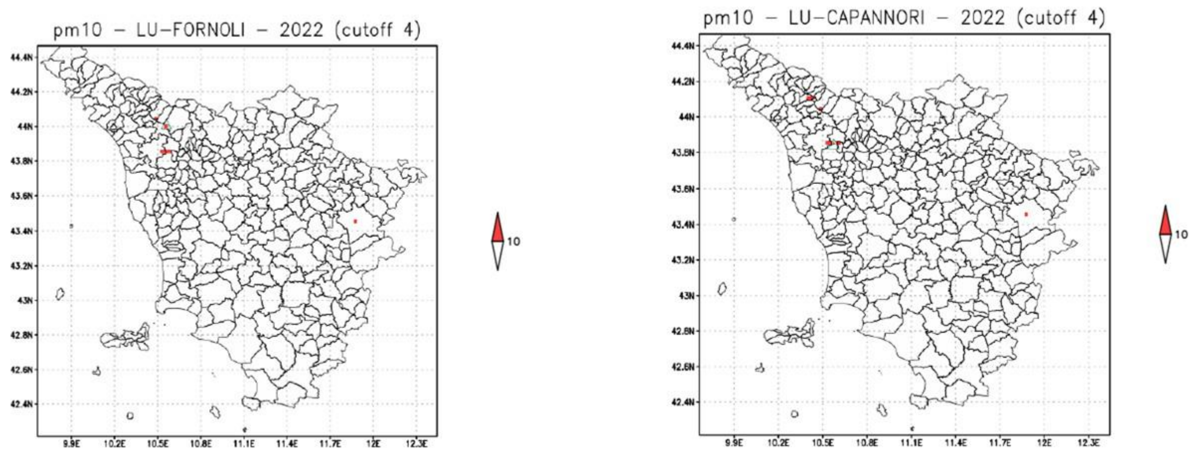


Fig. C7 – *PM10 Spatial Representativeness (red pixels) of LU-FORNOLI (left) and LU-CAPANNORI (right) monitoring stations.*

Appendix D- Examples of good practices by ARPA FVG

The regional environmental protection agency of Friuli Venezia Giulia produced some R scripts for the analysis of the SR according to the criteria proposed by the WG8. They are available on a public repository https://github.com/jobonaf/spatial-representativeness

ARPA-FVG analysed the SR based on PM10, ozone and NO_2 annual averages, with a similarity criterion based on a 20% relative tolerance and a 2 µg/m^3 absolute tolerance (cutoff). The FARM chemistry-transport model has been considered, using both its output “as-is” without bias correction (hereinafter “FARM”) and the output corrected with background observations (kriging with external drift, “KED”). Both datasets cover a 160x160 km^2 domain in north-eastern Italy with a 2km horizontal resolution. The analysis was performed on the 2015-2020 period for KED, 2017-2020 for FARM.

For each year, model, air quality index and station the area of the SR region and the population living in it have been calculated. Results for year 2020 are shown in Figs. D1 to D3. Some stations show a large interannual variability of the SR area for PM10, smaller for NO_2. The range and the ranking of the stations’ SR do not vary significantly between the two models (FARM vs KED).

The 20% relative tolerance method has been compared to an alternative method, based on an uncertainty-dependent threshold (UDT), where the relative tolerance is equal to U_{95}, as defined in the “Guidance document on modelling quality objectives and benchmarking” (Janssen et al., 2022). The UDT method leads to larger SR areas for PM10 and NO_2, smaller for ozone.

An analysis has been carried out on SR, in order to evaluate its sensitivity to changing values of relative tolerance and to the contiguity criterion (Figs. D4 to D6). Contiguity criterion doesn’t make much difference for PM10, except for a site located in a valley. Nitrogen dioxide is more sensitive to the contiguity criterion. The 20% tolerance seems reasonable for PM10 and NO_2, since smaller values would lead to a much larger interannual variability, while larger values would lead to a SR often coincident with the IPR AQ zone. On the other hand, for ozone annual average a smaller threshold (about 10%) for the relative tolerance could work better, avoiding the SR region to expand to the whole IPR AQ zone.

The SR regions of all the background stations have been overlaid, in order to assess the coverage and redundancy of the monitoring network in Friuli Venezia Giulia. The plain zone is well covered and the network is redundant, both for NO_2 (Fig. D7) and PM10 (Fig. D8), while the mountainous zone is not fully covered. It should be noted that these results, like the previous ones, could be very different by applying annual indicators different from the average.

The MoNet tool has been applied for clustering analysis of observed daily PM10 and hourly NO_2 over two domains: a) Po Valley and Slovenia (Fig. D9), b) Friuli Venezia Giulia (Fig. D10). PM10 based clustering is spatially more coherent, while NO_2 based clustering is more dependent from the station type. The results of the analysis highlight the need for greater harmonization in the zoning of neighbouring regions and could lead to a partial revision of the zoning. Furthermore, the tool is useful for highlighting local hot-spots.

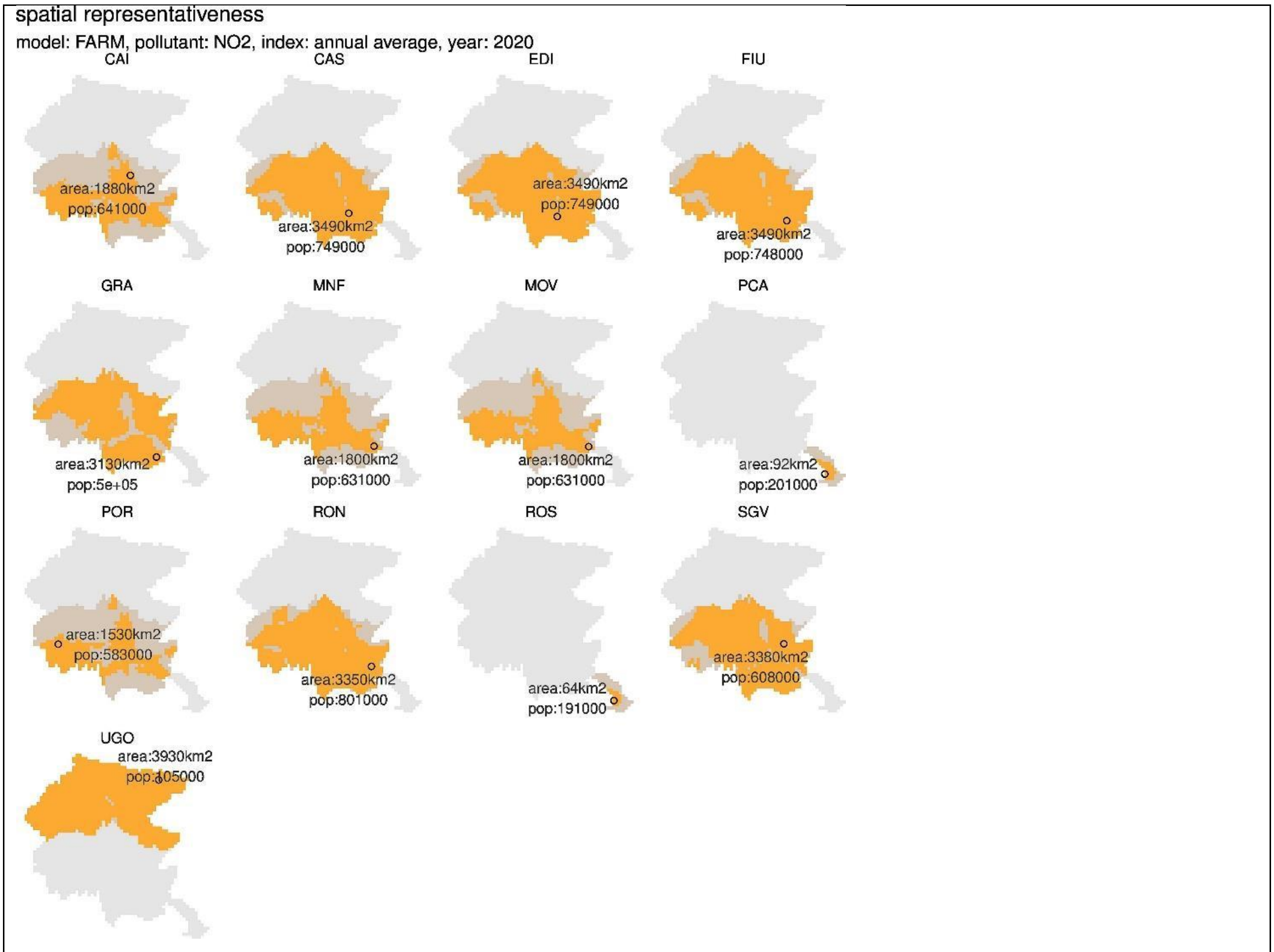


Fig. D1 – SR for NO_2. In orange the SR for each station, in dark grey the portion of the same IPR zone not included in the SR, in light grey the rest of the region Friuli Venezia Giulia.

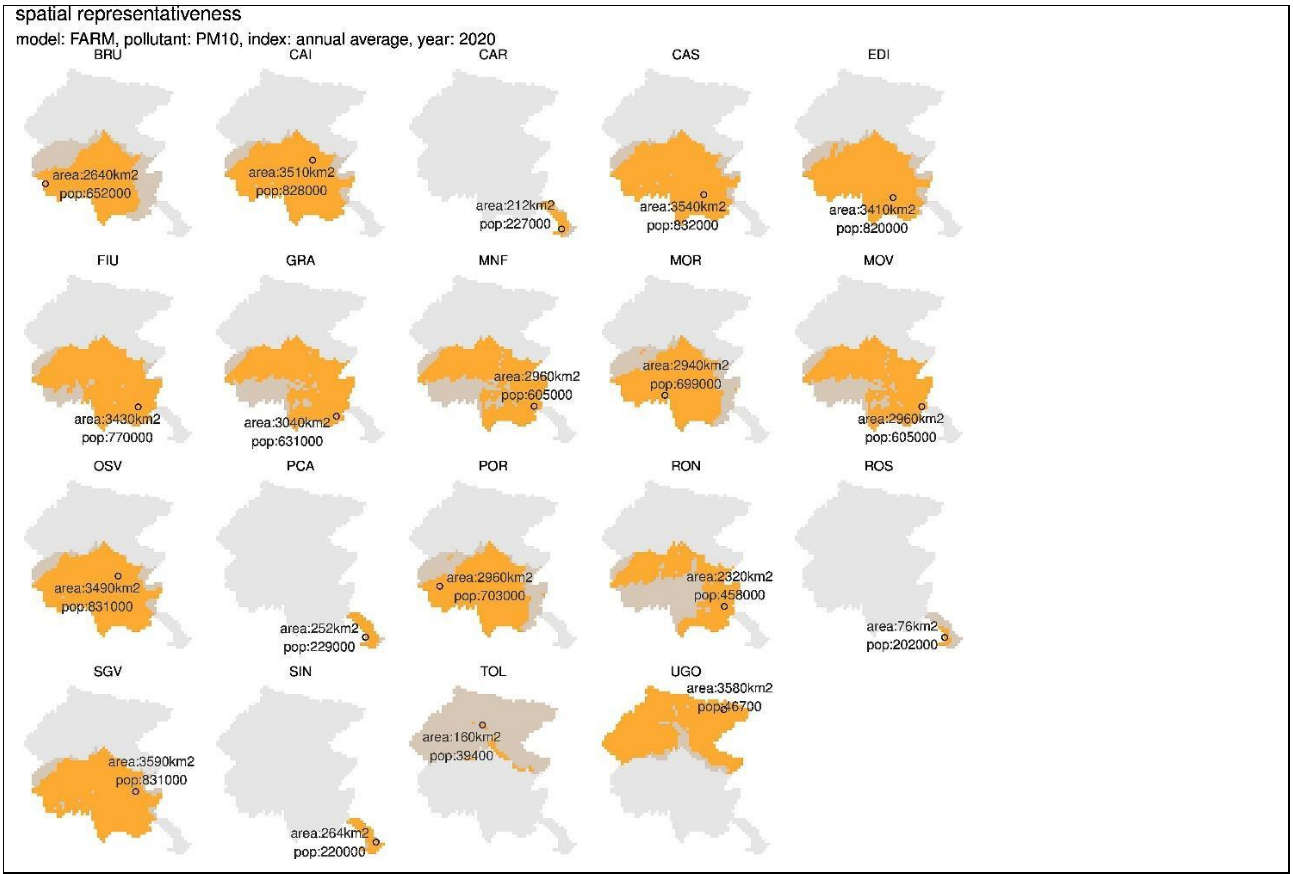


Fig. D2 – Same as Fig. D1, for PM10.

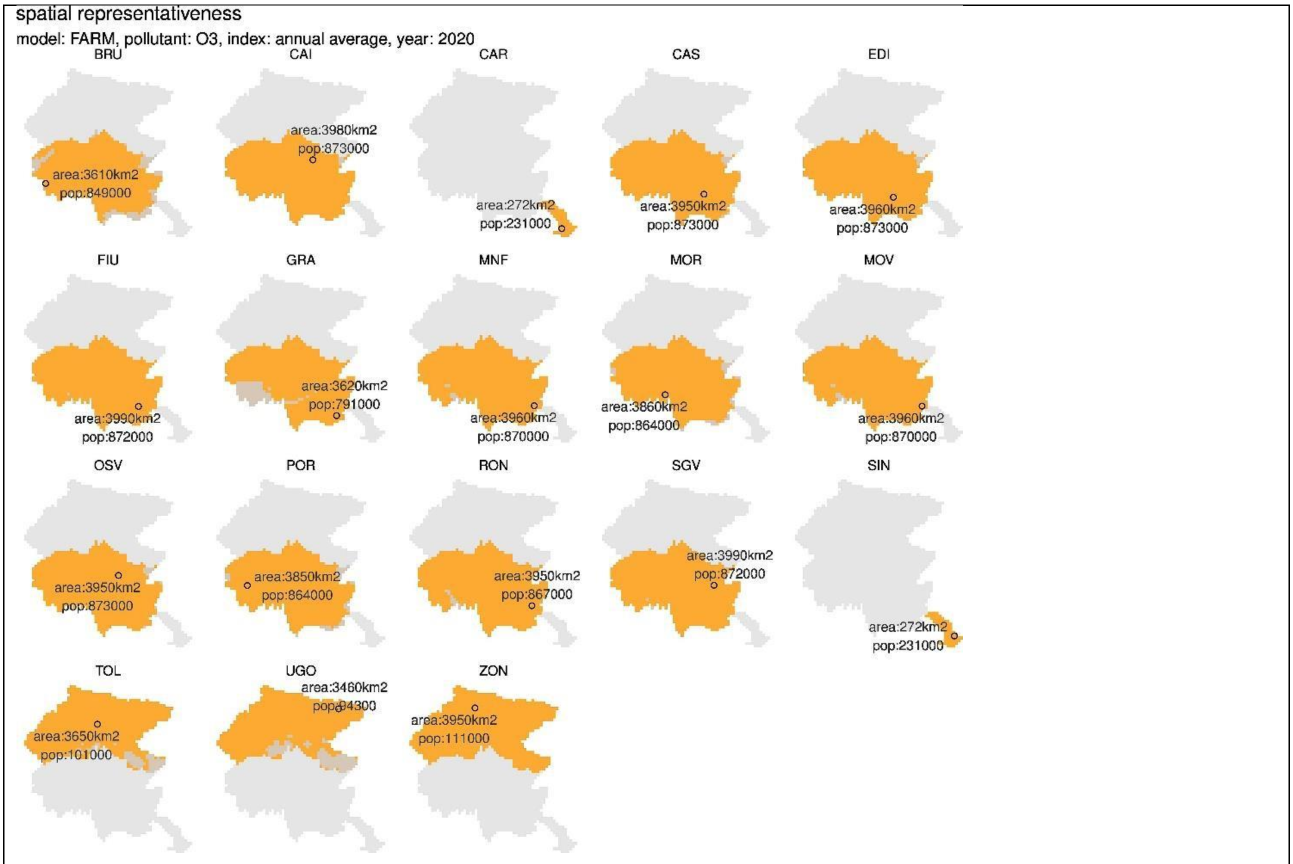


Fig. D3 – Same as Fig. D1, for ozone.

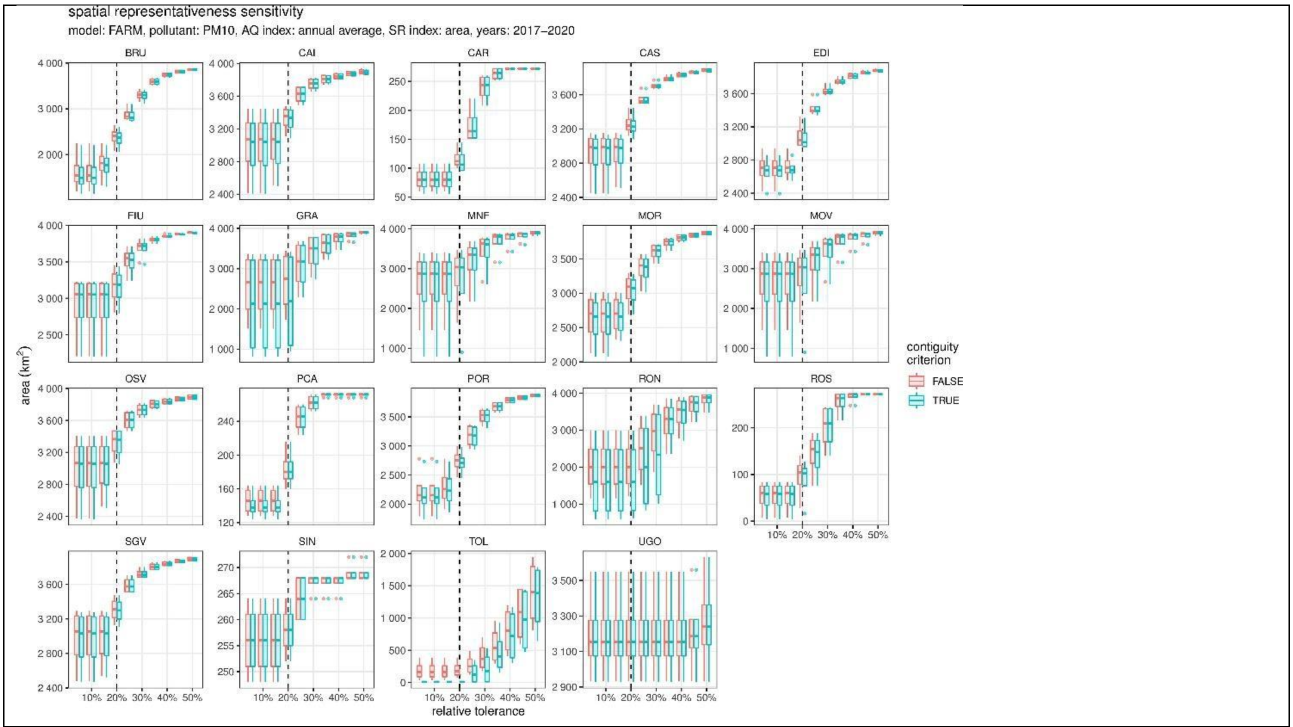


Fig. D4 –Analysis of the sensitivity of SR for PM10 to changing value of relative tolerance, with (blue) or without (red) the contiguity criterion.

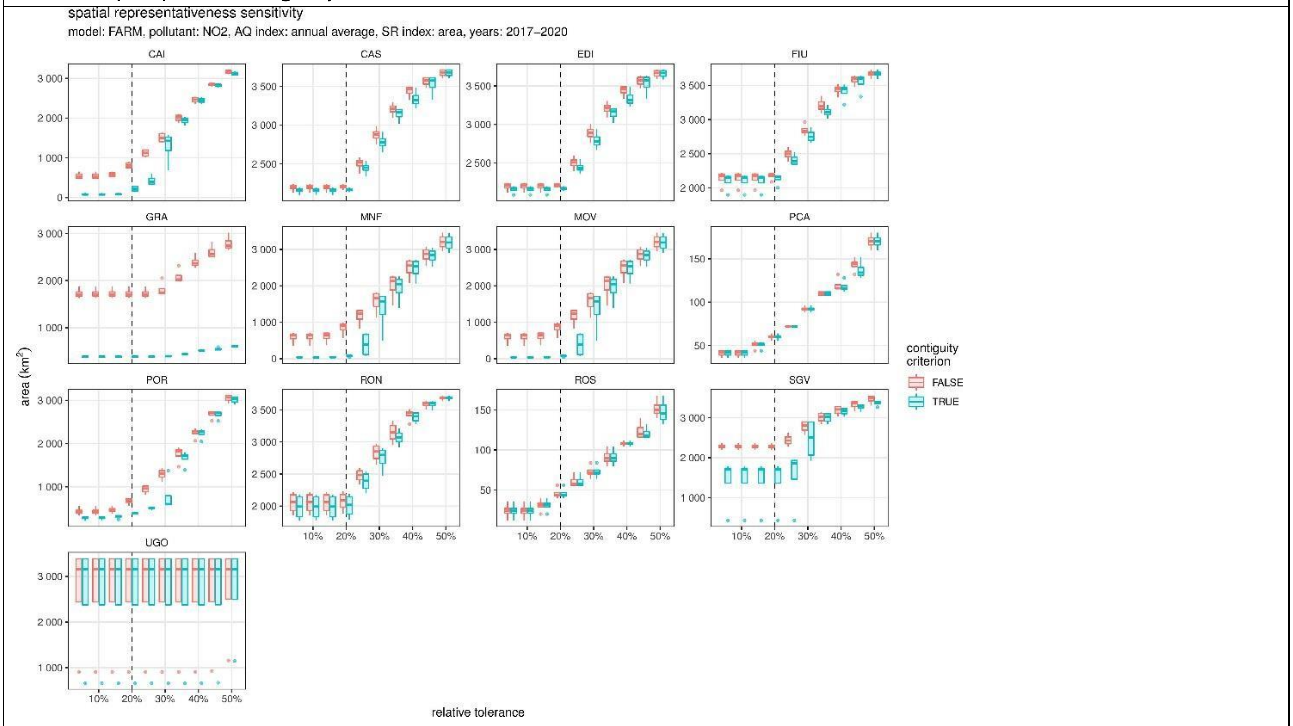


Fig. D5 –Same as Fig. D4, for NO_2.

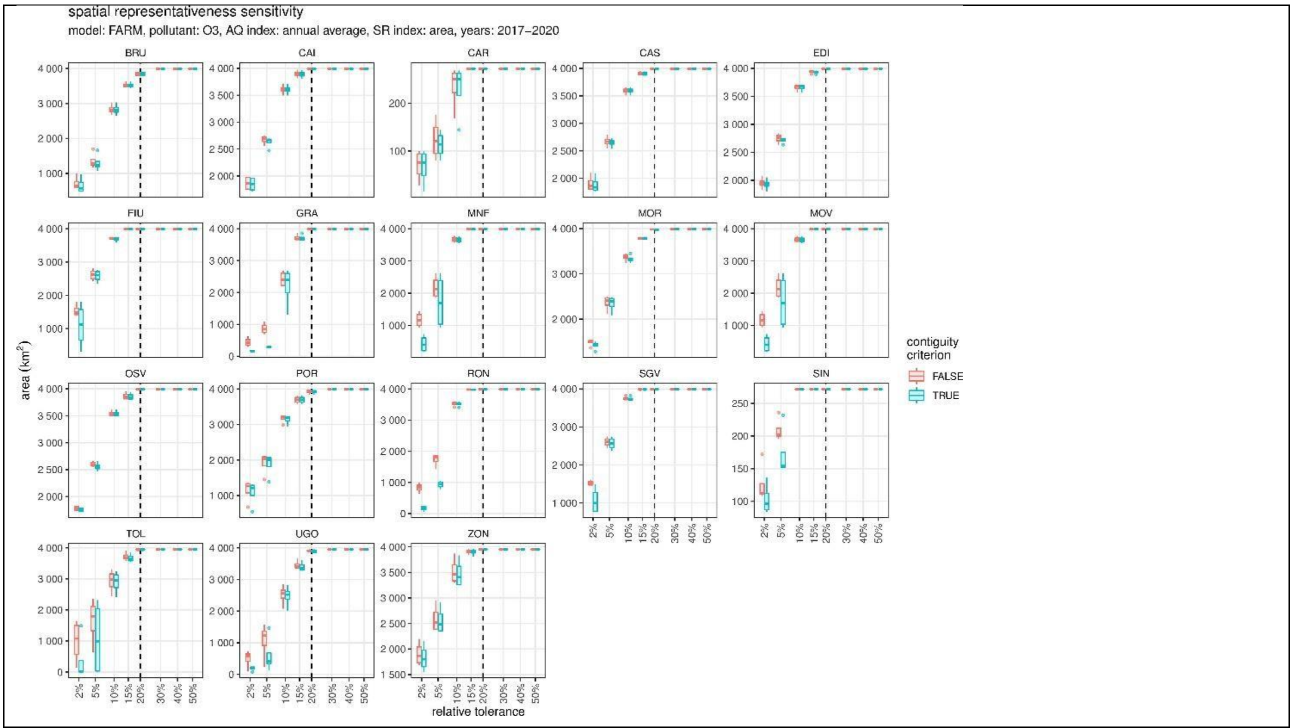


Fig. D6 –Same as Fig. D4, for ozone.

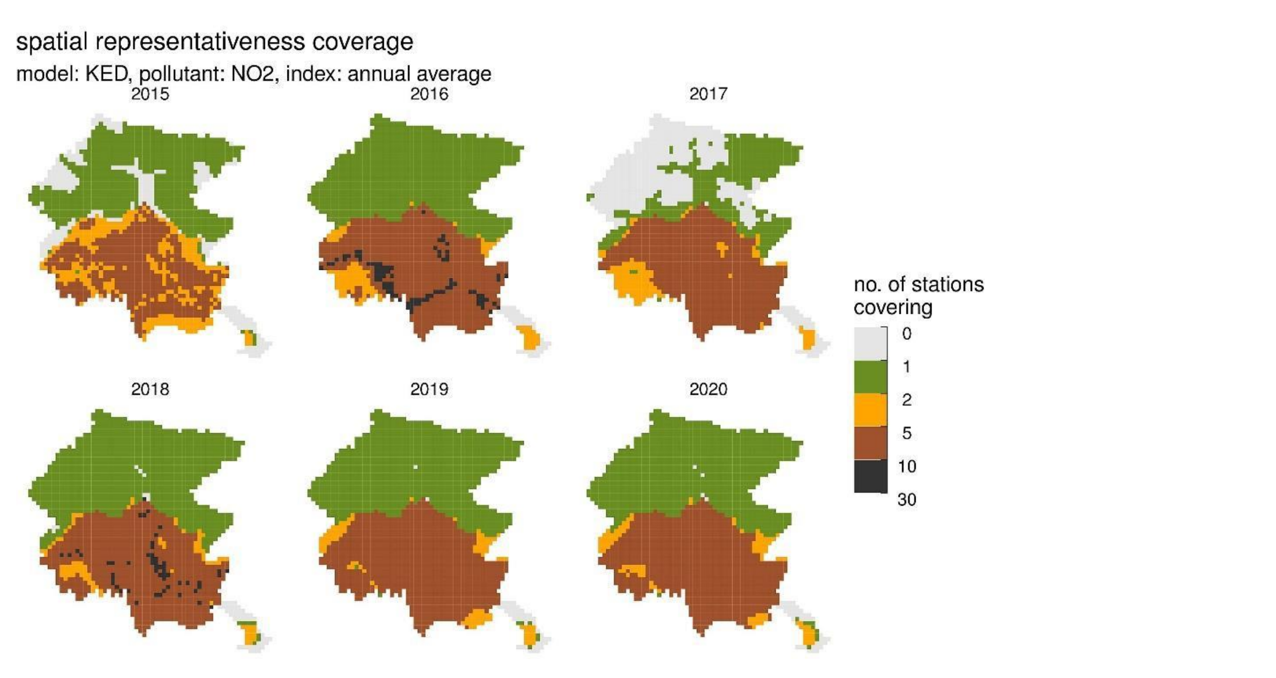


Fig. D7 –Maps of the spatial coverage for NO_2 monitoring network.

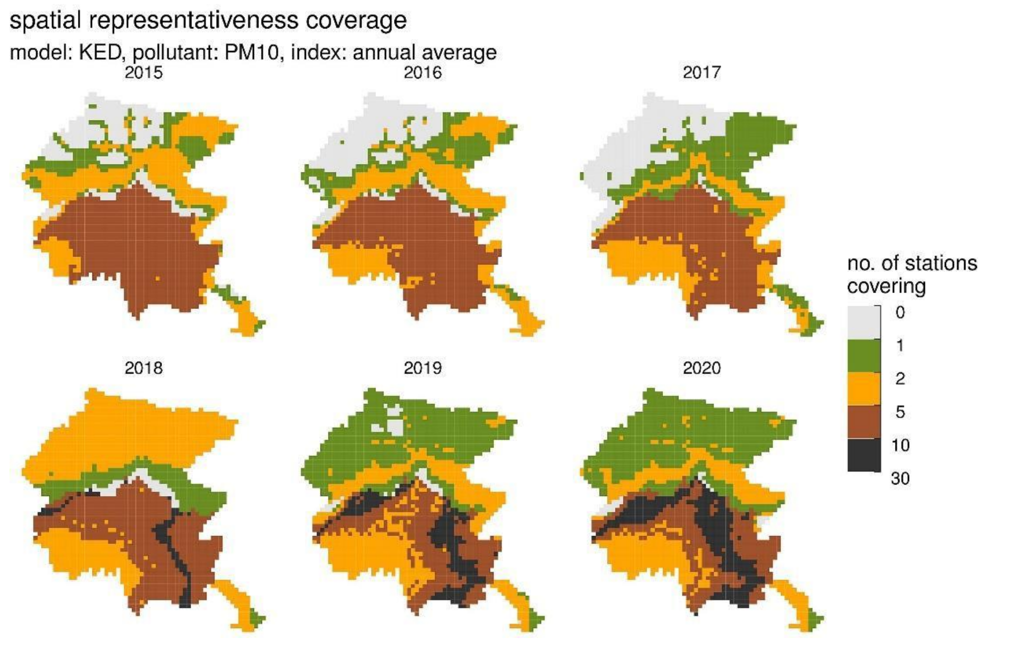


Fig. D8 –Same as Fig. D7, for PM10.

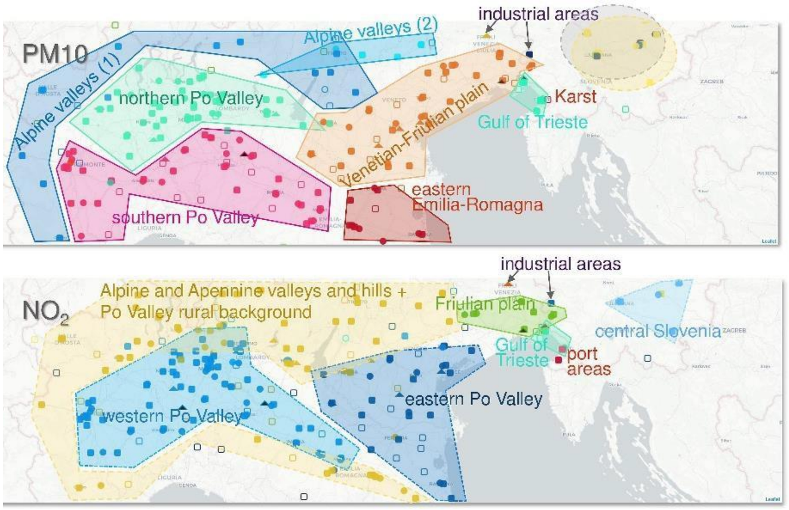


Fig. D9 –Clustering performed by the MoNet tool on observed PM10 (above) and NO$_2$ (below) in the Po Valley and Slovenia.

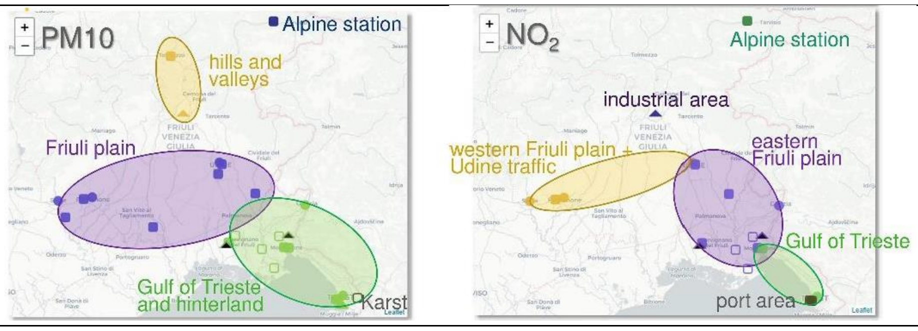


Fig. D10 – Clustering performed by the MoNet tool on observed PM10 (left) and NO$_2$ (right) in Friuli Venezia Giulia.

References

Janssen, S. Thunis, P., et al. (2022) FAIRMODE Guidance Document on Modelling Quality Objectives and Benchmarking (version 3.3), EUR 31068 EN, Publications Office of the European Union, Luxembourg, 2022, JRC129254, ISBN 978-92-76-52425-0, doi:10.2760/41988.

Piersanti, A., Vitali, L., Righini, G., Cremona, G., Ciancarella, L. (2015). Spatial representativeness of air quality monitoring stations: A grid model based approach. Atmospheric Pollution Research, 6 (6), 953-960. DOI: 10.1016/j.apr.2015.04.005.

Vitali, L., Ciancarella, L., Cionni, I., Cremona, G., Piersanti, A., Righini, G. (2013). Rappresentatività spaziale di misure di qualità dell'aria. Valutazione di un metodo di stima basato sull'analisi dei campi di concentrazione simulati dal Modello Nazionale MINNI. Rapporto Tecnico RT/2013/3/ENEA, ENEA, ISSN/0393-3016, http://openarchive.enea.it//handle/10840/4477.

APPENDIX 2

Feedback and results from FAIRMODE WG4-Microscal Modelling based on the FAIRMODE WG8 checklist for further testing of spatial representativeness of measurement stations

Important:
The information shown here is part of the results of Microscale models' intercomparison exercise carried out by the FAIRMODE WG4-Microscale Modelling and it will be part of a paper under preparation, which will be submitted for publishing in next months.

General information
Country / Zone / City:
Urban district of Antwerp. Domain used in the Intercomparison exercise of the WG4 for Microscale Models

Measurement station & description:
(station type, inlet height, other characteristics that may be relevant/important)
Two stations:
- Backgropund
- Traffic

Pollutant: NO_2

Year: 2016

Type of model(s) used (e.g. Gaussian, OSPM, Lagrangian , CFD, etc) and Model scale / resolution

- **1 simple Gaussian.** Grid resolution 20 m.
- **4 Gaussian with street-canyon parameterization**. Grid resolution from 1 to 10 m.
- **1 Lagrangian.** Grid resolution 3 m
- **2 Artificial Inteligence** trained with a CFD model. Grid resolution 3 m
- **12 CFD models**. Grid resolution from 1 to 5 m.

All use the same emission data (road traffic) and the same background concentration (except one CFD model PALM4U which is linked to WRF-Chem)

Domain: 800x800 m

Bias adjustment? (data fusion / data assimilation):

Five types of modelled NO_2 concentration for each model:

- **Raw data**
- **Bias corrected modelling data (*BC*).** Bias corrected data used the average bias of the monthly NO_2 concentration prediction of each model application respect the samplers' observations to correct the model estimates at the sampler locations.
- **Normalized with observation at two (background and traffic) stations (*NBG* or *NTF*).** They use the difference of monthly NO2 concentration prediction of model application at the

station location respect the observed data to correct all the sampler estimates from each model application.

- **Correction based on linear regression (*Ax+B*).** The linear regression functions were computed for every concentration data set of the modelling applications with the observed concentrations from the samplers and the slopes *A* and the intercepts *B* were computed for every modelling application.
- **Correction based on linear regression with intercept equal zero (*Ax*).** The coefficients *A* were computed for every modelling application as in the former case.

What to test?

- *Differences in the SR areas with different lower cut-offs*
    - *2 or 4 μg/m^3 for NO_2?*

  No lower cut-offs were investigated, but due to high concentrations recorded at stations (35 and 36 μg/m^3), the concentration tolerance half-interval is clearly higher than 4 μg/m^3 for 15% or 20% tolerances, and very close for 10%.
- *Differences in the SR areas using annual mean vs relevant percentile(s)*
  Not done
- *Annual variation in SR areas*
  Not done

- **Differences in the SR areas with different tolerance levels:**
  (10 or 15 % for background stations, 15 or 20 % for hotspot/traffic stations)

Main Conclusions:

- The annual SRAs estimated by the different model applications are different but share many areas. Most of the SRAs' estimates do not cover most of the main avenue where high NO_2 concentrations are predicted, which means that the measurements of the closest stations are not representative of the pollution in the avenue (Fig. 1).
- The SRAs are larger for the background station than for the traffic one, and for the higher tolerances (Fig. 1).
- The Gaussian models provide the larger SRAs (the largest SRA is for the Gaussian model without street-canyon parametrization). There is a notable variability of the SRA sizes for both tolerances computed with CFD models, especially for the traffic station (Fig. 2-4).
- In some cases, there are significant differences in the SRA estimates when using different methodologies for retrieving the annual mean NO2 concentration based on the same CFD model simulations (Fig. 2-4).
- There are important differences in the size of the SRA when using 10% or 20% tolerances. The differences are much more significant for the traffic station SRA (Fig. 1-4).
- SRA sizes increase strongly as tolerance increases but up to some critical tolerance threshold and then, the increase is very low until the possible maximum extension in the domain (the area not covered by buildings) (see Fig 5). The critical tolerance threshold is different for each station. It is higher for the traffic station than for the background station. However, there is a noticeable dispersion in the values of this critical threshold depending on the modeling application. In general, the Gaussian models have a critical tolerance threshold of less than 10% and 15% for the background and traffic stations, respectively. In contrast, the modeling applications based on non-Gaussian models have critical tolerances for higher values (15% and 20% or more, for the background and traffic stations, respectively). Nevertheless, there is noticeable variability within

the two groups of modeling applications, especially in the case of non-Gaussian models. These results can be explained by taking into account that this critical tolerance threshold is shorter when the SRA is larger for low tolerances (which happens mostly for the Gaussian models), that is, in such cases, increasing the tolerance makes the SRA to grow reaching before the possible maximum size. Additionally, the non-Gaussian models predicts more intense concentration gradients, which makes slower the growth of the SRA with the increasing tolerance.

- It appears that there is some relationship between the size of the SRA and the grid cell resolution (Fig. 6) and the concentration at the station location (Figure 5). It is observed that low grid resolution (large cell size) tends to provide larger SRAs, whereas high grid resolution (small grid cells) can result in both large and small SRAs for both stations and for 10% and 20% tolerances.
- Regarding the effect of the concentration at the station location (Fig. 7), a relationship is evident for the traffic station, particularly for a 10% tolerance. It seems that the size of the SRA decreases as the grid cell size increases.

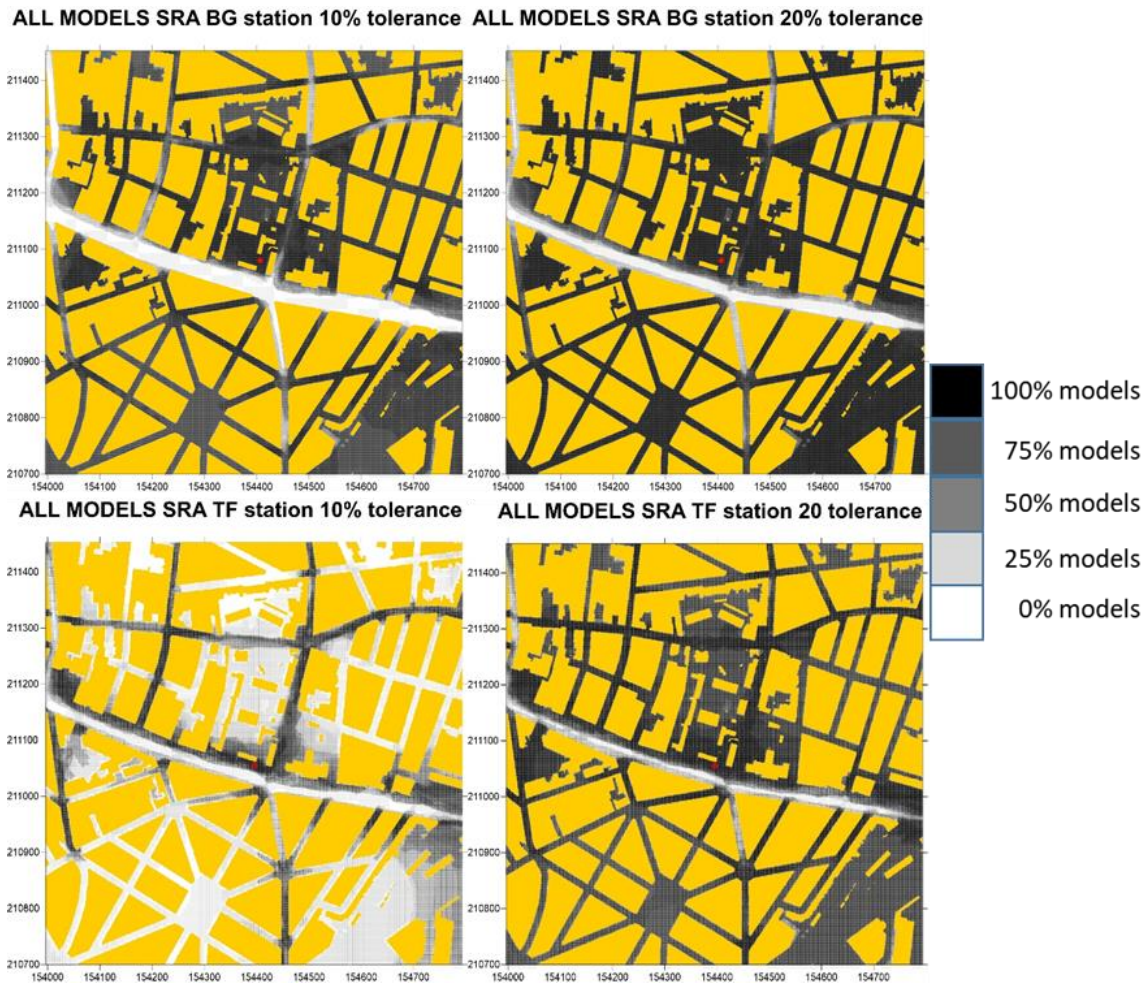


Figure 1. Overlapping of the spatial representativeness areas computed by all the model applications for the background (above) and traffic station (below) and for 10% (left) and 20% (right) tolerances. The darker the pixel, the more models estimate it is within the area of exceeding the limit value. The white color pixel indicates none model predicts it within the SRA.

Figure 2. Overlapping of the spatial representativeness areas computed by the different types of model applications for the background (left) and traffic station (right) and for 10% and 20% tolerances. The darker the pixel, the more models estimate it is within the area of exceeding the limit value. The white color pixel indicates none model predicts it within the SRA.

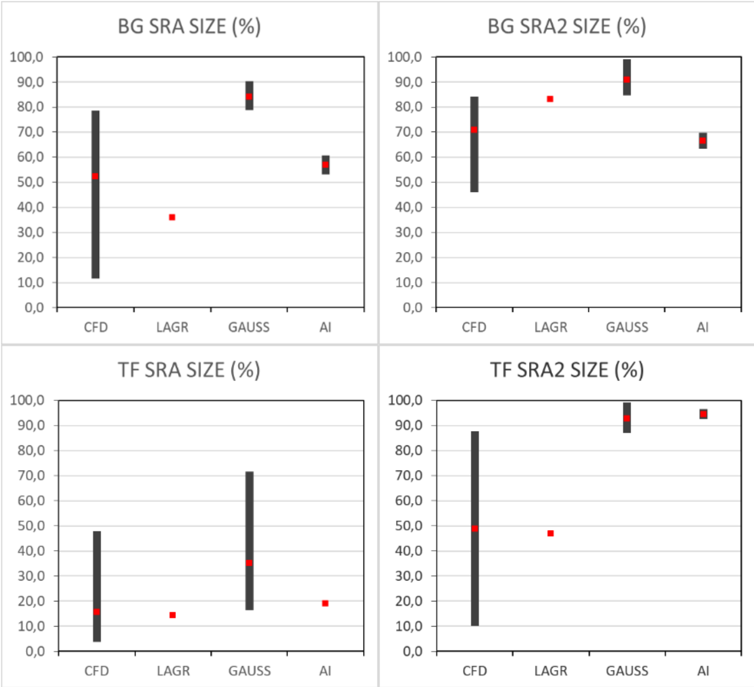


Figure 3. Mean and range of size of the spatial representativeness areas for the different types of model applications for the background (above) and traffic station (below) and for 10% (left) and 20% (right) tolerances. GAUSS = Gaussian models, CFD models, LAGR = Lagrangian models, and AI = Artificial Intelligence models.

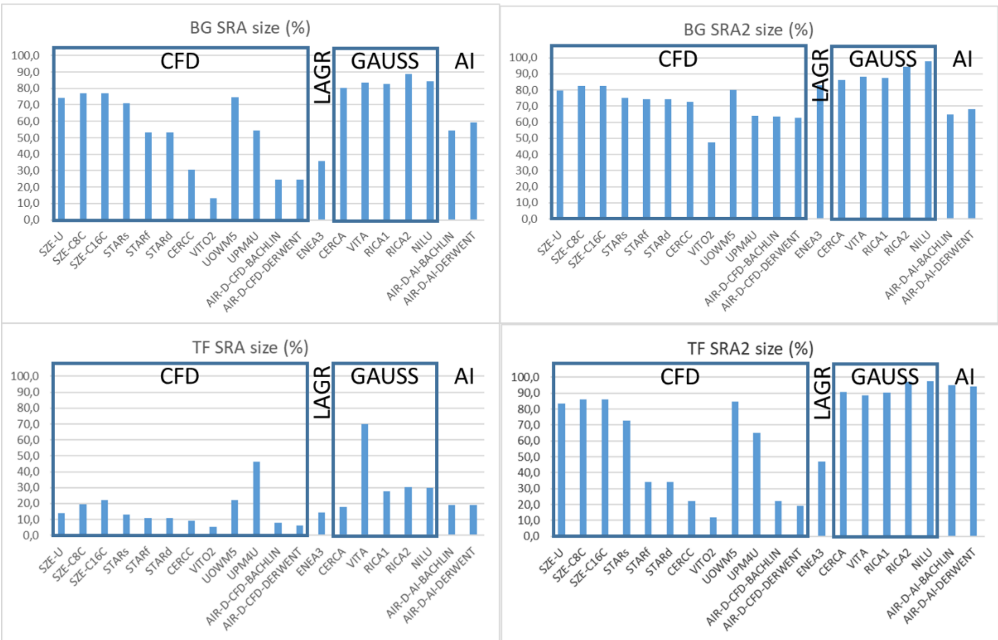


Figure 4. Size (% of non-built area of the domain) of the spatial representativeness areas computed by every model applications for the background (above) and traffic (below) stations and for 10% (left) and 20% (right) tolerances. GAUSS = Gaussian models, CFD models, LAGR = Lagrangian models, and AI = Artificial Intelligence models.

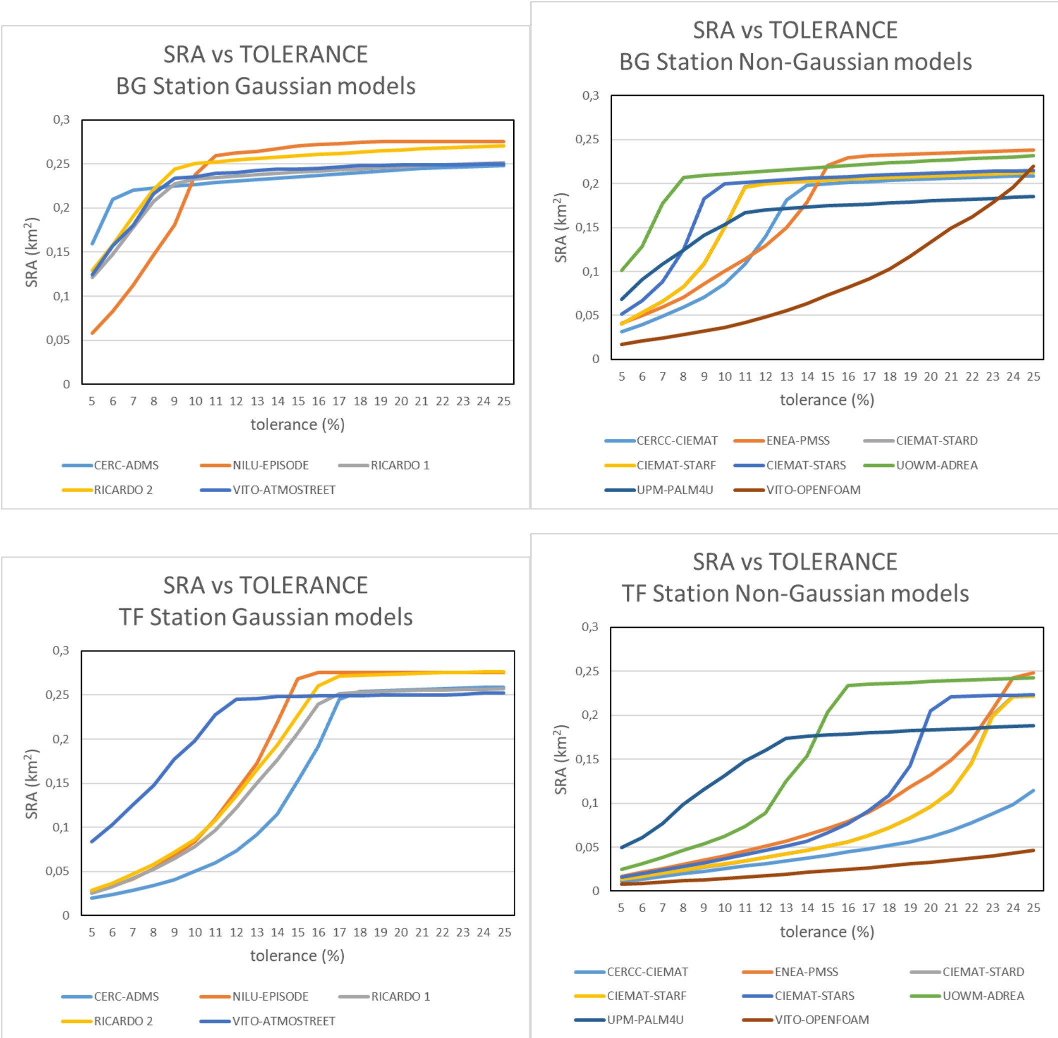


Figure 5. Size (km^2) of the spatial representativeness areas of the background (BG, above) and traffic (TF, below) stations versus the tolerance (from 5 to 25%) for the Gaussian models and non-Gaussian models.

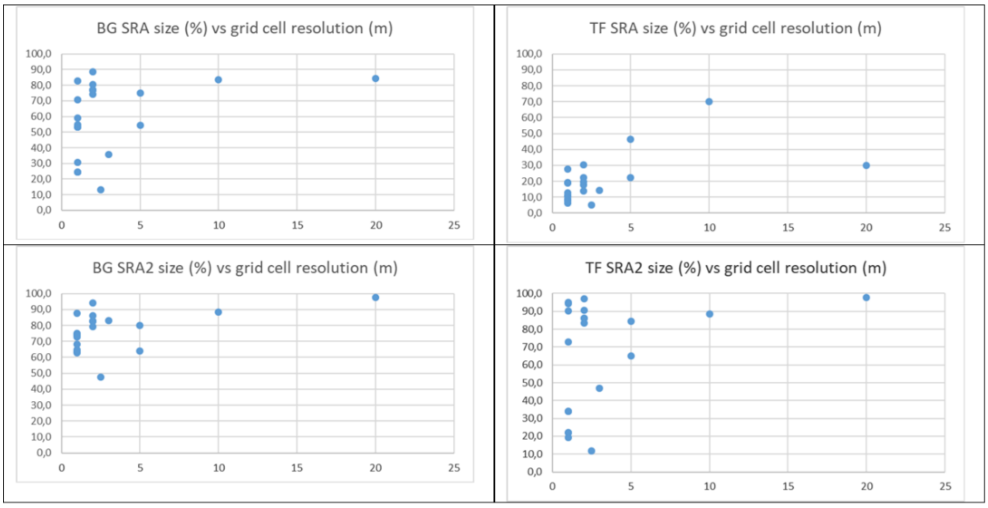


Figure 6. Size (% of non-built area of the domain) of the spatial representativeness areas of the background (BG, left) and traffic (TF, right) stations for 10% (above) and 20% (below) tolerances computed by every model applications versus the grid resolution.

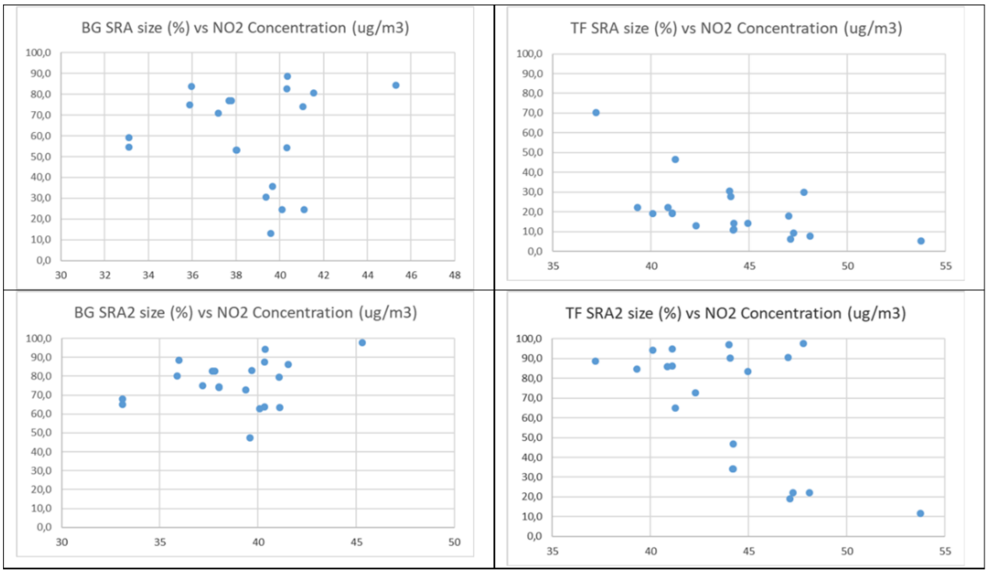


Figure 7. Size (% of non-built area of the domain) of the spatial representativeness areas of the background (BG, left) and traffic (TF, right) stations for 10% (above) and 20% (below) tolerances computed by every model applications versus the NO_2 concentration at the station location.

- **Differences in the SR areas with and without bias correction**

As a part of intercomaprison exercise of microscale models in urban areas, the WG4 have carried out an evaluation of the SRA estimates (based on monthly average concentration data) done by different models and model corrected data. Then, 5 different types of model data were used (see above the description of every type):

- **Raw data**
- **Bias corrected modelling data (*BC*).**
- **Normalized with observation at two (background and traffic) stations (*NBG* or *NTF*).**
- **Correction based on linear regression (*Ax+B*).**
- **Correction based on linear regression with intercept equal zero (*Ax*).**

The data were compared with observations from 28 samplers deployed in the domain, two of them located at the two AQ stations. Observed SRA were computed following the same procedure and tolerances as for the model data. Then, we have measured of samplers inside the SRA, which are used to check whether the models estimate the same samplers or not inside the SRA.

In Figures (8-10), the results of the Accuracy, False Alarm Rate and Bias of the SRA estimates (15% tolerances for both stations, for every model type, and for all model corrections).

The main conclusion is that it is not possible to determine what model data correction could be suitable because there is not a clear tendency to improve the raw data. It seems to slightly depend on the modelling approach (specifically, the ability of the models to simulate the concentration gradients, for example) but it could be very particular to the studied case. Surely further studies with other urban configurations should be needed.

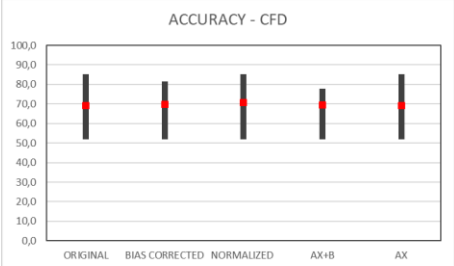
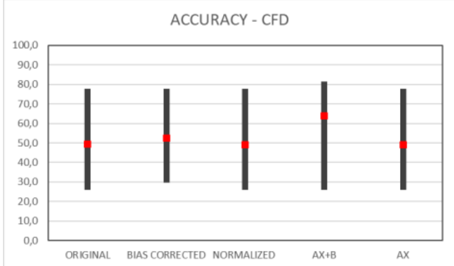
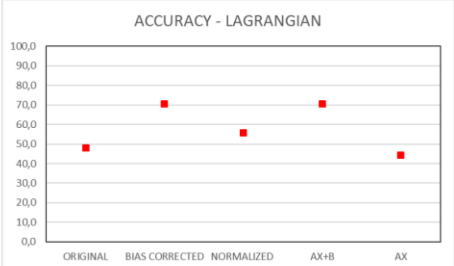
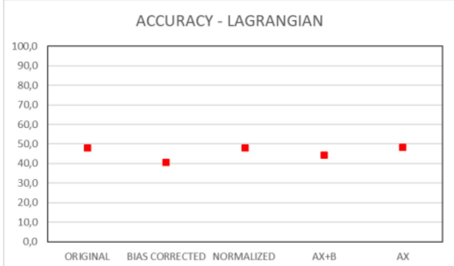
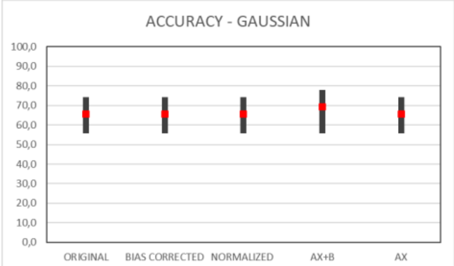
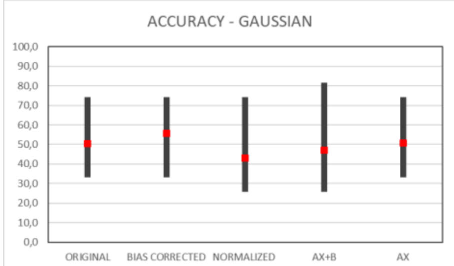
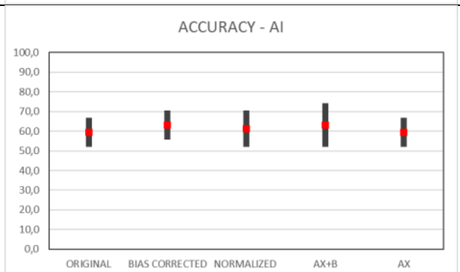
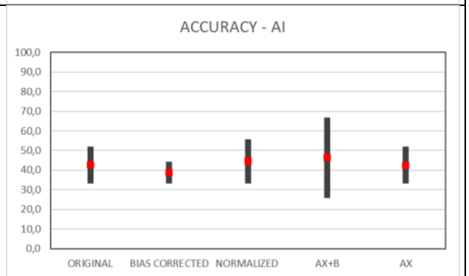
MODEL TYPE	BG STSATION 15%	TF STATION 15%
CFD		
LAGRANGIAN		
GAUSSIAN		
AI		

Figure 8. Accuracy Index (maximum-minimum range in black and mean value in red) for predictions of the spatial representativeness area (15% tolerance) of the background (BG, left) and traffic (TF, right) stations corresponding to different type of modelling data (Original or Raw data, Bias corrected, Normalized with concentration at traffic (TF) or background (BG) station, corrected by regression lines (AX+B, AX) grouped by the different type of modelling applications (CFD, Lagrangian, Gaussian and Artificial Intelligence (AI)).

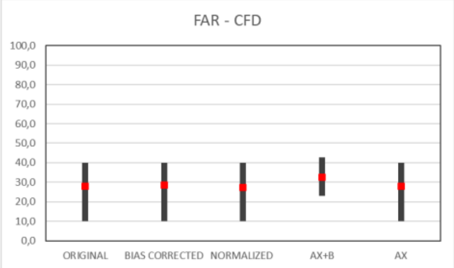
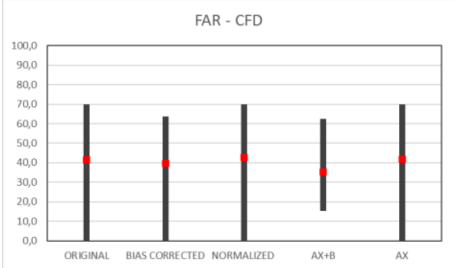
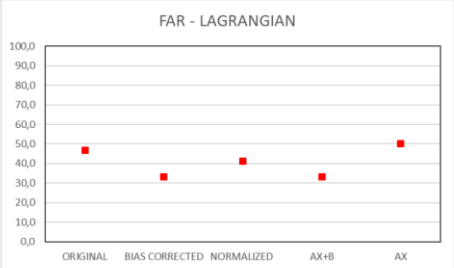
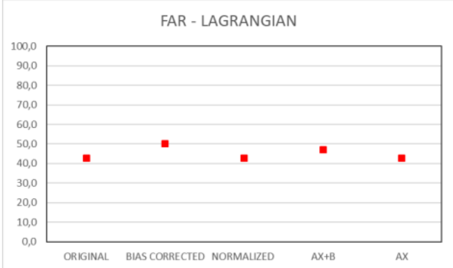
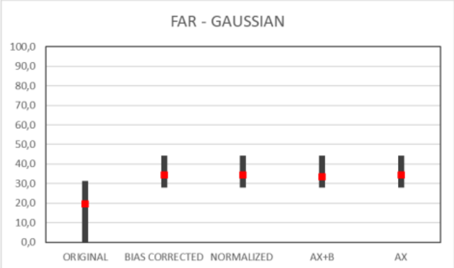
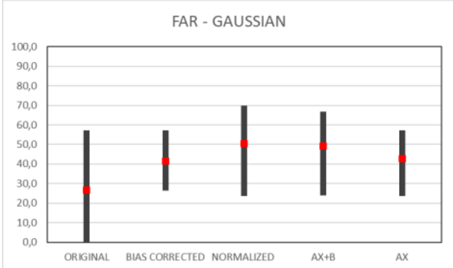
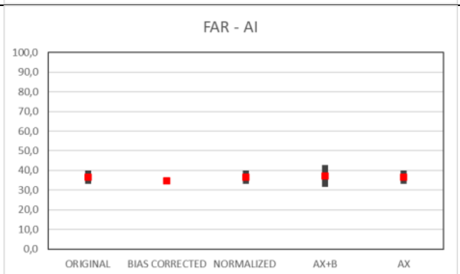
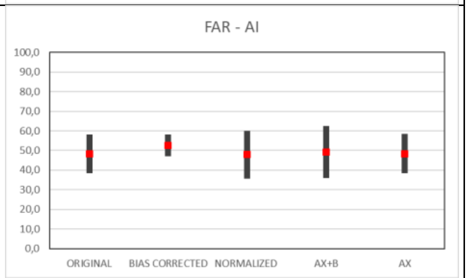
MODEL TYPE	BG STSATION 15%	TF STATION 15%
CFD		
LAGRANGIAN		
GAUSSIAN		
AI		

Figure 9. False Alarm Rate (FAR) (maximum-minimum range in black and mean value in red) for predictions of the spatial representativeness area (15% tolerance) of the background (BG, left) and traffic (TF, right) stations corresponding to different type of modelling data (Original or Raw data, Bias corrected, Normalized with concentration at traffic (TF) or background (BG) station, corrected by regression lines (AX+B, AX) grouped by the different type of modelling applications (CFD, Lagrangian, Gaussian and Artificial Intelligence (AI)).

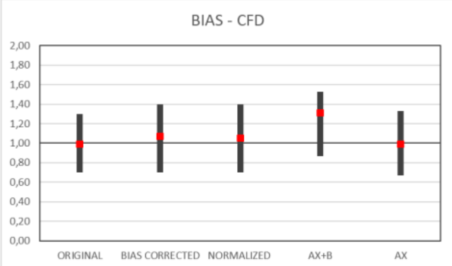
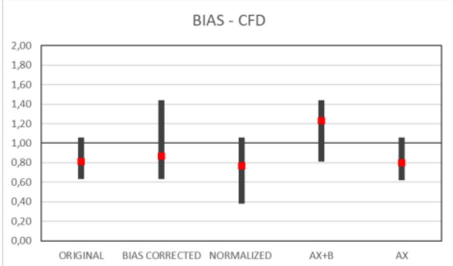
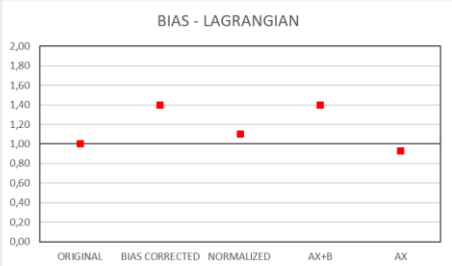
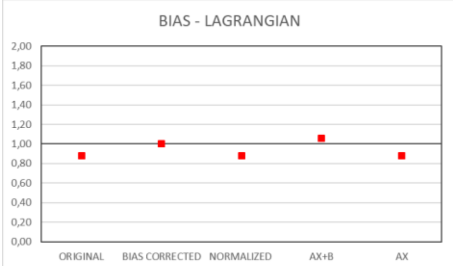
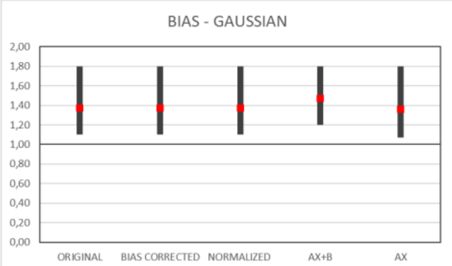
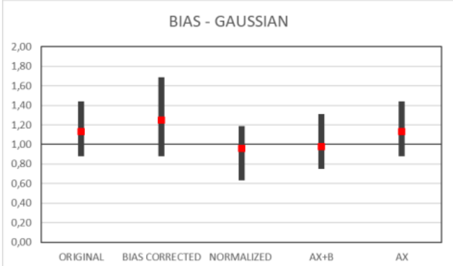
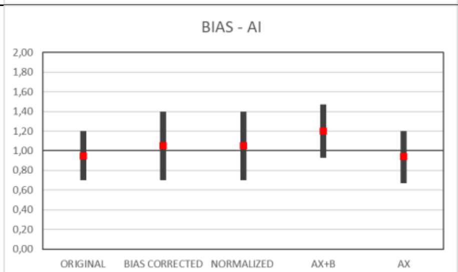
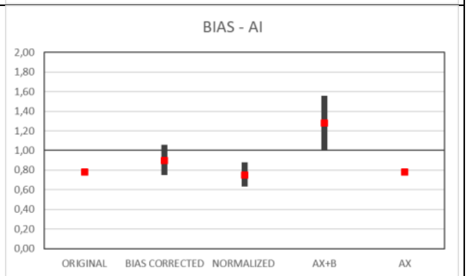
MODEL TYPE	BG STSATION 15%	TF STATION 15%
CFD		
LAGRANGIAN		
GAUSSIAN		
AI		

Figure 10. Bias (maximum-minimum range in black and mean value in red) for predictions of the spatial representativeness area (15% tolerance) of the background (BG, left) and traffic (TF, right) stations corresponding to different type of modelling data (Original or Raw data, Bias corrected, Normalized with concentration at traffic (TF) or background (BG) station, corrected by regression lines (AX+B, AX) grouped by the different type of modelling applications (CFD, Lagrangian, Gaussian and Artificial Intelligence (AI)).

Important considerations

Comments on the scale of gaps in existing monitoring networks when the different criteria above are applied. I.e. how large are the areas in a city / zone that are not covered by the SR areas of the zone's measurement stations? Are these gaps in the networks considered reasonable and can the information be useful to guide network design & evaluation?

Other important comments for consideration? (e.g. source-related issues)

NO COMMENTS

APPENDIX 3

Testing Spatial Representativeness of Monitoring Stations in Four Cities within the East Sweden Air Quality Management Association

Jenny Lindvall

SLB-Analys, Environment and Health Administration, City of Stockholm

Introduction

This document provides an account of the contribution from Sweden and SLB-Analys to the workshop on spatial representativeness (SR) of monitoring stations that was held by FAIRMODE Working Group 8 in December 2023. Participants at the workshop presented results from testing the proposed methodology for defining SR, developed by the working group over recent years. A checklist was circulated prior to the workshop to guide the testing process.

In the contribution from SLB-Analys, the SR area was calculated for monitoring stations in four midsize Swedish cities within the East Sweden Air Quality Management Association, with the city locations shown in Figure 1. This exercise tested several definitions of spatial representativeness to assess their impact on the results.

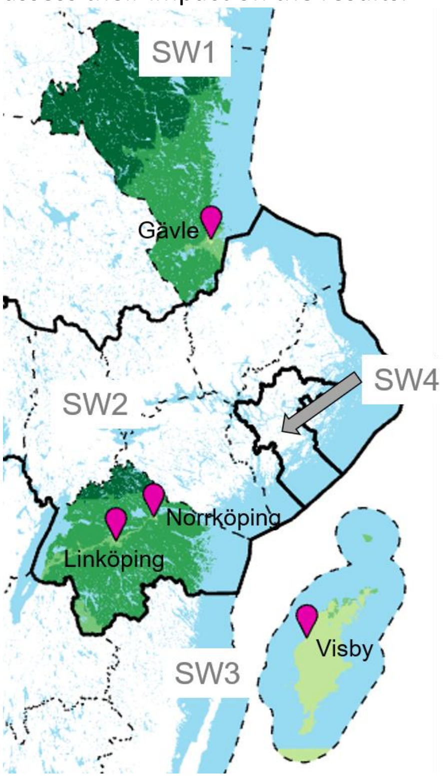


Figure 1.*The four cities included in the exercise and the corresponding air quality zones.*

Methodology summary

General information about the monitoring stations is provided in Table 1, with a summary of the test setup outlined below.

Table 1. *Monitoring stations included in the exercise.*

Zone	City	Measurement station	Station type	Year
SW1	Gävle	Staketgatan 22	Traffic site	2020
SW2	Norrköping	Trädgårdsgatan	Urban background site	2022
SW2	Norrköping	Kungsgatan 32	Traffic site	2022
SW2	Linköping	Hamngatan 10	Traffic site	2022
SW3	Visby	Brömsebroväg	Urban background site	2022
SW3	Visby	Österväg 17	Traffic site	2022

Models: The Airviro gaussian model and the OSPM street canyon model.

Bias Adjustment: Yes, applied, but in a manner that does not impact the results of this exercise.

Grid Resolution: 35x35 – 500x500 m^2

Pollutants Analyzed: PM10 and NO_2

Scope of Analysis:

- Differences in the SR areas with different tolerance levels:
  ±10% or ±15% for background stations
  ±15% or ±20% for traffic stations

- Differences in the SR areas with different lower cut-offs:
  2 or 4 $\mu g/m^3$ for NO_2
  2 or 4 $\mu g/m^3$ for PM10

Differences in the SR areas using annual mean vs relevant percentile(s) were only partially included as the percentiles are calculated from the annual mean, using empirical formulas. The differences between using annual mean and percentiles are therefore not fully explored.

Tests Not Conducted:

- SR areas for PM2.5, ozone, SO2, Benzene, CO, B(a)P or metals
- Annual variation in SR areas
- Differences in the SR areas with and without bias correction.

Model description

Airviro gaussian model

The Airviro gaussian model [1] has been used to calculate the horizontal distribution of air pollutant concentrations at two meters above ground level. In built-up areas, this corresponds to concentrations at two meters above roof level. Meteorological input is provided by the Airviro wind model, which is driven by climatological wind and temperature profiles. The model employs a variable grid resolution that adjusts based on emission source locations, with grid sizes ranging from 35×35 m^2 to 500×500 m^2. The highest resolution is applied in areas with the largest emission sources.

Airviro OSPM model

The Airviro OSPM model [2] has been used to calculate the concentrations of air pollutants in street segments with buildings at one or two sides of the road. The meteorology is taken from the Airviro wind model, driven by climatological wind and temperature profiles.

Meteorological parameters

To calculate wind fields, the Airviro wind model uses a climatology, i.e., a number of statistically derived weather conditions, as input data. The climatology is based on meteorological data, e.g., horizontal and vertical wind speed, wind direction, temperature, temperature differences and solar radiation, from so called virtual masts containing ten years of data from the SMHI meteorological analysis model MESAN [3]. The wind model also takes into account variations in local topography.

Emissions

The model calculations are based on emission data from the East Sweden Air Quality Management Association emissions database [4]. The database has detailed descriptions of emissions from road traffic, the energy sector, the industrial sector and shipping as well as agriculture, waste management and product usage.

In most parts of the modeled counties, the dominant source of air pollution is road traffic. Exhaust emissions are described using emission factors for different vehicles and road types according to the HBEFA model version 4.2 [5]. The composition of different vehicle categories and fuels, for example the proportion of electric and diesel cars are based on national data from the Swedish Transport Administration. Emissions of wear particles are mainly from road wear by studded tires but are also formed by wear of brakes and tires. Along heavily trafficked roads, wear particles make up the majority of PM10 levels. Emission factors for wear particles for different shares of studded tires are based on the NORTRIP model [6,7]. The shares of studded tires are based on observations by SLB-Analys [8] and the Swedish Transport Administration [9].

Note, that only emissions located within the counties are included in the calculations. Sources located outside the modeled counties are assumed to be included in the long-range transport based on calculations with the MATCH model and adjusted to regional background measurements.

Results

For this exercise, the suggested tolerance levels for NO_2 are ±10% or ±15% for background stations and ±15% or ±20% for traffic stations. Suggested lowest cut-offs are 2 or 4 µg/m^3. The exercise guidelines do not include the tolerance levels for PM10, but in this report they are assumed to be the same as for NO_2. The resulting tolerance levels for each monitoring station included in this study can be found in Tables 2–5.

Table 2. *Spatial representativeness tolerance levels for annual mean PM10 and the 90thpercentile daily mean PM10 for the urban background monitoring stations.*

Station	**Zone**	**PM10 annual mean**	**10%**	**10% with cut-off 2 µg/m³**	**10% with cut-off 4 µg/m³**	**15%**	**15% with cut-off 2 µg/m³**	**15% with cut-off 4 µg/m³**
Brömsebroväg 8	SW3	13,2	1,3	2,0	4,0	2,0	2,0	4,0
Trädgårdsgatan	SW2	10,3	1,0	2,0	4,0	1,5	2,0	4,0
Station	**Zone**	**PM10 90th perc daily mean**	**10%**	**10% with cut-off 2 µg/m³**	**10% with cut-off 4 µg/m³**	**15%**	**15% with cut-off 2 µg/m³**	**15% with cut-off 4 µg/m³**
Brömsebroväg 8	SW3	25,6	2,6	2,6	4,0	3,8	3,8	4,0
Trädgårdsgatan	SW2	19,3	1,9	2,0	4,0	2,9	2,9	4,0

Table 3. *Spatial representativeness tolerance levels for annual mean NO_2 and the 98thpercentile daily mean NO_2 for the urban background monitoring stations.*

Station	**Zone**	**NO_2 annual mean**	**10%**	**10% with cut-off 2 µg/m³**	**10 % with cut-off 4 µg/m³**	**15%**	**15% with cut-off 2 µg/m³**	**15% with cut-off 4 µg/m³**
Brömsebroväg 8	SW3	4,3	0,4	2,0	4,0	0,6	2,0	4,0
Trädgårdsgatan	SW2	6,0	0,6	2,0	4,0	0,9	2,0	4,0
Station	**Zone**	NO_2 **98th perc daily mean**	**10%**	**10% with cut-off 2 µg/m³**	**10% with cut-off 4 µg/m³**	**15%**	**15% with cut-off 2 µg/m³**	**15% with cut-off 4 µg/m³**
Brömsebroväg 8	SW3	13,3	1,3	2,0	4,0	2,0	2,0	4,0
Trädgårdsgatan	SW2	17,8	1,8	2,0	4,0	2,7	2,0	4,0

Table 4. *Spatial representativeness tolerance levels for annual mean PM10 and the 90th percentile daily mean PM10 for the air quality monitoring stations at traffic sites.*

Station	**Zone**	**PM10 annual mean**	**15%**	**15% with cut-off 2 µg/m³**	**15% with cut-off 4 µg/m³**	**20%**	**20% with cut-off 2 µg/m³**	**20% with cut-off 4 µg/m³**
Staketgatan 22	SW1	19,8	3,0	3,0	4,0	4,0	4,0	4,0
Hamngatan 10	SW2	21,6	3,2	3,2	4,0	4,3	4,3	4,3
Kungsgatan 32	SW2	17,1	2,6	2,6	4,0	3,4	3,4	4,0
Österväg 17	SW3	23,8	3,6	3,6	4,0	4,8	4,8	4,8
Station	**Zone**	**PM10 90th perc daily mean**	**15%**	**15% with cut-off 2 µg/m³**	**15% with cut-off 4 µg/m³**	**20%**	**20% with cut-off 2 µg/m³**	**20% with cut-off 4 µg/m³**
Staketgatan 22	SW1	40,1	6,0	6,0	6,0	4,0	4,0	4,0
Hamngatan 10	SW2	61,0	9,2	9,2	9,2	6,1	6,1	4,0
Kungsgatan 32	SW2	34,4	5,2	5,2	5,2	3,4	3,4	4,0
Österväg 17	SW3	51,5	7,7	7,7	7,7	5,1	5,1	4,0

Table 5. *Spatial representativeness tolerance levels for annual mean NO_2 and the 98th percentile daily mean NO_2 for the air quality monitoring stations at traffic sites.*

Station	Zone	NO_2 annual mean	15%	15% with cut-off 2 µg/m³	15% with cut-off 4 µg/m³	20%	20% with cut-off 2 µg/m³	20% with cut-off 4 µg/m³
Staketgatan 22	SW1	27,7	4,1	4,1	4,1	5,5	5,5	5,5
Hamngatan 10	SW2	15,4	2,3	2,3	4,0	3,1	3,1	4,0
Kungsgatan 32	SW2	18,3	2,7	2,7	4,0	3,7	3,7	4,0
Österväg 17	SW3	8,1	1,2	2,0	4,0	1,6	2,0	4,0
Station	**Zone**	**NO_2 98th perc daily mean**	**15%**	**15% with cut-off 2 µg/m³**	**15% with cut-off 4 µg/m³**	**20%**	**20% with cut-off 2 µg/m³**	**20% with cut-off 4 µg/m³**
Staketgatan 22	SW1	56,9	8,53	8,53	8,53	11,38	11,38	11,38
Hamngatan 10	SW2	36,7	5,50	5,50	5,50	7,33	7,33	7,33
Kungsgatan 32	SW2	41,3	6,20	6,20	6,20	8,26	8,26	8,26
Österväg 17	SW3	22,7	3,40	3,40	4,00	4,53	4,53	4,53

Urban background stations

For urban background stations, the suggested tolerance levels are ±10% and ±15% with possible cut-offs of 2 and 4 µg/m^3 for NO_2. The same cut-off values were considered for PM10, as the exercise guidelines did not provide specific recommendations for PM10 cut-offs.
Two cities with urban background monitoring stations are included in this exercise: Norrköping and Visby. Norrköping is a midsize city located in Östergötland county in the air quality zone SW2 (middle Sweden). Visby is a smaller town, but the largest town on the island of Gotland in the air quality zone SW3 (southern Sweden).
Figures 2 – 5 show the calculated SR areas for the two cities with different tolerance levels. For the Norrköping station and annual mean PM10, both the ±10% and the ±15% tolerance levels yield SR areas that not only cover the urban Norrköping region, but a large part of the entire county, including regional background areas. Using cut-off values would lead to even larger areas being included. It is obvious that these tolerance levels are too large for this station and substance. Although, not included in the exercise guidelines a tolerance level of 5 % was therefore investigated, which leads to a more reasonable extent of the SR area. However, even with a ±5% tolerance level, highways as well as smaller towns were included in the SR area.
For NO_2 (Figure 3) using either a ±10% or a ±15% tolerance level generates reasonable SR areas, which only cover the urban area of Norrköping as well as Linköping, which is a city of similar size located nearby. However, using a lower cut-off of 2 µg/m^3 leads to highways being included and with a lower cut-off of 4 µg/m3 leads to the entire county being included, which is not appropriate.
For Visby both a ±10% and a ±15% tolerance level gives rather reasonable results for PM10 as the modeled difference between the urban and rural area is larger, A lower cut-off of 2 µg/m^3 does not affect the results, but a 4 µg/m^3 cut-off leads to an unreasonably large SR area. For NO_2 the low concentrations of NO_2 gives a very narrow interval for the SR using the percentile tolerance level, which despite the small difference between the urban and rural region gives rather reasonable results. However, an industrial region in the eastern part of the island becomes included in the SR area indicating a need for some additional criteria for the SR area. Furthermore, using lower cut-offs of 2 or 4 µg/ m^3 is not appropriate here.

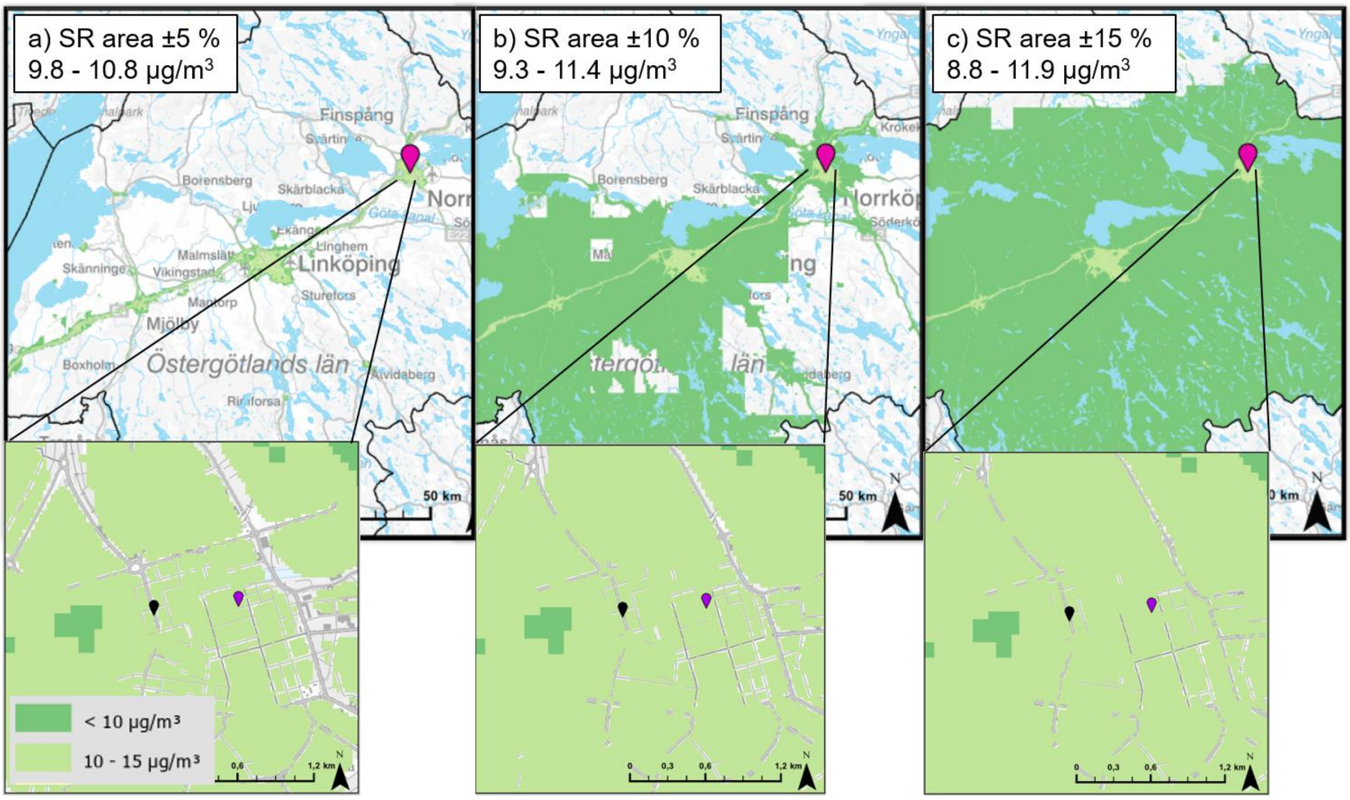


Figure 2. *Colored areas show the SR area of PM10 for the urban background monitoring station Trädgårdsgatan in Norrköping with a) a 5 % tolerance level and b) a 10 % tolerance level and c) a ±15% tolerance level. Using a 2 or 4 µg/m³ tolerance level is not shown, but would lead to even larger SR areas than the ±15% tolerance level.*

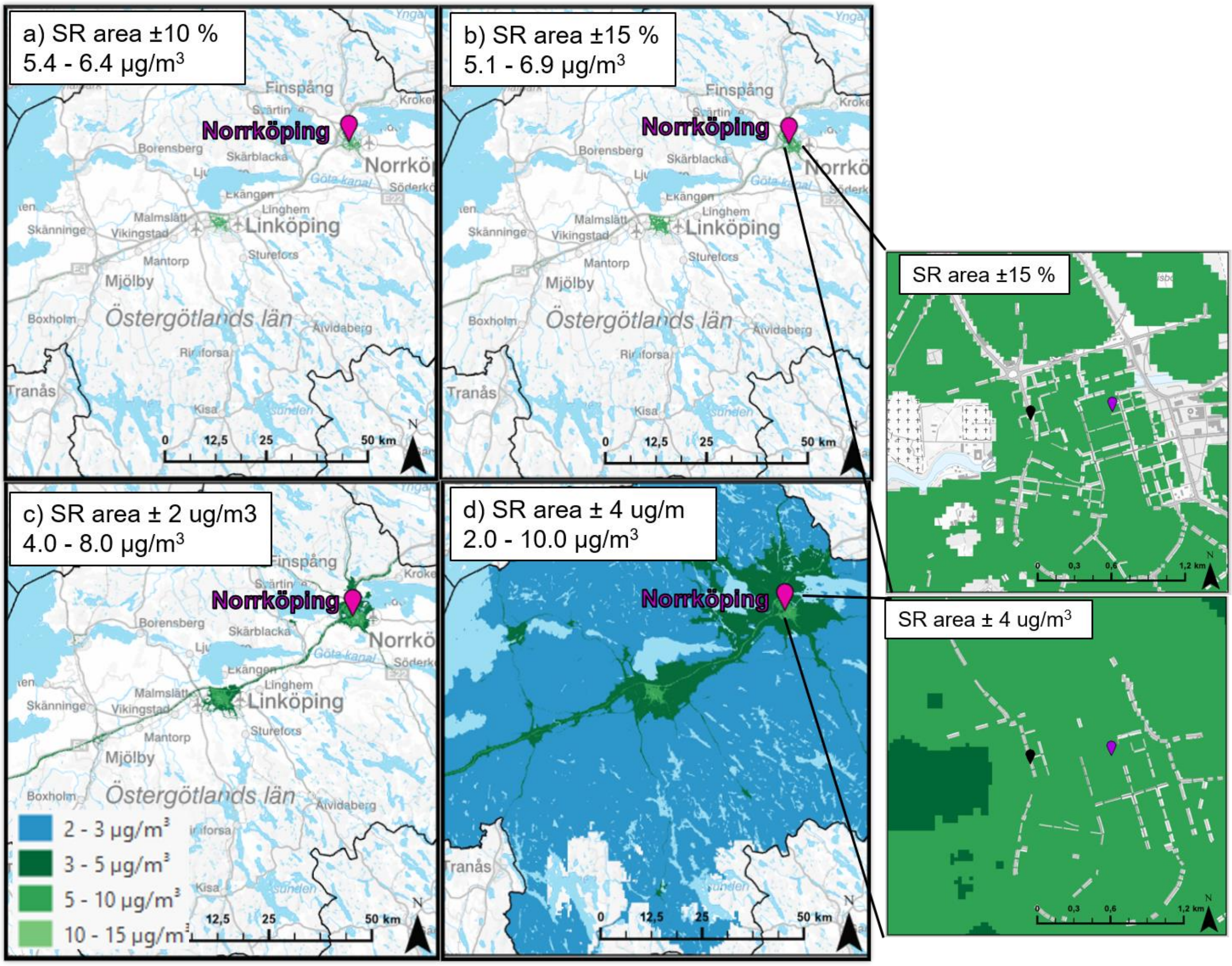


***Figure 3**. Colored areas show the SR area of NO_2 for the urban background monitoring station Trädgårdsgatan in Norrköping with a) a 10 % tolerance level and b) a ±15% tolerance level and c) a 2 µg/m^3 cut-off and d) a 4 µg/m^3 cut-off. For b) and d) the inner city of Norrköping is shown in a larger scale.*

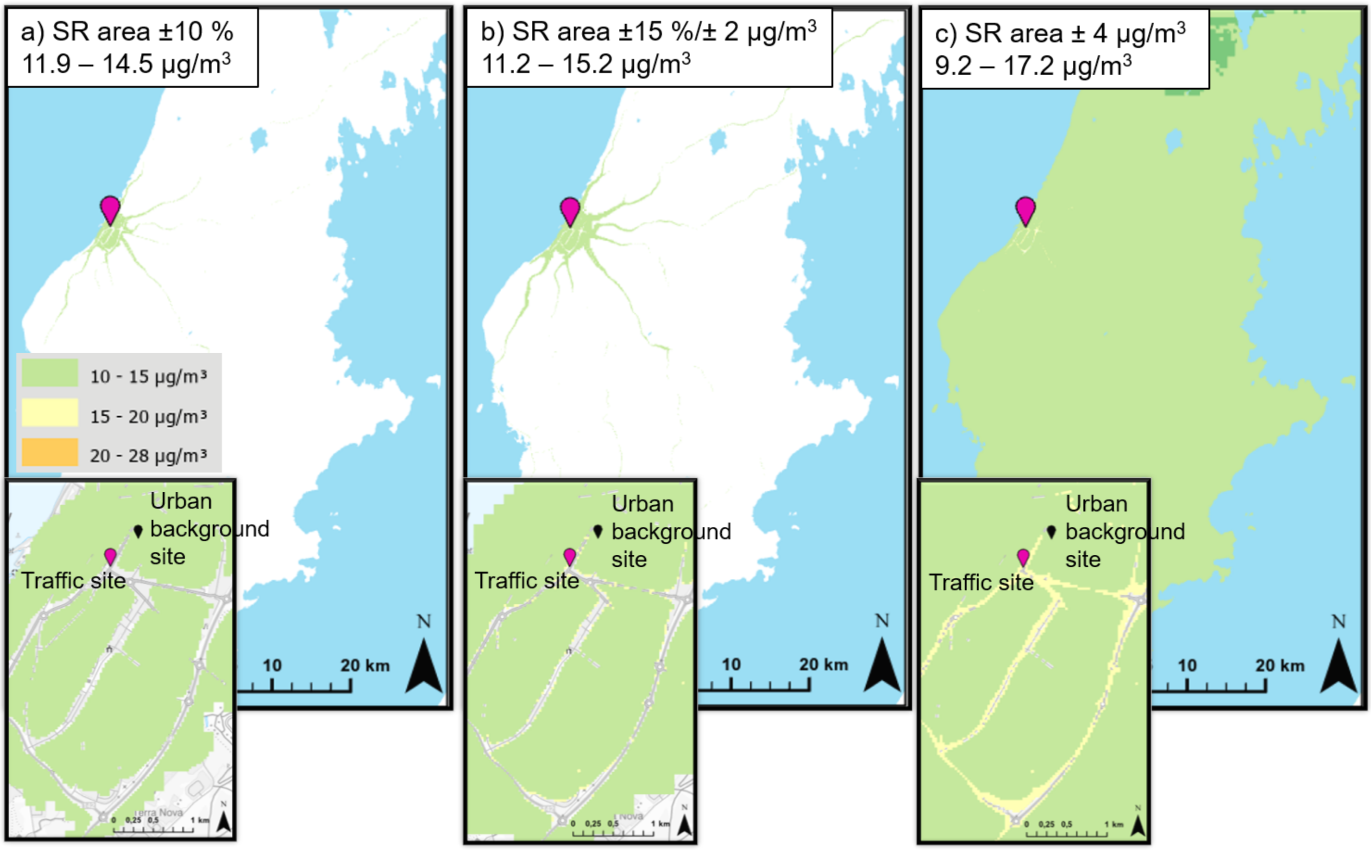


Figure 4. *Colored areas show the SR area of annual mean PM10 for the urban background monitoring station Brömsebroväg in Visby with a) a 10 % tolerance level and b) a ±15% tolerance level (equivalent to a 2 µg/m³ cut-off) and c) a 4 µg/m³ cut-off.*

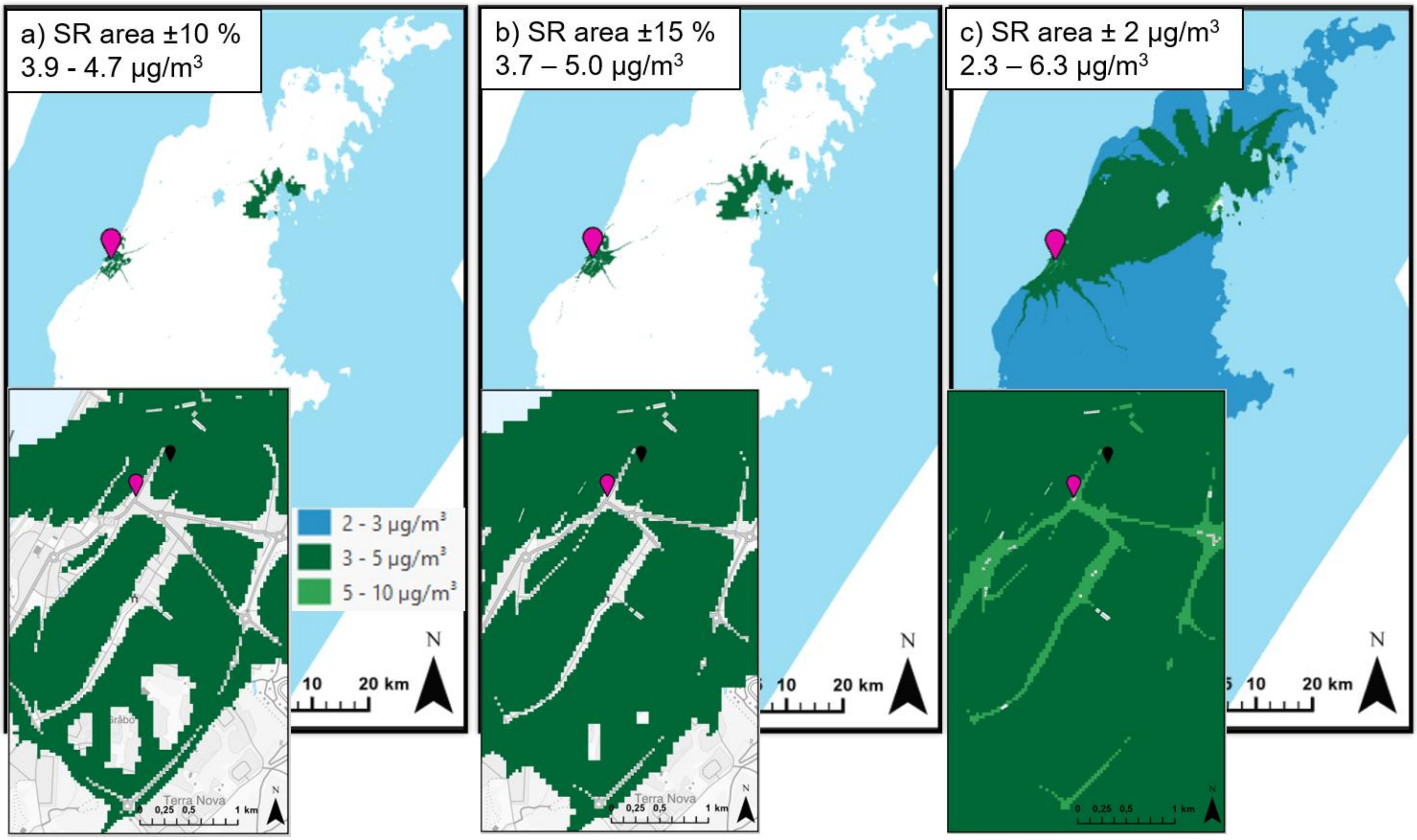


Figure 5. *Colored areas represent the SR area of annual mean NO_2 for the urban background monitoring station Brömsebroväg in Visby with a) a ±10% tolerance level and b) a ±15% tolerance level and c) a 2 µg/m³ cut-off.*

Traffic stations

For traffic or hotspot stations, the suggested tolerance levels are ±15% or ±20% with possible cut-offs of 2 and 4 µg/m^3 for NO_2. The same cut-off values were considered for PM10, as the exercise guidelines did not provide specific recommendations for PM10 cut-offs.

All four cities in this study have traffic air quality (AQ) monitoring stations. Linköping and Norrköping, located in Östergötland County within AQ zone SW2 (Middle Sweden), are midsize cities, while Visby, the largest town on the island of Gotland in AQ zone SW3 (Southern Sweden), is comparatively small. Despite this, Visby often exceeds the air quality limit for PM10 (90th percentile daily average), likely due to the use of limestone in pavements and winter road sanding as well as a high proportion of studded tires. Gävle, a midsize city in Gävleborg county, is situated in the southern part of AQ zone SW1, which covers the entire northern part of Sweden.

In this study, only the respective counties were included in the model calculations and not the entire AQ zones.

Figures 6–13 show the calculated SR areas for the traffic stations. In the city centers, the differences between the SR areas calculated at varying tolerance levels are generally small. While wider tolerance intervals include a larger number of street canyons within the SR areas, it remains unclear which tolerance level is most appropriate if only the city center is considered. Visby is an exception, where NO_2 levels are low and similar to the urban background (Figure 9). In this case, applying a lowest cut-off of 4 µg/m^3 for the NO_2 tolerance level results in an overly expansive SR area.

In several cases, highways outside the cities are included in the SR areas. In Visby, the SR area for NO_2 extends to include an industrial zone on the island's eastern side, which is undesirable. This suggests the need for additional criteria, beyond just tolerance levels, when defining the SR area.

For all tested tolerance levels, the SR area for the traffic stations in Linköping and Norrköping includes street canyons in both cities. Given that the AQ zones cover large parts of Sweden with cities of varying sizes, it is likely that, for all four cities, street canyons in other cities would also have been included in the SR area if the model domain had been larger.

It is also worth noting that, in general, only a few streets in each town are included in the SR area, while most streets are not represented by the monitoring stations using these definitions of representativeness. That is because AQ monitoring stations are located where the highest concentrations of PM10 and NO_2 are expected, rather than at the most representative locations.

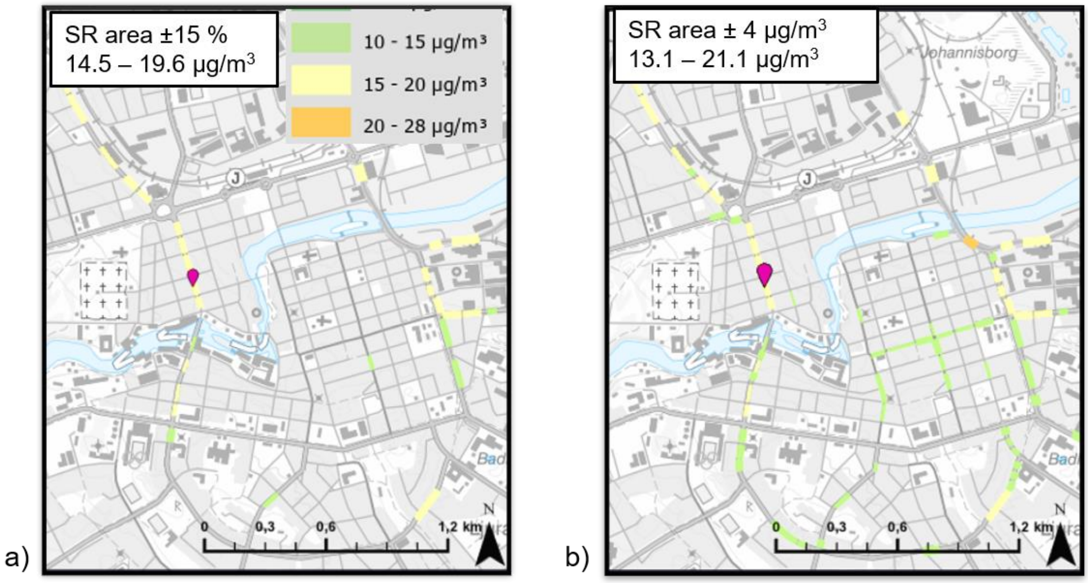


Figure 6. *The colored areas represent the SR area of annual mean PM10 for the monitoring station Kungsgatan 32 in Norrköping with a) a ±15% tolerance level and b) a 4 µg/m^3 cut-off. Using a 2 µg/m^3 cut-off does not affect the result. The ±20% tolerance level without a cut-off is not shown but yields a result between the ±15% tolerance level and the 4 µg/m^3 cut-off. Note that only the inner city of Norrköping is shown. The SR areas also include road links in Linköping as well as highways outside the cities.*

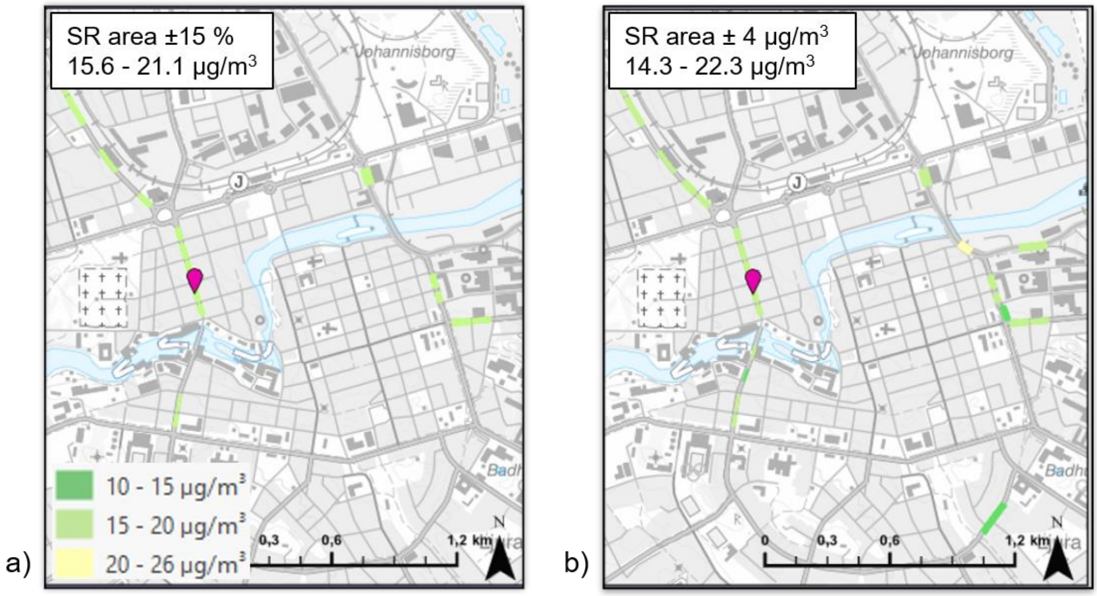


Figure 7. *The colored areas represent the SR area of annual mean NO_2 for the monitoring station Kungsgatan 32 in Norrköping with a) a ±15% tolerance level and b) a 4 µg/m^3 cut-off. Using a 2 µg/m^3 cut-off does not affect the result. The ±20% tolerance level without a cut-off is not shown but yields a result between the ±15% tolerance level and the 4 µg/m^3 cut-off. Note that only the inner city of Norrköping is shown. The SR area also includes road links in Linköping for all tolerance levels.*

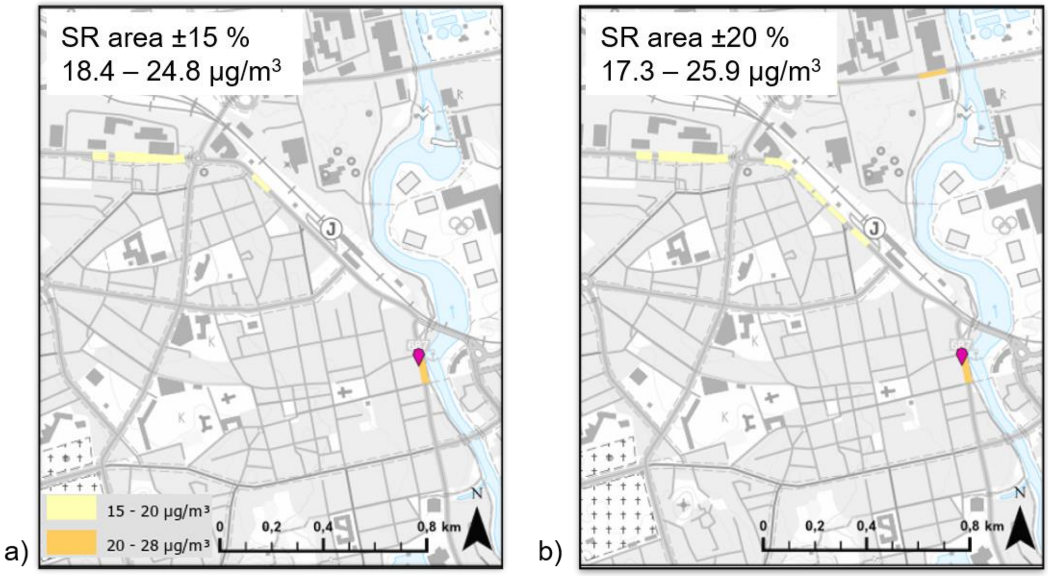


***Figure 6**. The colored areas represent the SR area of annual mean PM10 for the monitoring station Hamngatan 10 in Linköping with a) a ±15% tolerance level and b) a ±20% tolerance level. Using a 2 µg/m³ cut-off does not affect the result. Using a 4 µg/m³ cut-off would affect the ±15% tolerance level, giving a result between the ±15% tolerance level without cut-off and the ±20% tolerance level. A few road links in the city of Norrköping is also included in the SR area, but not shown above.*

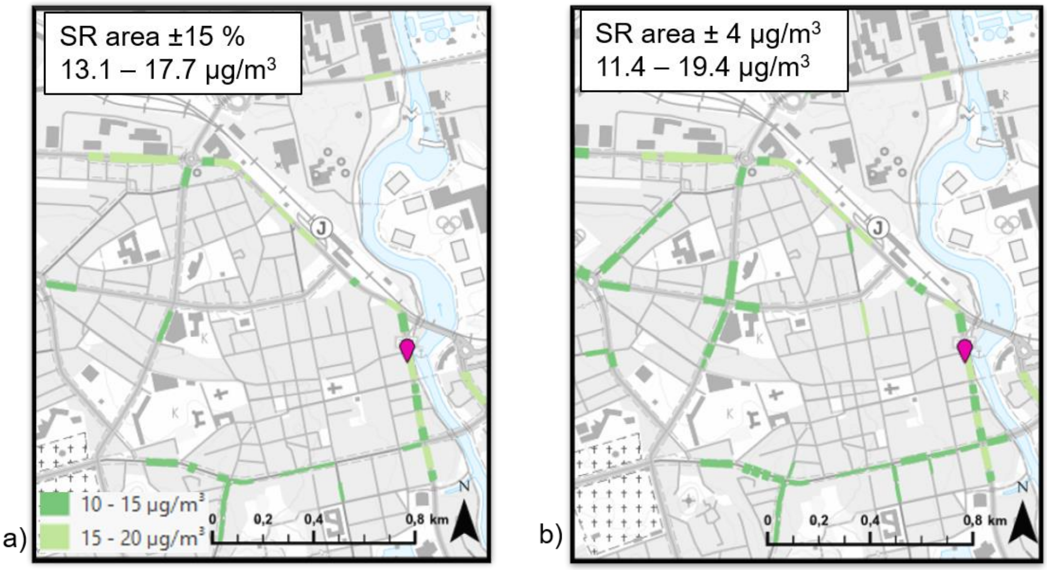


***Figure 7.** The colored areas represent the SR area of annual mean NO_2 for the monitoring station Hamngatan 10 in Linköping with a) a ±15% tolerance level and b) a 4 µg/m³ cut-off. Using a 2 µg/m³ cut-off does not affect the result. The ±20% tolerance level is not shown, but the result is very similar to the 4 µg/m³ cut-off in the inner city of Linköping. For all tolerance levels, road links in Norrköping is also included in the SR area. Using a 4 µg/m³ cut-off results in street canyons in smaller towns as well as highways also becomes included in the SR area.*

Figure 8. *The colored areas represent the SR area of annual mean PM10 for the monitoring station Österväg in Visby with a) a ±15% tolerance level and b) a ±20% tolerance level. Using a 2 µg/m^3 cut-off does not affect the result. Using a 4 µg/m^3 cut-off would affect the ±15% tolerance level and yields a result between the ±15% tolerance level without cut-off and the ±20% tolerance level. One road link in the small town of Hemse is also included in the SR area (not shown).*

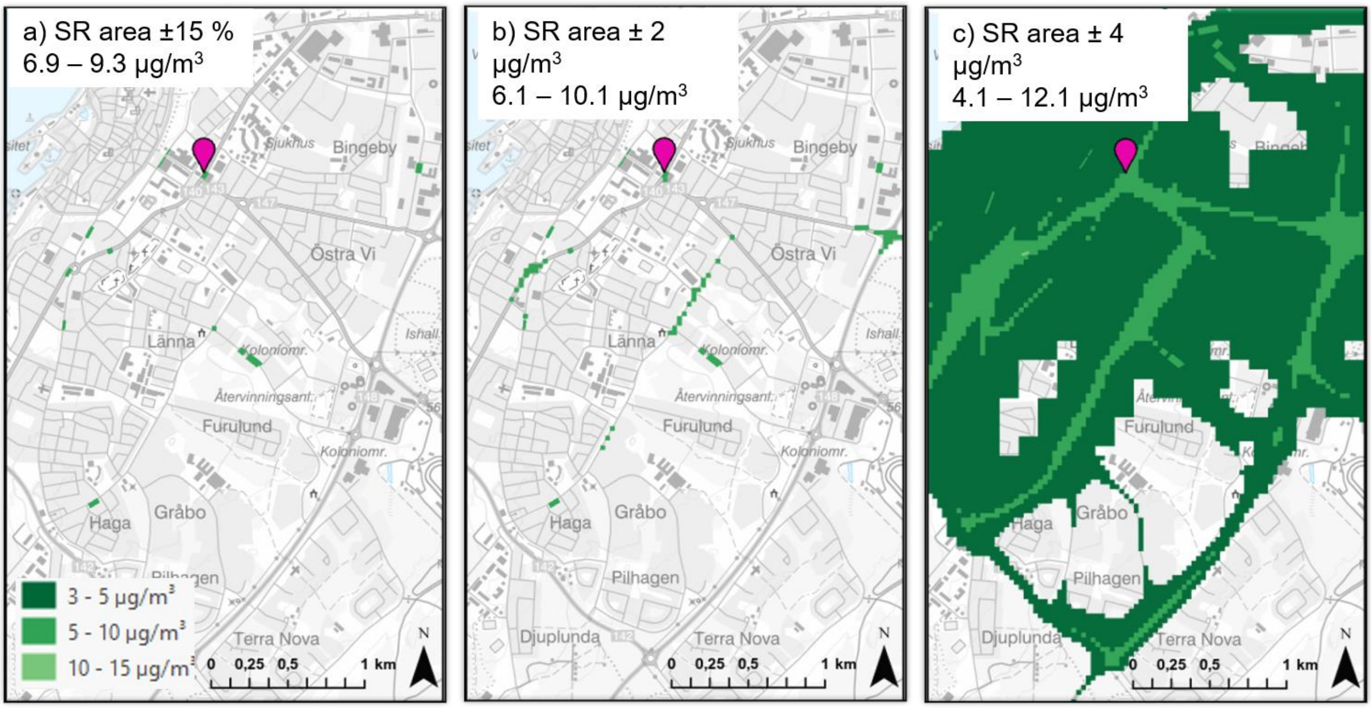


Figure 9 *The colored areas represent the SR area of annual mean NO_2 for the monitoring station Östeväg in Visby with a) a ±15% tolerance level and b) a 2 µg/m³ cut-off and c) a 4 µg/m³. Not shown is the ±20% tolerance level without a cut-off, which would yield a SR area falling between the SR area with a ±15% tolerance level without cut-off and the SR area using a 2 µg/m³ cut-off. For all tolerance levels, the SR area also encompasses a substantial portion of an industrial region in the eastern part of the island Gotland.*

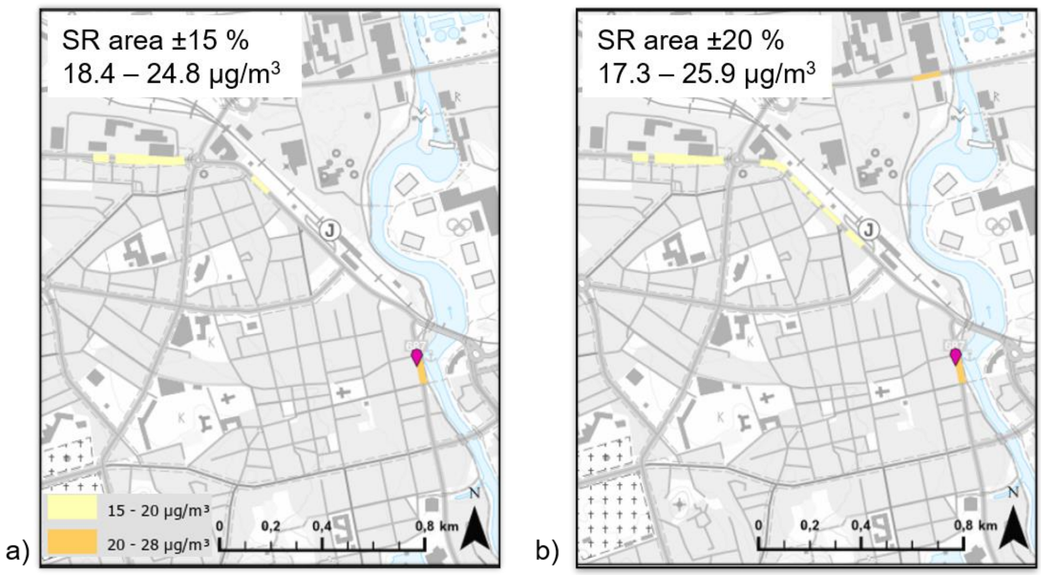


Figure 12. *The colored areas represent the SR area of annual mean PM10 for the monitoring station Staketgatan 22 in Gävle with a) a ±15% tolerance level and b) a ±20% tolerance level (which is the same as using a 4 µg/m³ cut-off). Using 2 µg/m³ cut-off does not alter the results. A few highways (not shown) are also included in the SR area with a ±20%/±4 µg/m³ tolerance level.*

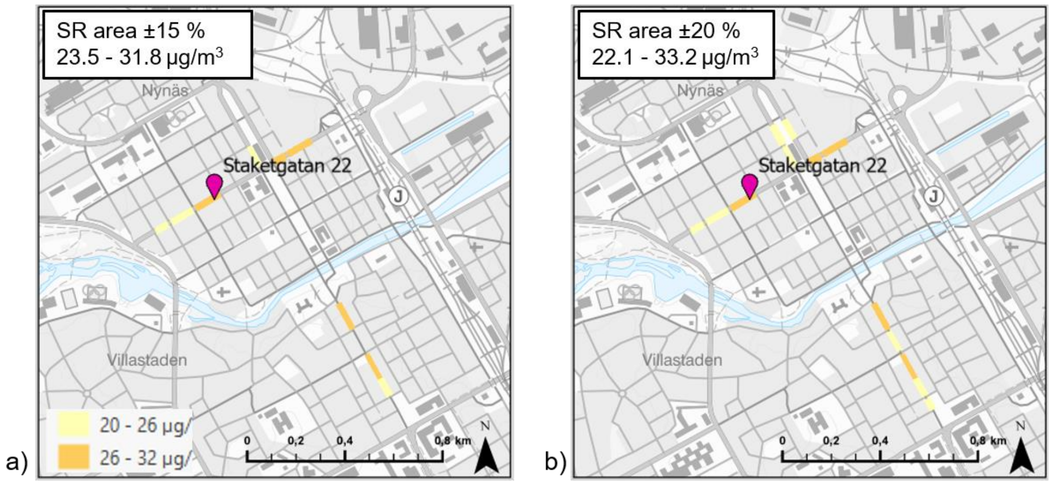


Figure 13. *The colored areas represent the SR area of annual mean NO_2 for the monitoring station Staketgatan 22 in Gävle with a) a ±15% tolerance level and b) a ±20% tolerance level. Using 2 or 4 µg/m^3 cut-off does not alter the results.*

Differences in the SR areas using annual mean vs relevant percentile(s)

Calculating SR areas using the 90th percentile daily mean for PM10 or the 98th percentile daily mean for NO_2 yields results similar to those obtained with the annual mean (not shown). This similarity likely arises from the daily mean being derived from the annual mean, using an empirical formula rather than through time-series model calculations. Applying identical lowest cut-offs for annual and daily averages naturally produces different results, as daily averages tend to be higher.

Conclusions

This study evaluates the proposed methodology by FAIRMODE Working Group 8 for defining spatial representativeness (SR) of air quality monitoring stations. We examined SR areas for stations in four midsize Swedish cities under varied tolerance levels and cut-offs for PM10 and NO_2. The results indicate that the suggested tolerance levels produce reasonable SR areas for some conditions but are less suitable for others.

There was not such a large difference in SR areas using tolerance levels of ±15% or ±20% for traffic stations within the cities. However, the SR areas often include highways and/or other cities or municipalities, which is questionable. This indicates a need for additional criteria, such as limiting the SR area boundaries to within the city limits. Other potential criteria could include road type (e.g., street canyon, motorway) or area type (e.g., urban, industrial, rural).

For background stations in Sweden, a lower tolerance level, such as ±5% or ±10%, appears more appropriate, as the difference between regional and urban background pollution levels can be small in Sweden. Using cut-offs can be particularly problematic for background stations, as these cut-offs may inadvertently expand SR areas beyond relevant urban boundaries.

Furthermore, zone-based limits are also less useful in Sweden, given that the air quality zones cover such large areas.

Calculations for SR areas using annual means and percentile-based metrics yield similar results. However, this could be an artifact of deriving daily means through empirical formulas rather than time-series modeling.

References

[1] Airviro Dispersion - Airviro. https://www.airviro.com/airviro/modules/dispersion/dispersion-1.6846.

[2] Operational Street Pollution Model (OSPM) - Aarhus University - Department of Environmental Science. https://envs.au.dk/en/research-areas/air-pollution-emissions-and-effects/the-monitoring-program/air-pollution-models/ospm/.

[3] Haggmark L, Ivarsson K-I, Gollvik S, Olofsson P-O. Mesan, an operational mesoscale analysis system. Tellus A **52**:2–20 (2000). https://doi.org/10.1034/j.1600-0870.2000.520102.x.

[4] Luftföroreningar i Östra Sveriges Luftvårdsförbund - Utsläppsdata för ABCDEIX-län år 2020. SLB-analys; 2022. Rapportnummer SLB 2:2022. https://www.slbanalys.se/slb/rapporter/pdf8/slb2022_002.pdf.

[5] HBEFA - Handbook Emission Factors for Road Transport. https://www.hbefa.net/e/index.html.

[6] Denby BR, Sundvor I, Johansson C, Pirjola L, Ketzel M, Norman M, et al. A coupled road dust and surface moisture model to predict non-exhaust road traffic induced particle emissions (NORTRIP). Part 1: Road dust loading and suspension modelling. Atmospheric Environment **77**:283–300 (2013). https://doi.org/10.1016/j.atmosenv.2013.04.069.

[7] Denby BR, Sundvor I, Johansson C, Pirjola L, Ketzel M, Norman M, et al. A coupled road dust and surface moisture model to predict non-exhaust road traffic induced particle emissions (NORTRIP). Part 2: Surface moisture and salt impact modelling. Atmospheric Environment **81**:485–503 (2013). https://doi.org/10.1016/j.atmosenv.2013.09.003.

[8] Användning av dubbdäck i Stockholms innerstad, vintersäsongen 2019/2020. SLB-analys; 2020. Rapportnummer SLB 25:2020. https://www.slb.nu/slb/rapporter/pdf8/slb2020_025.pdf.

[9] Undersökning av däcktyp i Sverige – vintern 2022 (januari–mars). Trafikverket; 2022. Rapportnummer 2022:128. http://trafikverket.diva-portal.org/smash/get/diva2:1698191/FULLTEXT01.pdf.

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APPENDIX 4

Feedback and results from Environment Agency Austria (Umweltbundesamt GmbH) based on the FAIRMODE WG8 checklist for further testing of spatial representativeness of measurement stations

General information

Country / Zone / City:

Austria

- Salzburg (city)
- Graz (city)
- Enns valley around Liezen (rural area)

Measurement station & description:

All Monitoring stations are included. Inlet height around 4 m.

Pollutant:

NO_2, PM_{10}

Year:

NO_2: 2019

PM_{10}: 2013

Type of model(s) used (e.g. Gaussian, OSPM, Lagrangian, CFD, etc):

GRAMM/GRAL Langrangian model, chemical transport model, developed by Technical University Graz[3]

Model scale / resolution:

spatial resolution 10 m.

Bias adjustment? (data fusion / data assimilation):

no

What to test?

- *Differences in the SR areas with different tolerance levels:*
  10 % or 15 % for background stations, 15 % or 20 % for hotspot/traffic stations
- *Differences in the SR areas with different lower cut-offs 2 or 4 µg/m³*
- *15 % irrespective of the concentration levels (i.e. even for very low concentrations)*

Important considerations

Comments on the scale of gaps in existing monitoring networks when the different criteria above are applied. I.e. how large are the areas in a city / zone that are not covered by the SR areas of the zone's measurement stations? Are these gaps in the networks considered reasonable and can the information be useful to guide network design & evaluation?

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[3] https://gral.tugraz.at/

Other important comments for consideration? (e.g. source-related issues)

Data used

Station	Type[1)]	Area[2)]	NO_2 (µg/m³)
Salzburg[3)] Lehen	B	S	20.6
Salzburg Mirabellplatz	T	U	23.0
Salzburg Rudolfsplatz	T	U	36.9
Graz[3)] Don Bosco	T	U	38.6
Graz Mitte	B	U	26.7
Graz Nord	B	S	19.3
Graz Ost	T	U	24.6
Graz Süd	B	S	25.6
Graz West	B	S	23.4
Liezen[3)]	B	S	14.6
Klöch (415 m)	B	R	6.9
Masenberg (1180 m)	B	R	3.0

[1)] B: background, T: traffic

[2)] U: urban, S: suburban, R: rural

[3)] Salzburg: 157 000 inh., Graz: 303 000 inh., Liezen: 8000 inh.

Results - examples

Figure 1: NO_2 Salzburg

Green: Salzburg Lehen; orange: Salzburg Mirabellplatz, red: Salzburg Rudolfsplatz

±10% (B),± 20% (T); lower cut-off±2 µg/m³ ±15% (all); lower cut-off±2 µg/m³

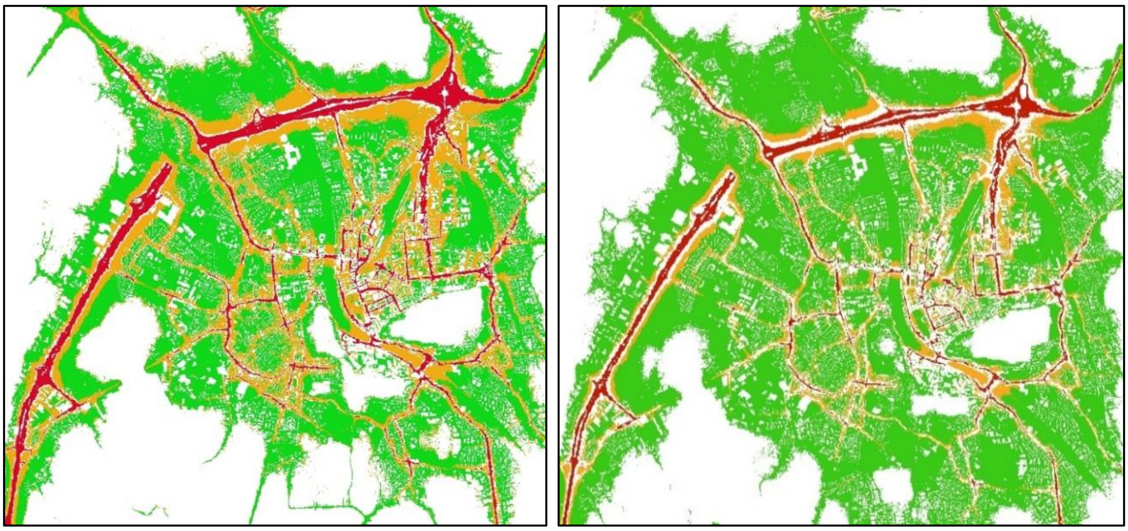
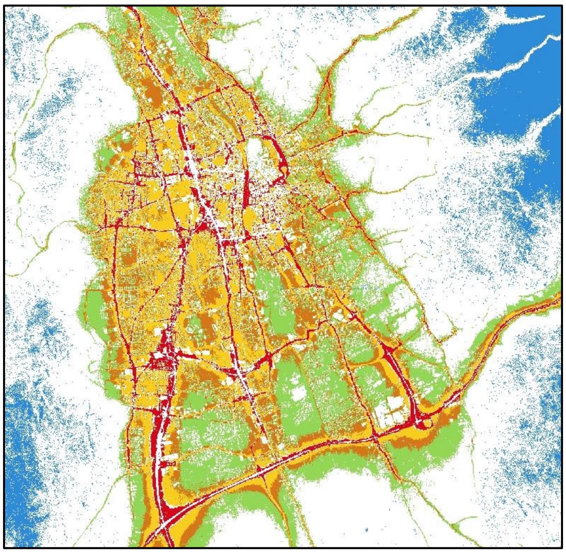


Figure 2: NO_2 Graz

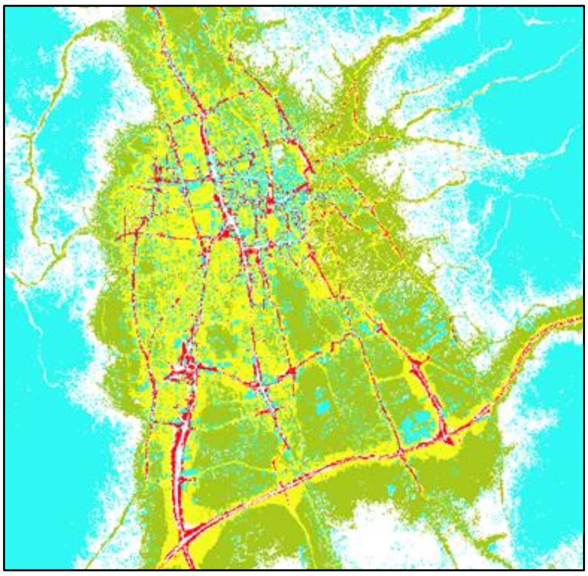
Blue: Klöch; green: Graz Nord; yellow: Graz Mitte; orange: Graz Ost; red: Graz Don Bosco.

±10% (B),± 20% (T); lower cut-off±2 µg/m³



±15% (all); lower cut-off±2 µg/m³

±15% (all); lower cut-off±4 µg/m³ [1)]

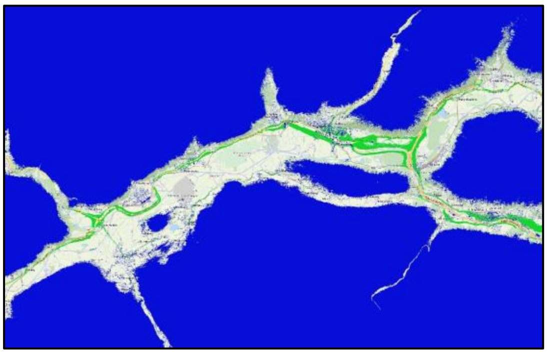


[1)] Note: Due to an artefact in the model data, grid cells without values (i.e. in fact buildings) have a small uniform concentration value and therefore look like a part of the representative area of the rural station Klöch.

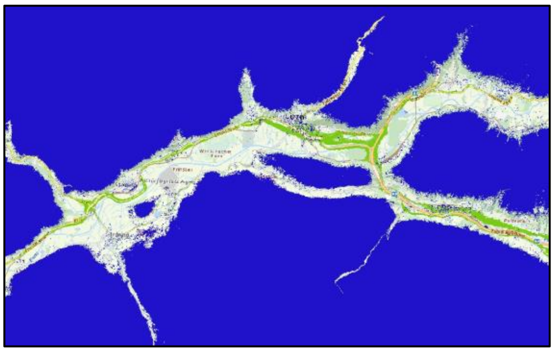
Figure 3: Enns valley around Liezen

Blue: Masenberg; green: Liezen.

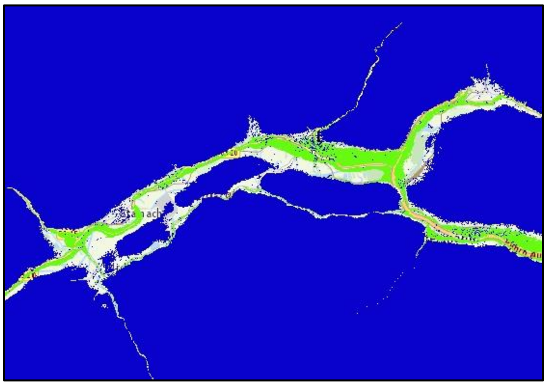
±10% (B),± 20% (T); lower cut-off±2 µg/m³



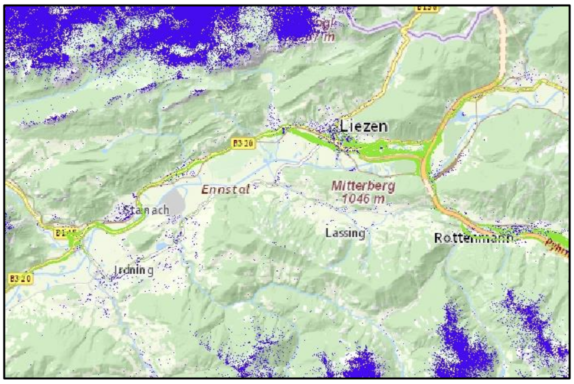
±15% (all); lower cut-off±2 µg/m³



±15% (all); lower cut-off±4 µg/m³



±15% (all)



<u>Conclusions:</u>

There is not much difference in representative areas for ±10% (background), ±20% (traffic, industrial) on one hand and uniform ±15% for all station types.
±15% yields more overlaps of urban and suburban stations.

A lower cut-off of ±2 µg/m³ for NO_2 leaves large gaps between the (existing) suburban and rural stations. ±4 µg/m³ for NO_2 yields almost complete coverage by (existing) stations.
For PM_{10}, a lower cut-off of±2 µg/m³ yields almost complete coverage by (existing) stations.

A uniform tolerance of ±15% even for lower concentrations yields very narrow representative areas in the low concentration range and very large gaps between (existing) stations.

APPENDIX 5

FAIRMODE WG8 – Spatial representativeness

Feedback from Environment Agency Austria (Umweltbundesamt GmbH) on additional criteria for spatial representativeness of air quality monitoring stations

1. Additional source-orientated criteria for delimiting spatial representative areas (SRAs):
   Separate areas with similar concentrations, where levels are determined by different major sources:
   - Kerb-side Motorways –kerb-side urban roads
   - Urban background – surroundings of motorways
   - industrial emissions

2. Delimitation of SRAs of rural (regional) background sites: Not by zone boundaries, but according to topographic/climatic characteristics.

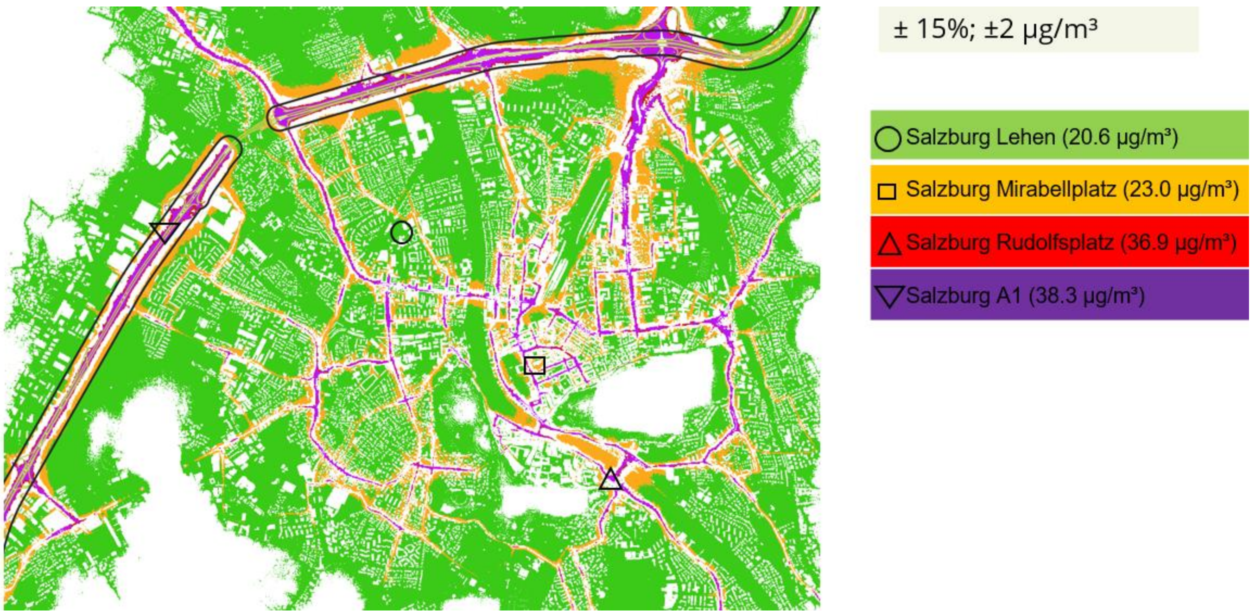
General criteria for representative areas (as agreed last year, 2024):
Annual mean ± 15 %
Lower concentration interval (NO_2, PM_{10}): ± 2 µg/m³

Data used for examples
NO_2 model data (model GRAM/GRAL; Langrangian model, chemical transport model, developed by Technical University Graz, https://gral.tugraz.at/)

Areas: Salzburg (city), Styria (whole province)
Spatial resolution 10 m
Reference year 2019.

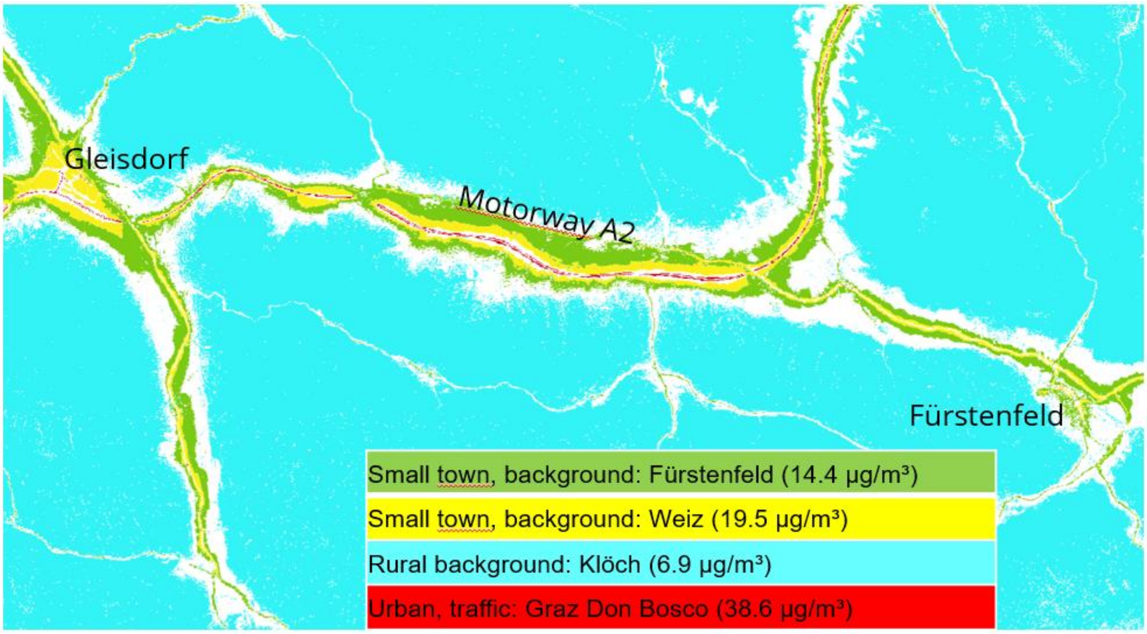
Discussion of representative areas near motorways

Figure 1: NO_2 Salzburg, representative areas of the monitoring sites Salzburg Lehen, Salzburg Mirabellplatz (urban background), Salzburg Rudolfsplatz (central urban traffic) and Salzburg A1 (motorway) (Source: Amt der Salzburger Landesregierung; Environment Agency Austria)



The representative areas of Salzburg Rudolfsplatz (central urban kerb-side; red) and Salzburg A1 (motorway; violet) largely overlap.
The black lines indicate the area immediately influenced by the motorway (up to 100 m distance).

Figure 2: NO_2 Styria, region east of Graz, representative areas of Fürstenfeld and Weiz (urban background, small towns), Klöch (rural background) and Graz Don Bosco (central urban, traffic) (Source: Amt der Steiermärkischen Landesregierung; Environment Agency Austria)



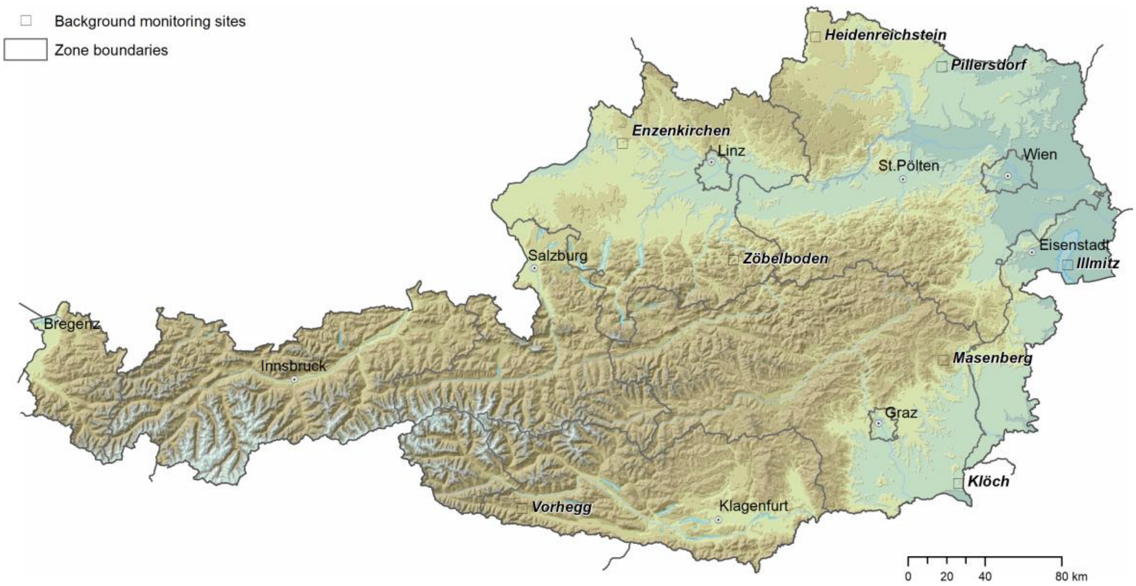
The representative areas of background sites in small towns cover large areas in the surroundings of the motorway A2 and of major rural roads.

Proposed additional criteria:
With respect to different sources, different measures, and different trends, even in case of similar concentrations

1. Urban kerb-side stations should not be considered representative for kerb-side stations at motorways
2. Urban or suburban background stations should not be considered representative for areas near motorways and major rural roads.

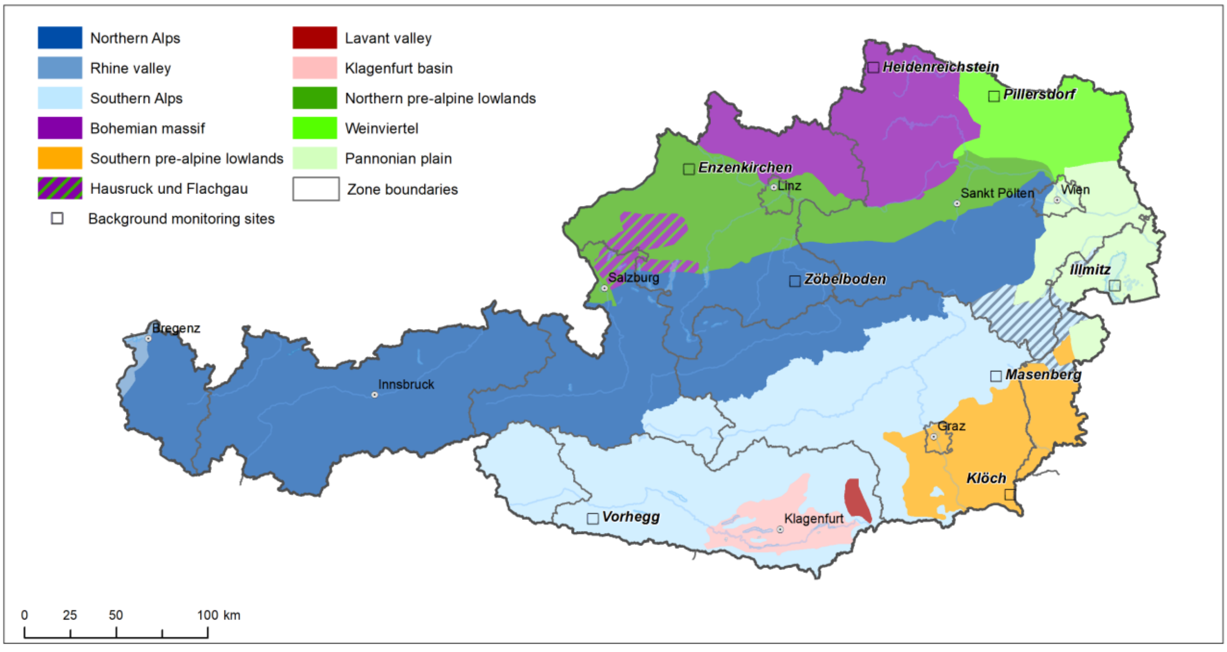
Discussion of representative areas of rural (regional) background sites

Figure 3: Topography of Austria (Source: Environment Agency Austria)



Based on topographical units and climatic conditions, the following regions with different dispersion characteristics have been delimited.

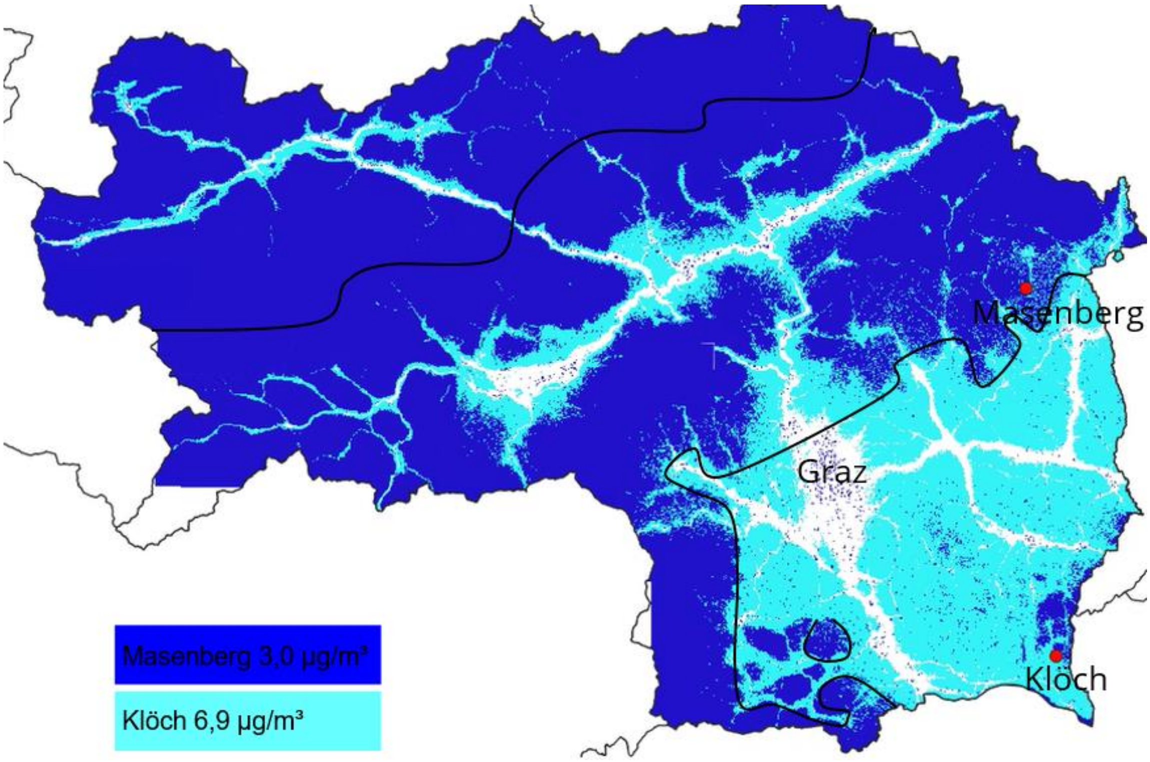
Figure 4: TopographicAl/Climatic Regions and rural background sites (Source: Environment Agency Austria).



It is proposed to confine the representative areas of rural (regional) background sites not by zone boundaries, but by topographical/climatic regions.

Otherwise, additional rural background sites might be necessary.

Figure 5: NO_2 Styria, representative areas of the rural background sites Klöch and Masenberg (Source: Amt der Steiermärkischen Landesregierung; Environment Agency Austria).



White areas: Concentrations higher than in Klöch + 2 µg/m³.[1)]

[1)] Note: Due to an artefact in the model data, grid cells without values (i.e. buildings) have a small concentration value and therefore are shown in dark blue.

The representative area of Klöch (445 m) and Masenberg (1137 m) - which do almost not overlap - cover the rural areas either in the southern pre-alpine lowlands and in the elevated alpine area (both south and north of the central divide).

The boundary between the southern pre-alpine lowlands and the southern Alps largely corresponds with the limit between the representative areas of Klöch and Masenberg.

Within the Alps, some areas show concentrations fulfilling the representativeness criteria for Klöch, which do not represent a regional scale background concentration of large-scale flat or hilly terrain. These are mountainous areas influenced by emissions of the agglomeration Graz and of major valleys, and the bottom of valley with low population density, i.e. by different conditions for pollution transport and dispersion.

Therefore it is proposed to delimit representative areas of rural background sites at least along the boundaries of alpine and non-alpine regions. Representative areas might overlap in alpine areas (north/south of the central divide) and in non-alpine hilly areas.

In alpine areas, representative areas of rural background sites are, in any case, altitude dependant.

In addition, a criterion for the maximum spatial extent of representative areas of rural background sites should be applied.

It is questionable if e.g. Zöbelboden (990 m) is representative for the whole northern alpine region (with an west-east extension of almost 600 km). This issue might be even more relevant in large countries with large-scale uniform landscape (e.g. Poland, northern Germany).

After the recent discussion, a maximum radius of 200 km is suggested.

APPENDIX 6

Testing Spatial Representativeness of Monitoring Stations in Germany

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Content

1. Modelling system for air quality assessment on national level

1.1. General Model Description

For several years, the chemistry transport model REM-CALGRID (RCG; Stern, 2003) is operated at UBA to analyse the air quality retrospectively and in scenarios. Based on a comprehensive set of input data, RCG is simulating the underlying physical and chemical processes during the transport of gaseous components and particles in the atmosphere. The processes of emission and deposition are also considered. Particles are treated mass based with several PM-components like OC, EC, SIA and SOA in size fraction <2.5µm and <10µm. Processes causing natural emissions of sea-salt and natural dust are also contributing to PM. In the gas phase, a carbon bond mechanism (CBM-IV) is applied and photochemistry is calculated.

RCG is operated on a geographical grid and in nesting mode to calculate the air quality for Germany on a 2 km x 2 km grid. Therefore, the outer domain covers Europe with a resolution of approximately 35 km x 25 km. From the concentrations simulated in the Europe-domain, boundary conditions (side and top) are extracted for the next nesting step that covers Germany and parts of the surrounding countries in 8 km x 7 km. The simulation results of this domain, are used as boundary conditions for the final domain covering the Federal Republic of Germany. In the vertical dimension, the model considers only parts of the troposphere up to a height of 4 km. Air pollutants present in layers above 4 km are assumed to play a minor role for the surface concentrations but might be considered via the top boundary conditions of the outer domain. The RCG modelling system is also operated for smaller domains covering single German states at a higher horizontal resolution of 0.5 km x 0.5 km.

The RCG model is optimised to be applied for the national air quality assessment and planning and is therefore reduced in complexity. Its main purpose is to deliver the classical air pollutants considered in the ambient air quality directive in the required temporal aggregations. Complex processes like the development of the size distribution of particles and the underlying physics are not considered. The model is not parallelised and can therefore be operated on every PC. However, to calculate the air quality for whole Germany in 2 km x 2 km the annual model run is split into 20 temporal overlapping parts of 2-3 weeks. These parts are then calculated in parallel and therefore more computational resources are needed. The results of the RCG modelling system are combined with measurements by using the method of optimal interpolation (OI). Some resulting maps for the period 2000 – 2023 are shown the appendix (Figure A1 – Figure A4).

1.2. Input Data

The meteorological driver is taken from the ICON models operated by the German Meteorological Service (Deutscher Wetterdienst, DWD). The two outer RCG-domains are driven by using meteorological input of the ICON-EU and the inner domain with data of the ICON-D2[4] model with a horizontal resolution of approximately 2 km x 2 km. There is no feedback from air pollutants to the meteorology.

Another important input dataset is the information of anthropogenic emissions. In Germany, this data is derived from the Gridding Emission Tool for ArcGIS (GRETA, Schneider et al. 2016). The gridded

[4] https://www.dwd.de/DE/leistungen/modellvorhersagedaten/modellvorhersagedaten.html

primary emissions are based on the reported national total emissions of the pollutants PM_{10}, $PM_{2.5}$, NO_x, SO_2, NH_3, CO and NMVOC. The European emissions outside of Germany are taken from the Copernicus atmosphere monitoring service (CAMS[5]). Specific VOC emissions are derived by country- and sector-specific splitting factors delivered with the CAMS dataset. Emissions of $PM_{2.5}$ are split into different components such as EC and OC also by predefined factors. Furthermore, emissions of B[a]P are calculated as fractions of EC.

The temporal profiles are currently static monthly, weekly and daily cycles per country and emission sector. In the future, a more dynamic approach will be applied using additional information connected to the temporal behaviour of emission sources e. g. operation time of power plants.

The RCG model can be operated using different boundary conditions. The easiest way of selection boundary conditions is to use a given climatology to derive the concentrations of air pollutants at the boundary of the European domain. This method is commonly in operation. There is also the possibility to run RCG with boundary conditions of the CAMS EAC4 global model. With this option, long range or even intercontinental transport of air pollutants is much better represented than using a predefined climatology. Another option is the use of air pollutant concentrations from the CAMS regional models directly at the boundaries of the high-resolution inner domain.

There is a variety of additional input datasets to describe the situation in the modelling domain e. g. land-cover data, tree species map, topography, soil type etc.

1.3. Model Evaluation

The RCG modelling system was evaluated for the model run 2022 with and without data fusion (Optimal Interpolation, see chapter 2.5) by using the officially reported rural, suburban and urban background measurements in Germany. For NO_2, the model underestimates the concentration by ~25%. The FAIRMODE MQI is fulfilled for hourly (0.61) and annual (0.77) values of MQI. For $PM_{2.5}$ the model underestimates the background concentrations by ~35%. Despite the relatively high Bias, the RCG fulfils the MQI with 0.69 on daily basis and 0.62 for annual values. It is well known in the FAIRMODE community, that MQI for $PM_{2.5}$ is not stringent enough. For PM_{10}, the Bias is around -10% and MQI is fulfilled with 0.88 (daily) and 0.68 (annual). Especially for PM, Bias values are not evenly distributed over the domain of Germany. There is a tendency to a higher Bias in the Eastern region of Germany.

The results of the optimal interpolation were evaluated with a of leave-one-out cross validation. The results indicate that the Bias for NO_2, PM_{10} and $PM_{2.5}$ was reduced with OI to values lower than 10 % and MQI was further improved in comparison to the raw model results.

The evaluation was extended to simulated BaP concentrations. The model underestimates the measured concentration by 50% on annual averages. Despite this large uncertainty in modelled values, MQI according to the new ambient air quality directive is fulfilled, due to the low concentration range of this pollutant observed in Germany with an average of 0.13 µg/m³ at background sites. The observed values are therefore much smaller than the maximum uncertainty at the limit value (0.5 µg/m³) as input into the MQI equation. According to the Technical support document on the use of modelling for various application domains under the Ambient Air Quality Directive (Third Draft), it is

[5] https://atmosphere.copernicus.eu/

assumed that the maximum uncertainty at the limit value stays constant below the limit value. With these assumptions, MQI as defined in the new directive, is not suitable for the evaluation of modelling quality in regions with very low concentrations of BaP.

Beside the comparison with observations, the RCG-modelling system was recently compared to other chemistry transport models for Germany (Thürkow et al., 2024).

2. Spatial representative area - examples of good practices

The present work has been done in the framework of FAIRMODE WG8 activity and represents a case study of the spatial representativeness definition. For this exercise we use the national modelling system RCG in 2x2km² resolution as described in chapter 1.

Due to the model resolution, only rural and urban background stations were considered in this exercise.

Following the latest recommendations of the Technical support document on the use of modelling for various application domains under the Ambient Air Quality Directive (Third Draft), we applied the following setting to derive the spatial representative areas (SRA) of sampling points (SPO).

- Annual mean concentrations of the year 2022
- 15 % tolerance level for all station types
- Modelled concentrations at the location of the sampling point
- Geographical area include non-contiguous domains
- Minimum tolerance level
  - PM_{10}, NO_2, O_3: +- 2µg/m³
  - $PM_{2.5}$, Benzene: +- 1µg/m³
  - BaP: +- 0.2 ng/m³
- Air quality zones for 2022

The following figures show the results, where coloured grid cells are covered by the SRA of at least one SPO. Areas, which are uncovered, are plotted in white colour. Uncovered areas with modelled concentration values below the assessment thresholds are shown in red.

2.1 SRA results based on RCG modelling system for Germany

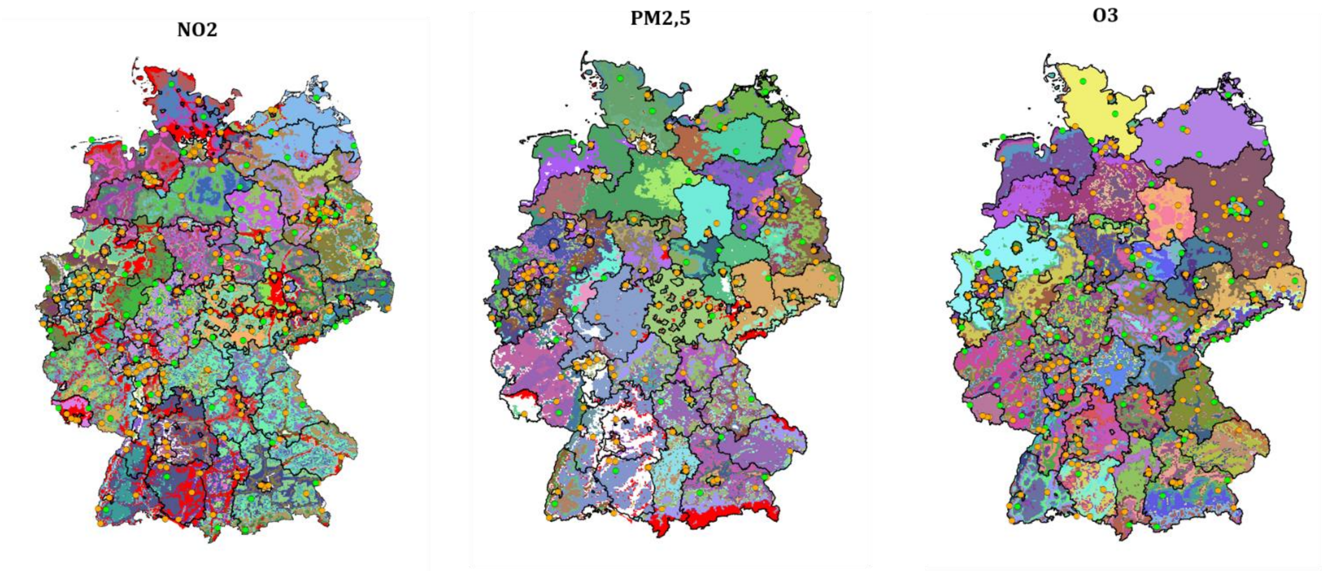

Figure 1: Calculated SRA for NO_2, $PM_{2.5}$ and Ozone using RCG modelling system (year 2022); coloured areas: grid cells with SRA of at least one sampling point; white areas: not covered by SPO; red areas: not covered by SPO but concentrations below assessment threshold; orange dots: urban SPO; green dots: rural SPOs

Figure shows the results of the SRA for the pollutants NO_2, $PM_{2.5}$ and ozone for the year 2022. In general, most of the German domain is covered by the SRA of the SPOs using the current network design. For NO_2, some rural areas with very low modelled concentrations below the assessment threshold (see 2024/2881 Annex II) are not covered (red coloured grid cells). For $PM_{2.5}$ some areas in southern Germany and Saarland are not covered. These areas have to be analysed in detail regarding network design (missing SPO or uncovered concentration range). Due to the higher concentration level of ozone, all areas are covered by SRA of the SPOs.

Conclusion / recommendation:

Following the requirements of the AAQD and the guidance's step-by-step methodology, most areas of Germany are covered by the SRA of the rural and urban background stations using the current network design and zone delineation.

Due to the new requirements of the AAQD, it could be necessary to adjust the current monitoring network design. Based on the first results of SRA the German Länder start this re-design process.

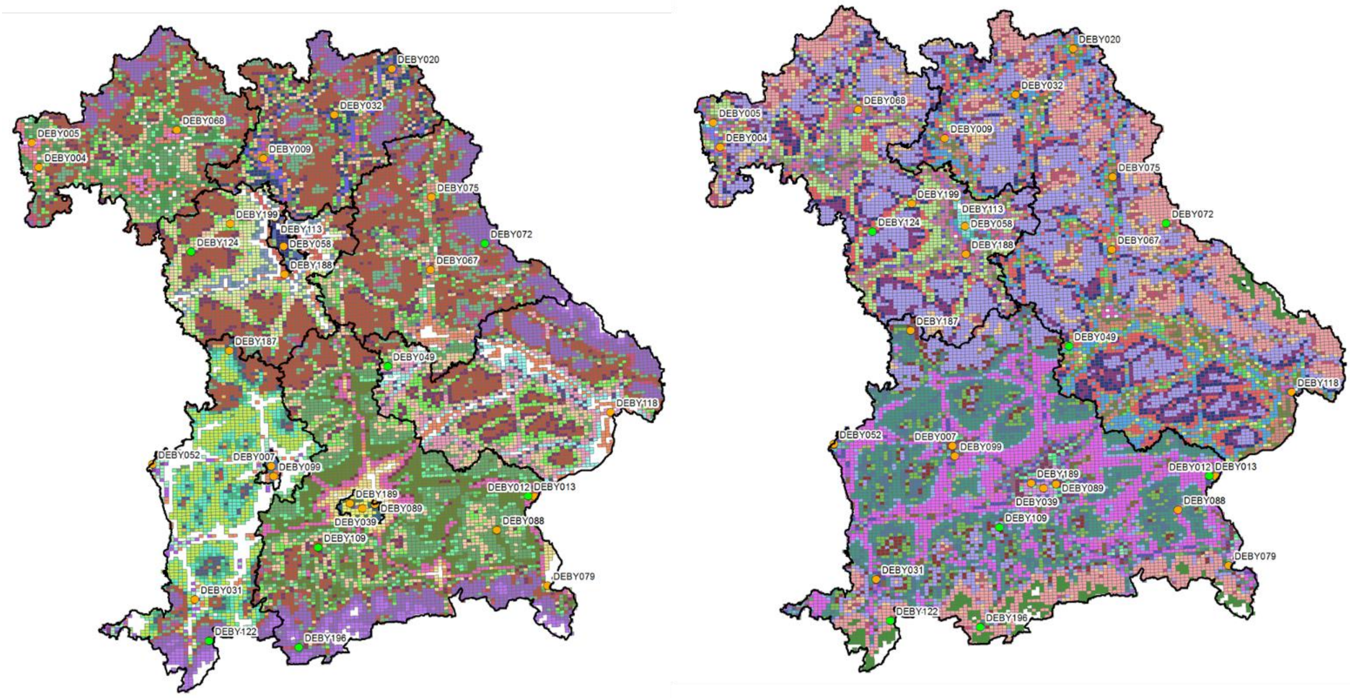

Figure 2: Calculated SRA for Bavaria NO_2 using RCG modelling system (year 2022); left figure: AQ zones 2022, right figure: possible new AQ zones; coloured areas: grid cells with SRA of at least one sampling point; white areas: not covered by SPO; orange dots: urban SPO; green dots: rural SPOs

Figure 2 illustrates one example for Bavaria. The left figure shows the SRA for NO_2 (coloured grid cells covered by the SRA of at least one SPO) SRA using the current network design and AQ zones. The right figure shows a possible new configuration with new AQ zone delineation. The results indicate that with the new configuration the coverage of the area with SRA is slightly increased.

2.2 Geographical limitation of rural background stations

Figure shows the SRAs using rural and urban background stations. As pointed out in the new AAQD (Point B, point 5(a), of Annex IV), SRAs shall be limited in their extension by the borders of the relevant air quality (AQ zones). Due to the siting criteria (the required station density according to the AAQD has no relation to AQ zones) of rural background SPOs, this limitation should not be applied.

Conclusion / recommendation:

Therefore, we decided to limit rural background SPOs by the boundary of the NUTS1 level, which is the geographical domain of the 16 German air quality networks. *Figure 3* shows the results of the SRA of rural background stations (green dots) for the pollutants NO_2, $PM_{2.5}$ and ozone for the year 2022. Where a rural background stations is available the SPOs cover most of the rural areas. Due to the higher modelled NO_2 concentrations in urban areas and close to highways, the rural SPOs are not representative for those areas. For pollutants with a small concentration gradient between urban and rural areas like ozone and $PM_{2.5,}$ some rural SPOs are also representative for those areas. Therefore, considering further datasets like land use or orographic information could be useful for further limitation (see chapter 2.6).

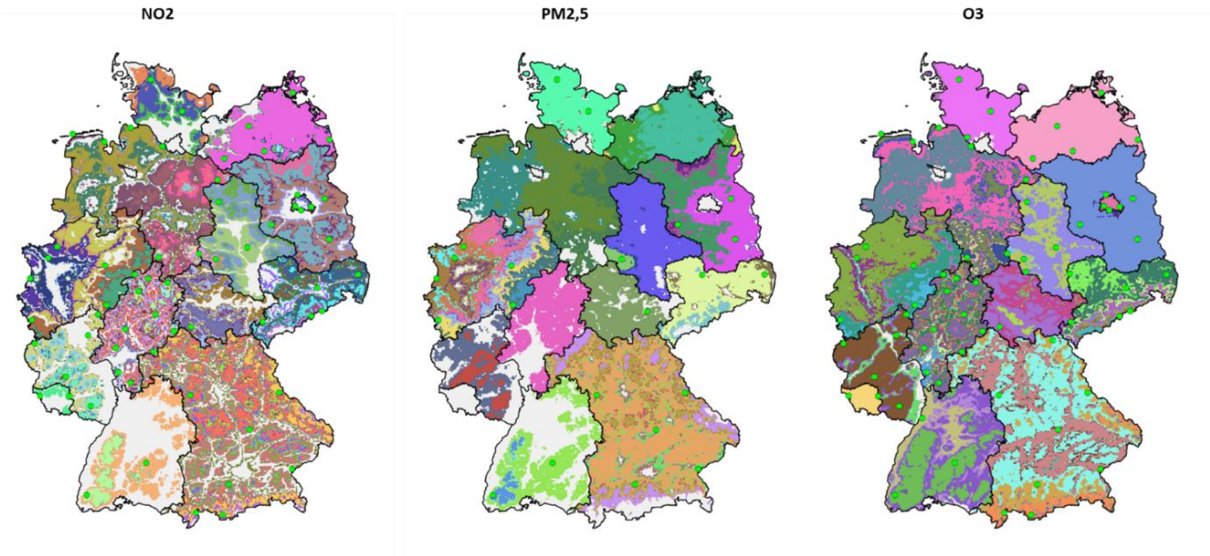

Figure 3: SRA of rural background SPOs using NUTS 1 for limitation

2.3 SRA results for BaP

As pointed out in chapter 1.3, modelled BaP concentrations have a relatively high bias by around a factor of 2, but would fulfil the MQI. A simple bias correction might be necessary, but was not applied. We assume that the bias is linked to a high uncertainty in the emission estimation. However, the *Figure 4* (left side) shows the modelled concentrations, which are in very low range. *Figure 4* (right side) illustrates the derived SRA of the BaP SPOs. Due to the mentioned very low modelled concentrations, the criteria for the lower cut-off (+- 0.2 ng/m³) determines the SRAs derivation. In summary, due to above described issue, AQ zones with at least one SPO are completely covered by those SRA.

Conclusion / recommendation:

Therefore, we suggest to do further exercise in order to adjust the method to be also applicable in regions where BaP concentrations are very low. In this context, the quality of modelled BaP concentrations should be discussed as well.

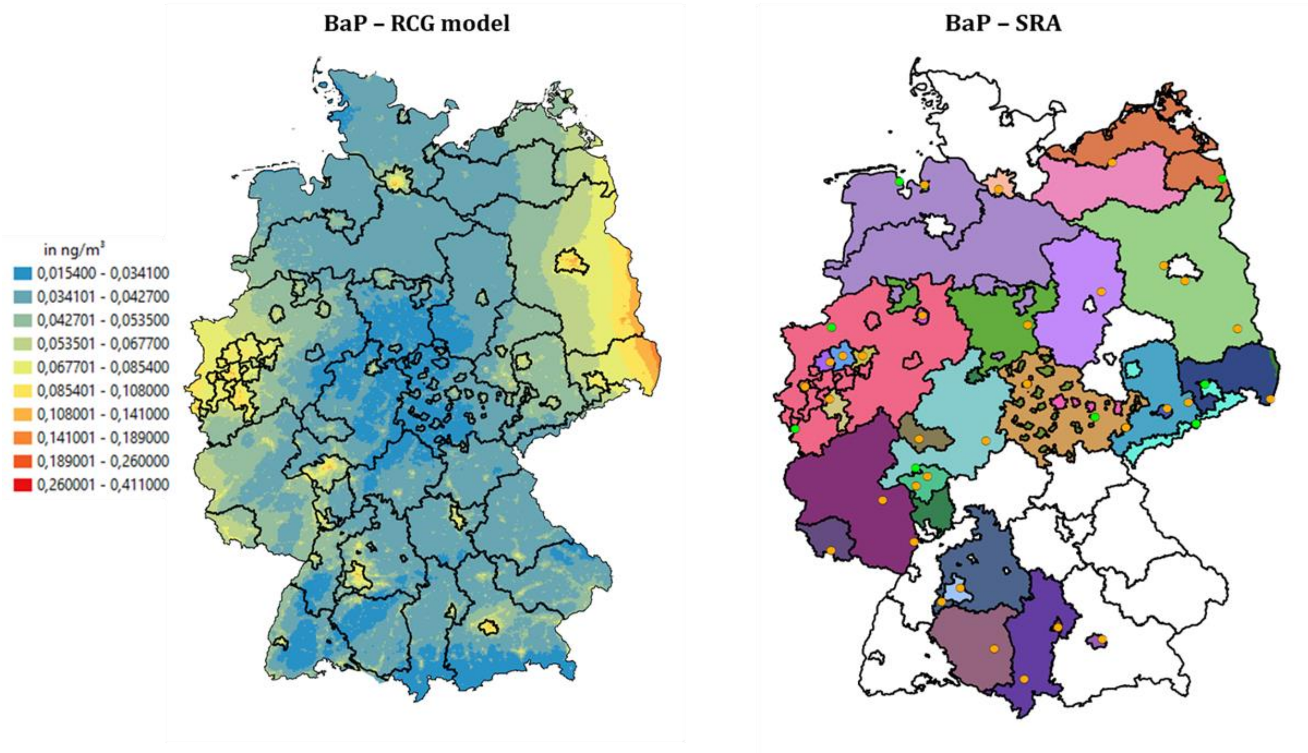

Figure 4: Left figure: modelled BaP concentrations; right figure: SRA using urban and rural background stations, coloured areas: grid cells with SRA of at least one sampling point; white areas: not covered by SPO

2.4 SRA results for benzene

Similar to BaP, modelled benzene concentrations have a relatively high bias by around a factor of 2, but would fulfil the MQI. A simple bias correction might be necessary, but was not applied. We assume that this is linked to a high uncertainty in the emission estimation. However, the *Figure 5* (left side) shows the modelled concentrations, which are in very low range. *Figure 5* (right side) illustrates the derived SRA of the benzene SPOs. Due to the mentioned very low modelled concentrations, teh criteria for the lower cut-off (+- 1 µg/m³) determines the SRAs derivation. In summary, due to above described issue AQ zones with at least one SPO are completely covered by those SRA.

Conclusion / recommendation:

Therefore, we suggest to do further exercise in order to adjust the method to be also applicable in regions where benzene concentrations are very low. In this context the quality of modelled benzene concentrations should discussed as well.

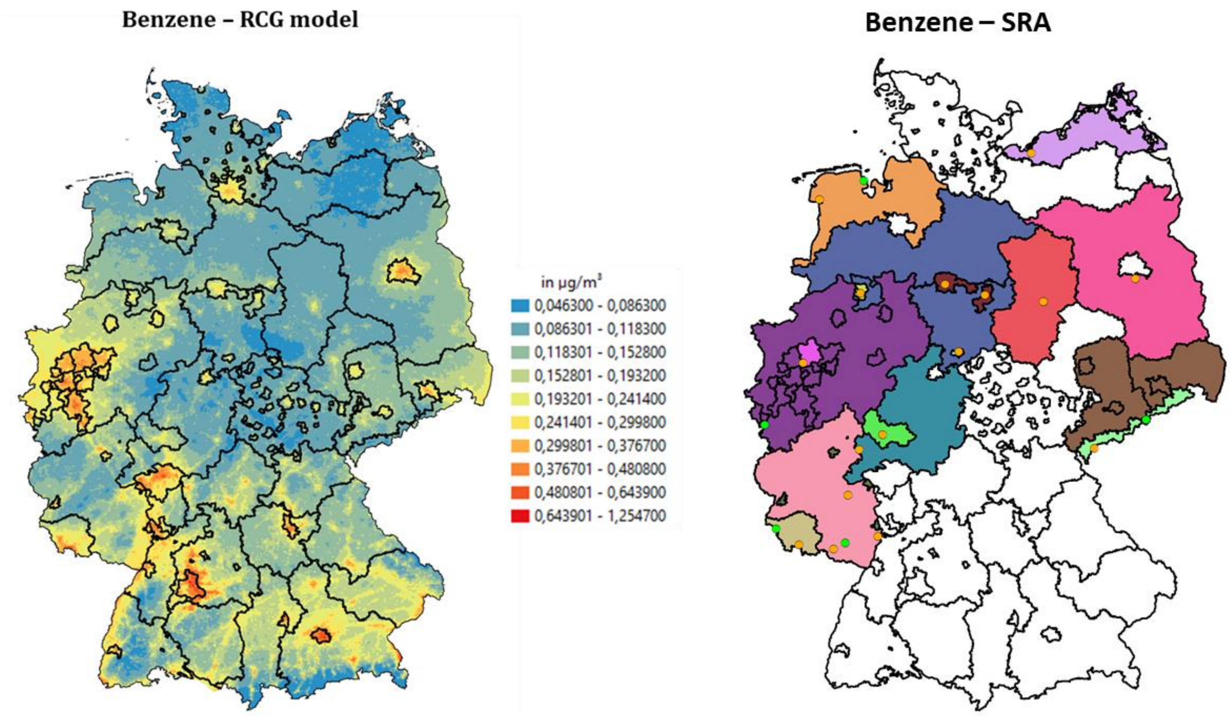

Figure 5: Left figure: modelled benzene concentrations; right figure: SRA using urban and rural background stations, coloured areas: grid cells with SRA of at least one sampling point; white areas: not covered by SPO

2.5 SRA results based on OI (data fusion) for Germany

As pointed out in the new AAQD and in the guidance as well, modelling application should be fit-for-purpose. The evaluation of the RCG results (raw model) used in this approach indicate that the raw concentrations are often biased, where the magnitude of the bias depends on the pollutant under consideration. A common method to reduce the bias is data assimilation, where observations are combined with modelling results. For the RCG modelling results, the method of optimal interpolation (OI, Flemming et al. (2004)) is applied. In this method, the modelling field is modified based on measurements at official sampling points. The circular area around the measurement location in which the modelling field is modified depends on the station classification.

Figure 6 shows the SRA results for NO_2, $PM_{2.5}$ and PM_{10} using the OI modelling system (data fusion, year 2022). In comparison to *Figure* the SRAs are different and especially for NO_2 the uncovered areas increased. This effect could be explained due to the OI data fusion method, which can lead to artificial patterns and have a large impact on the resulting SRAs.

The effect is even more visible if the model resolution is increased. *Figure 7* illustrates on the left figure the SRA results for NO_2 using the raw model in 500x500m² resolution and in comparison, on the right side the SRAs using the data fusion dataset.

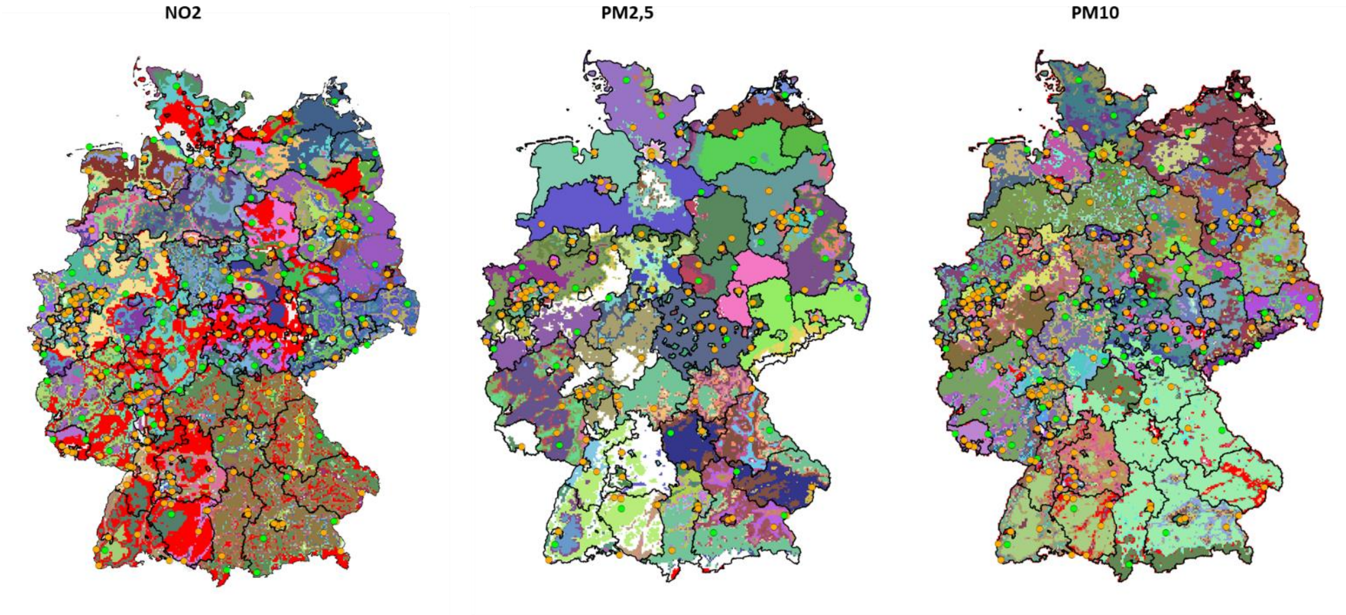

Figure 6: Calculated SRA for NO_2, $PM_{2.5}$ and PM_{10} using OI modelling system (data fusion, year 2022); coloured areas: grid cells with SRA of at least one sampling point; white areas: not covered by SPO; red areas: not covered by SPO but concentrations below assessment threshold

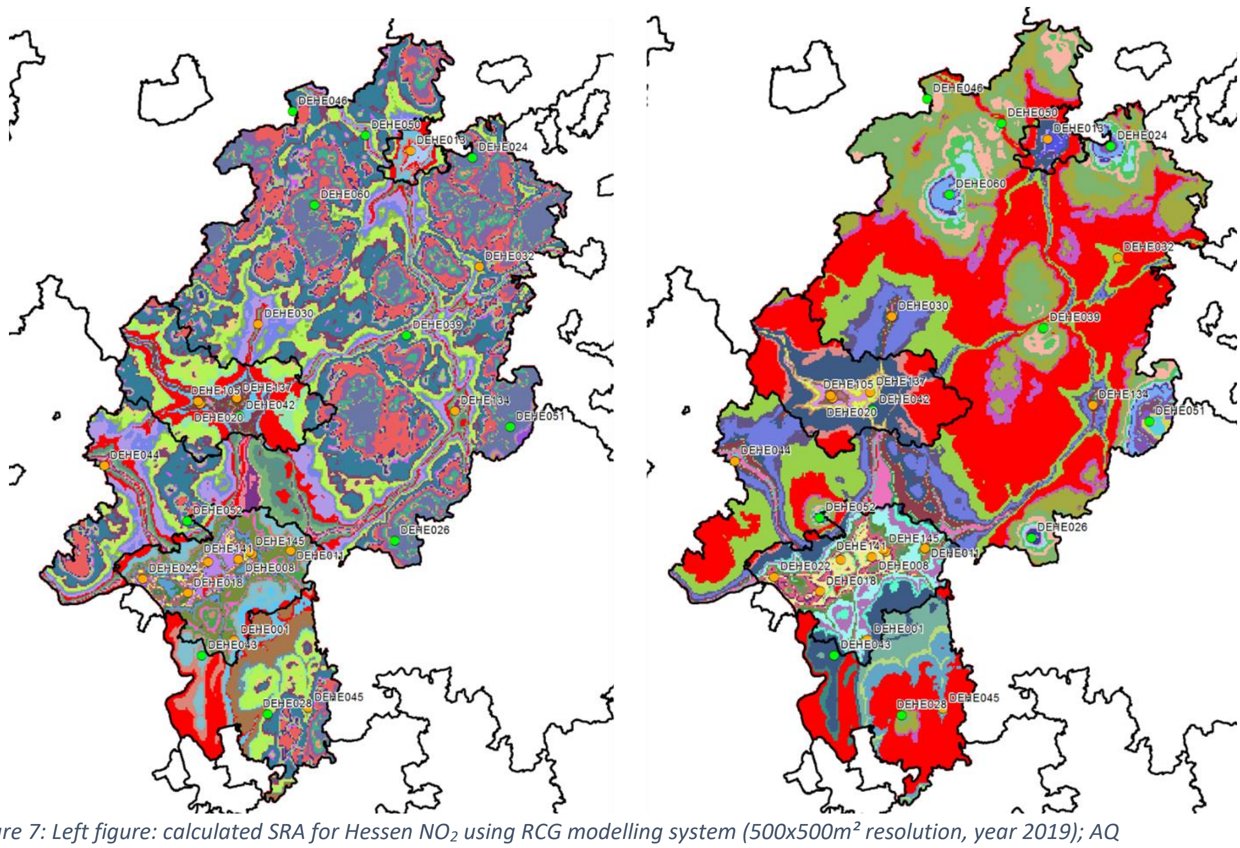

Figure 7: Left figure: calculated SRA for Hessen NO_2 using RCG modelling system (500x500m² resolution, year 2019); AQ zones 2019, right figure: calculated SRA for Hessen NO_2 using OI modelling system (500x500m² resolution, year 2019); coloured areas: grid cells with SRA of at least one sampling point

Conclusion / recommendation:

Cross validation results indicate that the model bias is drastically reduced to values under 10% by applying the OI. However, we assume that for the purpose of the determination of SRAs, these adjusted modelling fields are not suitable.

In this section we further explain, why we expect that the OI results are not suitable for the determination of SRAs. It is most important that the concentration patterns in the area of a sampling point are well represented by the modelling system. Consequently, it is important to describe the input conditions (emissions, meteorology, land cover, topography etc.) to the modelling system as detailed as possible. If these input conditions are well represented, the derived air pollutant concentration field from dispersion calculation should be comparable to the real spatial distribution of air pollutant concentrations. The simulated concentration fields are then physically and chemically consistent with the conditions around a sampling point, insofar as we are able to describe these conditions and the underlying physical and chemical processes. However, these concentration fields may still be biased due to errors in e. g. emission strengths. If these errors are mitigated by assimilation techniques such as OI, the above described consistency is weakened, as the OI introduces circular areas in the modelling fields where concentrations are adjusted to the measurements. An OI corrected modelling field is therefore not suitable for SRA determination.

However, there are exceptions to this. Assimilation techniques such as 4-D Var actively adjust the emissions strength in the assimilation process and not only the resulting concentration fields. They keep the physical and chemical consistency between input and modelled concentration field. We expect, that the resulting concentration fields are suitable for SRA determination in this case. However, such methods will not often be applied in the practice of air quality assessment as they are computationally very expensive.

2.6 First tests on using further criteria for geographical limitation (land cover data)

Following the FAIRMODE approach (15 % tolerance level, non-contiguous), a sampling point could be representative for all grids cell in an AQ zone (or NUTS1 for rural background), which are in the calculated concentration range.

As mentioned in chapter 2.2, especially for pollutants with a small concentration gradient between urban and rural areas like ozone and $PM_{2.5}$ some rural background SPOs could be representative for urban areas. Furthermore, urban background SPOs could cover rural areas as well.

Therefore, considering further datasets like land cover, source-related criteria or orographic information could be useful for further limitation, which could help to reduce the “overlap” of SRAs of SPOs, which may be triggered by completely different emissions sources.

In a first test we used the national CORINE Land Cover (CLC) in 5ha resolution for further geographical limitation. The CLC classes 111, 112, 121, 141 and 142 were used to distinguish the model grid cells between „urban“ or „non-urban“.

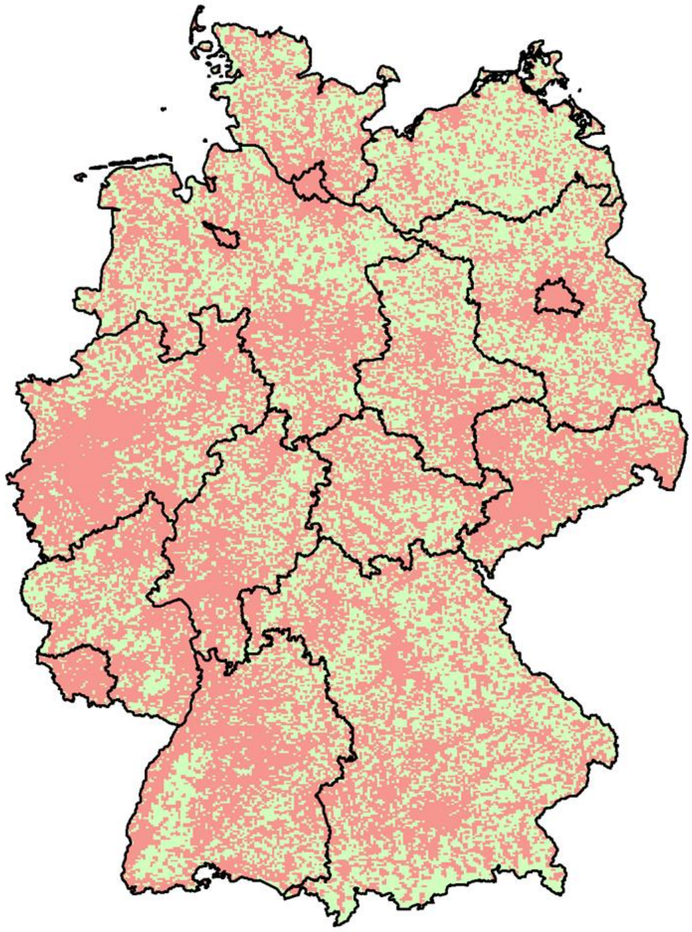

Figure 8: Urban (red) and non-urban (green) grid cells

Figure 8 shows the urban (red) and non-urban (green) grid cells. For this exercise a grid cell was classified as urban if it is intersected with at least one CLC-polygon of the urban classes. In a next step a further requirement was implemented to SRA tool. Urban background SPOs could only be representative for urban areas and rural background SPOs only for non-urban areas.

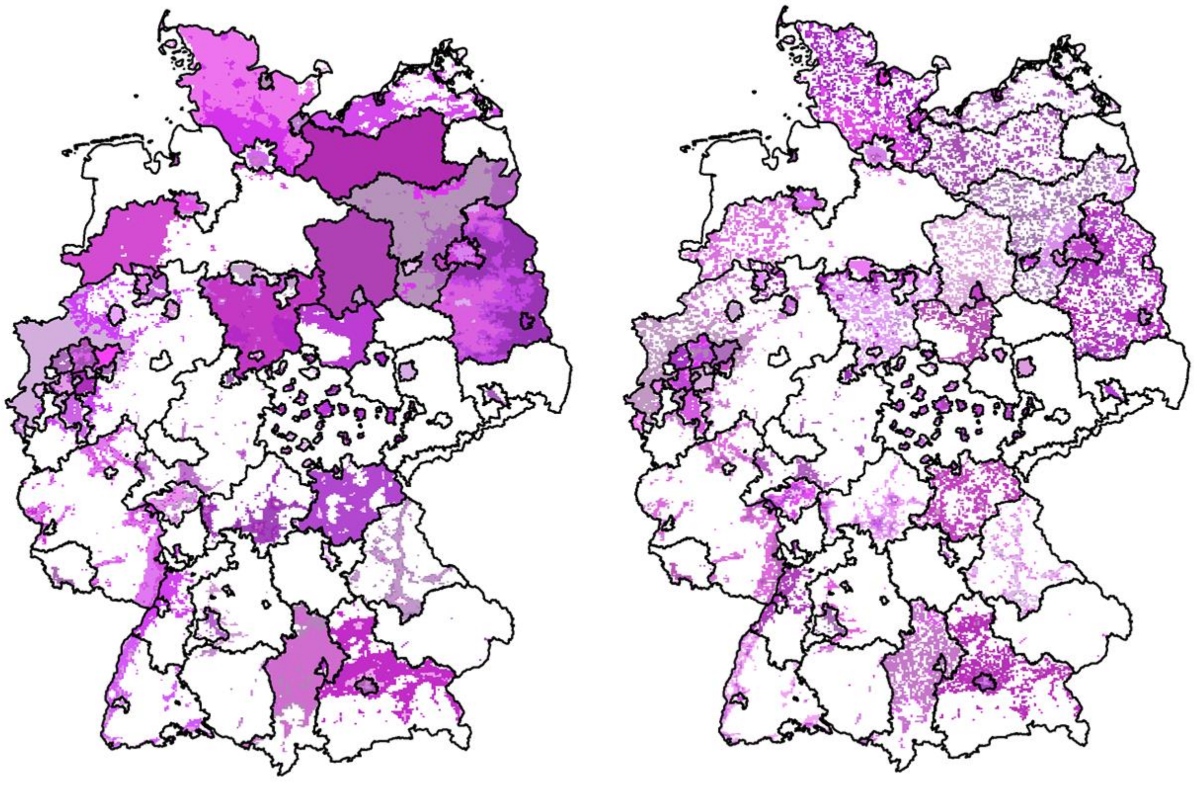

Figure 9: SRAs of urban background SPOs for $PM_{2.5}$; left figure: without further limitation; right figure: using additional land cover information (urban areas)

Figure 9 shows the comparisons of $PM_{2.5}$ urban background SRAs between no further limitation (left figure) and using additional land cover information (right figure). Especially in the northern part of Germany, urban background SPOs cover big parts of the whole AQ zones. Using additional land cover information could be helpful to limit those SRAs (right figure).

Figure 10 illustrates the comparisons of $PM_{2.5}$ rural background SRAs between no further limitation (left figure) and using additional land cover information (right figure).

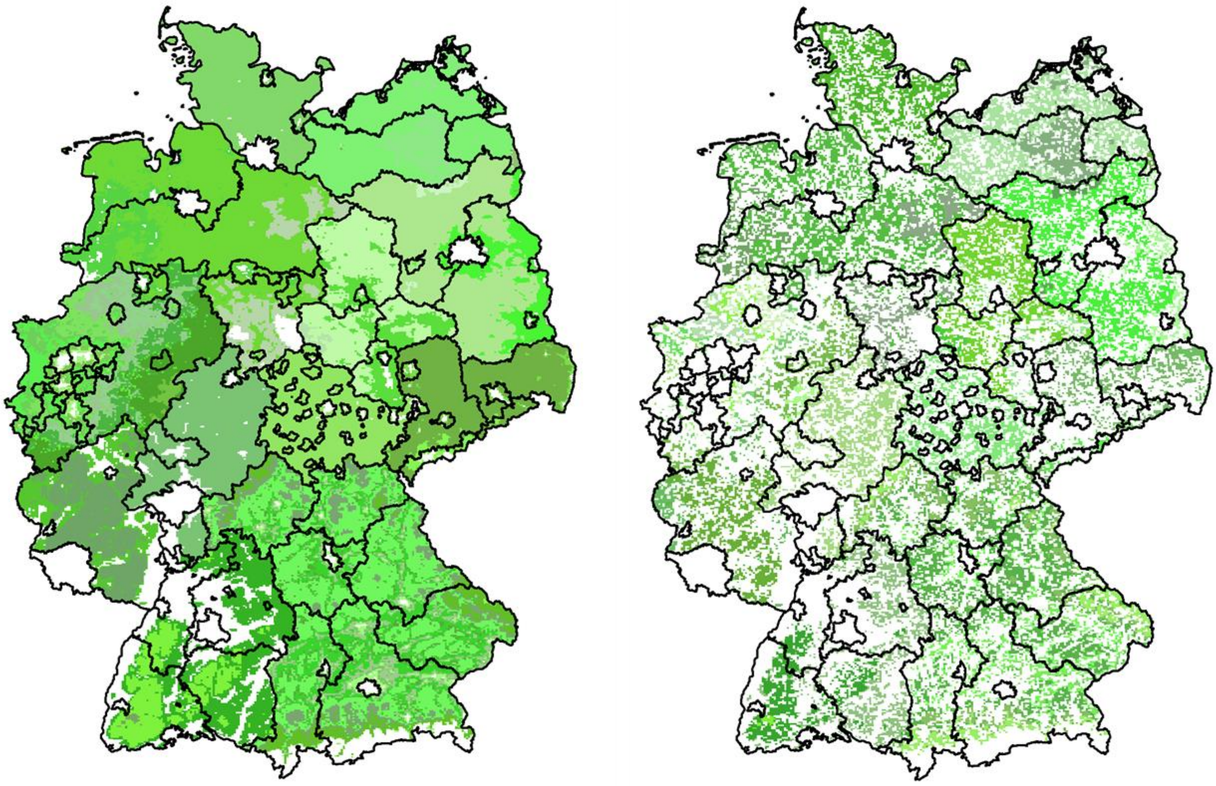

Figure 10: SRAs of rural background SPOs for PM2.5; left figure: without further limitation; right figure: using additional land cover information (non-urban areas)

<u>Conclusion / recommendation:</u>

The first results show that using additional information like land cover datasets could be helpful to reduce the “overlap” of SRAs of SPOs, which may be triggered by completely different emissions sources. On the other hand, using additional information increase the non-contiguity of SRAs.

In a next step the classification of the grid cells could be improved for example by using percentages to identify the dominant land cover class. Furthermore, land cover data could be combined with other datasets like orographic data or source-related criteria. To identify the dominant emission sources leading to the concentration in a grid cell, source apportionment applications like the Tagging-approach might useful to get further information about the dominant emissions sources on a grid cell basis. This information might be considered to introduce the information of the pollutant origin in the deviation of SRA. Maybe the data of the CAMS policy services might be useful in this context.

3. Spatial Representativeness – Street Canyons, Berlin

3.1 Study Focus and Methodology

This study examines air quality monitoring in Berlin, with a specific focus on nitrogen dioxide (NO_2) annual mean concentrations in street canyons. Street canyons, which are roadways flanked by buildings on both sides, can trap pollutants and lead to elevated levels of air pollution. Understanding NO_2 distribution in these urban environments is crucial for assessing exposure risks and designing effective air quality management strategies.

To predict NO_2 concentrations near roadways, the study utilizes the IMMISLuft street canyon model, which is based on the Canyon Plume Box (CPB) dispersion model. This model simulates how pollutants disperse within street canyons, taking into account factors such as traffic emissions, meteorological conditions and urban geometry, with the main purpose of identifying areas where air quality may be particularly poor.

A key objective of the study is to evaluate the spatial representativeness of air quality monitoring stations for NO_2. Using data from 2015 as a baseline, the study also provides projections for 2020 and 2025 to assess potential trends in NO_2 concentrations over time. These projections help determine whether existing monitoring locations effectively capture pollution patterns or if additional monitoring sites are needed to provide a more accurate representation of air quality across Berlin's street canyons.

3.2 Comparison of Measured vs. Modelled NO_2 Values (2015)

The study utilized data from 28 urban traffic monitoring sites in Berlin to assess NO_2 concentrations in street canyons. These sites included six automatic monitoring stations that provided hourly reference measurements, ensuring high temporal resolution and accuracy. Additionally, 22 passive samplers were deployed, offering biweekly indicative measurements. While passive samplers do not capture short-term fluctuations, they contribute valuable long-term data for evaluating spatial patterns in NO_2 distribution.

The modelled and measured NO_2 values are generally consistent, indicating that the IMMISluft street canyon model effectively represents real-world pollution annual mean levels. The minimum measured NO_2 annual mean concentration in 2015 was 41 µg/m³, while the model predicted a slightly lower value of 37.2 µg/m³. Conversely, the maximum measured annual mean concentration in 2015 reached 73 µg/m³, whereas the model estimated a slightly higher value of 78.9 µg/m³. These results demonstrate that the model provides a reliable approximation of NO_2 annual mean levels across different urban locations, supporting its use in air quality assessments and planning efforts.

3.3 Spatial Representativeness of NO_2 Monitoring Sites

Many NO_2 monitoring sites in Berlin report similar annual mean concentration levels, which helps ensure adequate coverage even for urban traffic locations that are not directly monitored. This redundancy in measurements strengthens confidence in the representativeness of the monitoring network, as it suggests that unmonitored areas with similar traffic and environmental conditions likely experience comparable pollution levels.

The IMMISluft model further supports the adequacy of the monitoring site distribution by confirming that the spatial patterns of NO_2 concentrations are well captured. The model's alignment with measured annual mean values reinforces the reliability of both the monitoring network and the predictive modelling approach, validating its use for assessing air quality in Berlin's street canyons.

Tolerance levels of ±15% or ±20%, when considering the spatial representativity of monitoring sites, do not have a significant impact on the spatial representativeness of Berlin's air quality monitoring sites. This suggests that minor variations in pollutant concentration thresholds do not alter the ability of monitoring stations to reflect broader air quality patterns in the city. Regardless of these tolerance levels, the overall assessment of NO_2 distribution remains consistent.

Despite a projected decline in NO_2 levels from 2015 to 2025, the spatial representativeness of monitoring sites remains stable over time. This indicates that the existing network is robust and continues to provide reliable data on air pollution trends. Additionally, the number of monitoring stations in Berlin is deemed sufficient for assessing NO_2 distribution. While supplementary indicative measurements can offer more localized insights, they are not essential for ensuring overall spatial representativeness, reinforcing the effectiveness of the current monitoring system.

However, one limitation remains: low NO_2 levels cannot be effectively assessed due to the lack of measurements in less polluted areas. Since monitoring stations are primarily placed in locations with high traffic and expected high NO_2 pollution, cleaner areas are underrepresented in the data. While this does not impact the study's focus on high-exposure zones, it does mean that a comprehensive citywide air quality assessment would require additional data from low-pollution environments.

This could be a limitation if a more comprehensive citywide air quality assessment were required, but it does not impact the primary goal of tracking pollution in the most affected locations.

3.4 Proposals for Improving Spatial Representativeness

Modelling applications should primarily focus on areas with high NO_2 concentrations, as these locations pose the greatest risk to public health and are most relevant for air quality management. The IMMISluft model has proven effective in capturing pollution patterns in high-traffic street canyons, making it a valuable tool for assessing air quality in these critical zones.

However, if there should be a need to monitor low NO_2 levels, adjustments to the current monitoring strategy would be necessary. This could involve deploying additional indicative measurements in cleaner areas or refining site selection criteria to include a broader range of urban environments. Factors such as high-traffic streets with varying congestion patterns or specific street configurations that influence pollutant dispersion could be considered to enhance the representativeness of air quality assessments across the city. By expanding monitoring efforts strategically, a more comprehensive understanding of NO_2 distribution in both high- and low-pollution areas could be achieved.

3.5 Findings on PM10 and PM2.5 (Particulate Matter)

The study also examines particulate matter (PM_{10} and $PM_{2.5}$) concentrations at traffic sites, revealing a consistent decline over time. In 2017, PM_{10} annual mean concentrations at traffic sites ranged between 23 and 28 µg/m³, while background levels were slightly lower at 16 to 22 µg/m³. By 2020, traffic site concentrations had decreased to 18–22 µg/m³, with background levels at 14–18 µg/m³.

This downward trend continued in 2023, with PM_{10} concentrations at traffic sites reaching 17–20 µg/m³ and background levels at 13–17 µg/m³. A similar decline was observed for $PM_{2.5}$, which started at 16–19 µg/m³ in 2017 and gradually dropped to 11–12 µg/m³ by 2023, with background concentrations following a comparable pattern.

Unlike NO_2, PM_{10} and $PM_{2.5}$ require different spatial considerations due to their distinct emission sources and dispersion characteristics. While NO_2 concentrations are strongly influenced by traffic emissions in street canyons, particulate matter can originate from various sources, including road dust, industrial emissions, and atmospheric transformations. This broader range of contributing factors means that PM pollution is less confined to specific locations and tends to be more evenly distributed across urban environments.

As a result, specific spatial representativeness calculations for PM_{10} and $PM_{2.5}$ at traffic sites are not deemed necessary. Since PM_{10} and $PM_{2.5}$ concentrations are influenced by regional background levels in addition to local traffic emissions, its distribution is less dependent on individual street configurations. Therefore, while ongoing monitoring remains important, the existing network is considered sufficient for capturing overall trends in particulate matter pollution without requiring additional spatial assessments or tolerance levels, when modelling applications are deployed.

3.6 Conclusions and Recommendations

Berlin's NO_2 monitoring network is effectively positioned to capture pollution levels in high-exposure areas, ensuring that major traffic-related NO_2 hotspots are well represented. The placement of monitoring stations aligns with known high-concentration locations, making the network a reliable tool for assessing air quality in the city's busiest and most polluted areas.

However, incorporating additional measurements in areas with low NO_2 concentrations could enhance overall spatial representativeness. Since current monitoring sites focus primarily on high-pollution zones, cleaner areas remain underrepresented. Expanding the network with carefully selected monitoring locations or supplementary indicative measurements could provide a more comprehensive picture of NO_2 distribution across Berlin.

An intelligent approach to monitoring network design can further optimize coverage while minimizing the need for an excessive number of kerbside monitoring sites. By strategically selecting locations based on traffic intensity, street configurations, and pollutant dispersion patterns, it is possible to maintain robust air quality assessments with fewer stations, improving efficiency without compromising data quality.

However, the requirement to cover all roads should not lead to additional monitoring sites having to be installed, especially not at the expense of sites on heavily polluted roads, even though they may be redundant from a representativeness point of view. Other requirements for measurements, especially with regard to health protection, must be allowed to prevail.

For particulate matter (PM_{10} and $PM_{2.5}$), the current monitoring strategy appears sufficient without requiring additional spatial representativeness evaluations. Since PM pollution is influenced by both local and regional sources, existing monitoring stations provide a reliable overview of its distribution.

Appendix

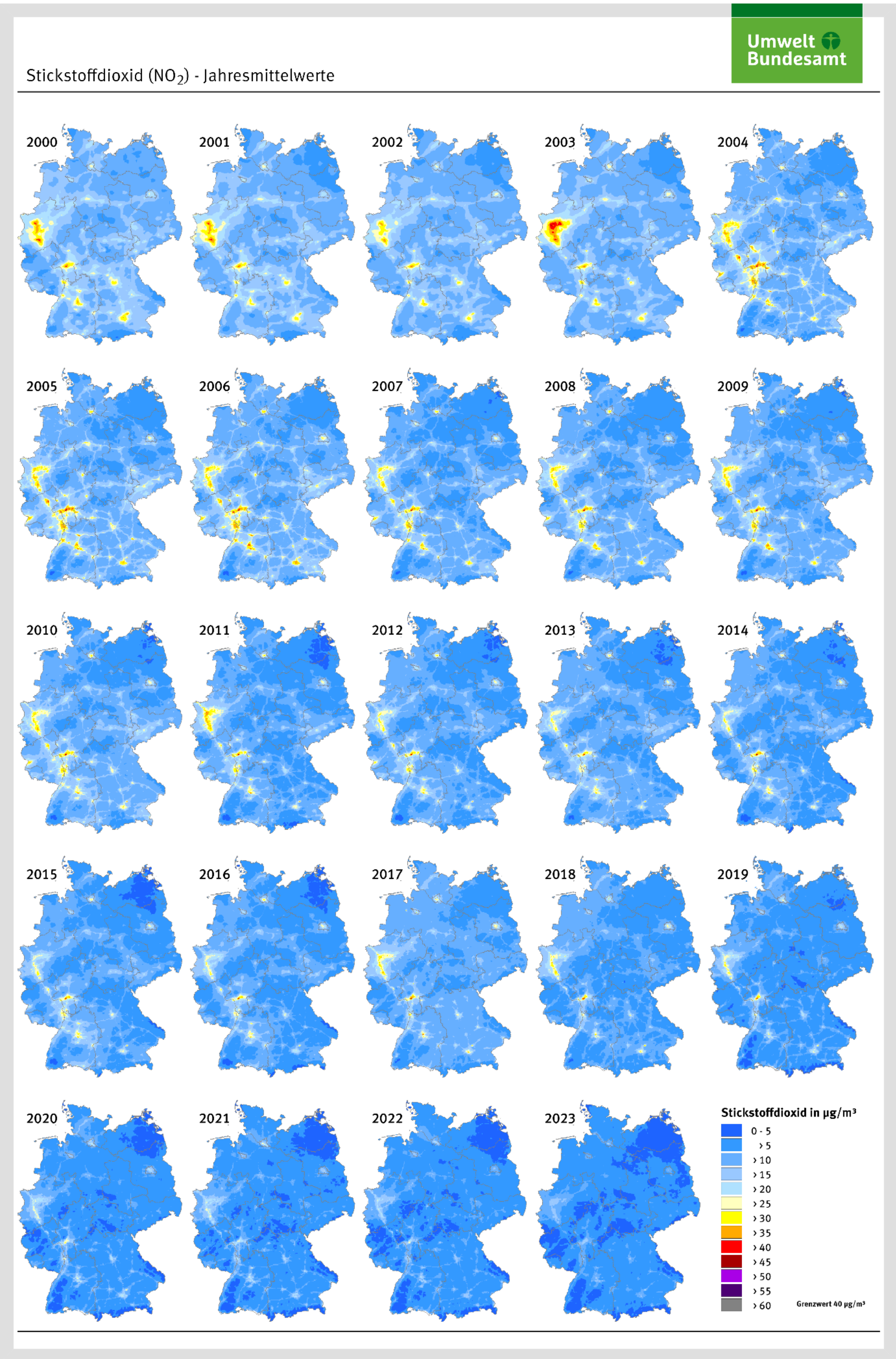

Figure A1: Modelled NO2 annual mean concentrations 2000 - 2023

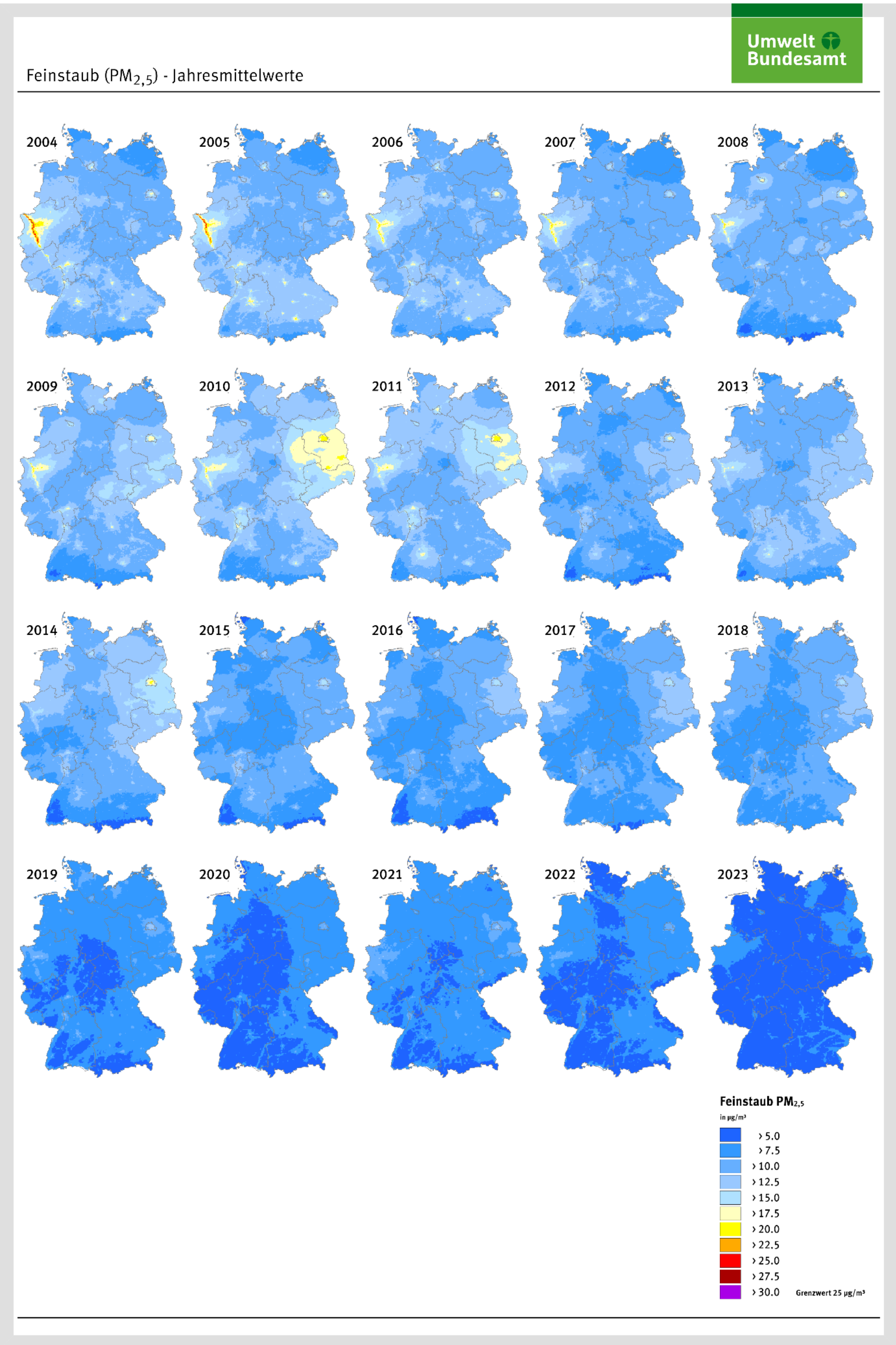

Figure A2: Modelled $PM_{2.5}$ annual mean concentrations 2004 - 2023

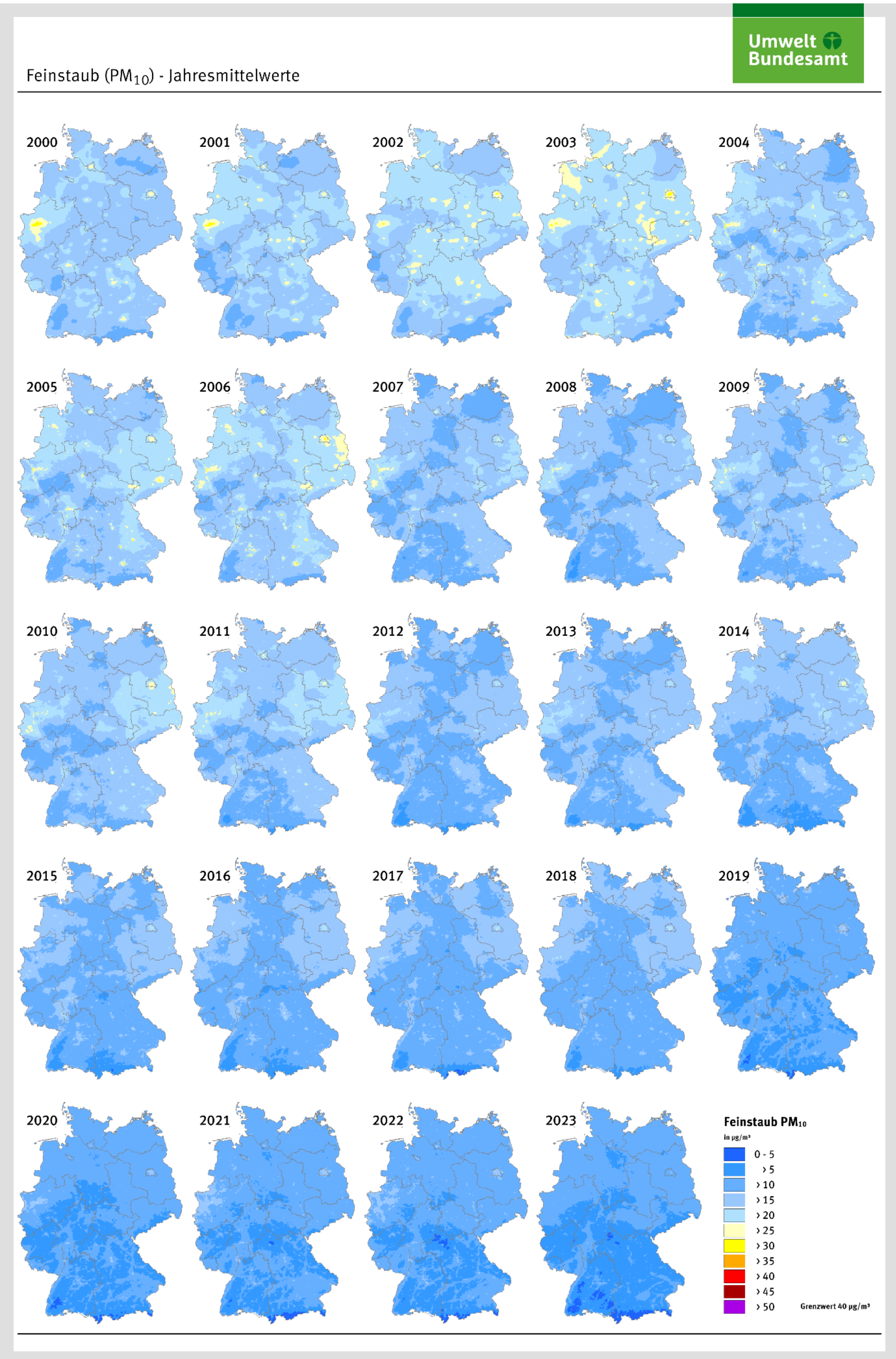

Figure A3: Modelled PM_{10} annual mean concentrations 2000 - 2023

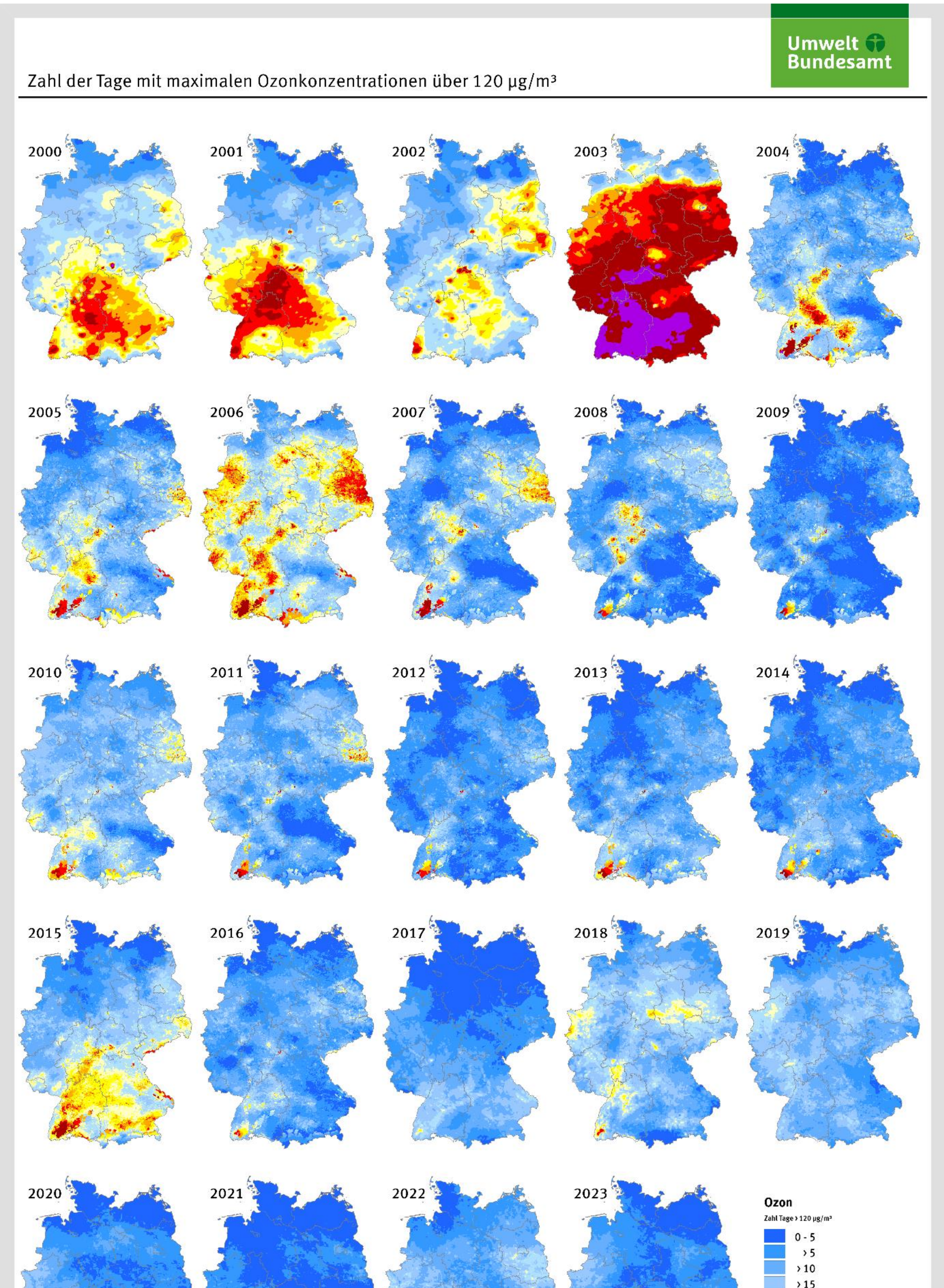

Figure A4: Modelled MDA8 number of exceedances for ozone 2000 - 2023

References

Stern, R.: Entwicklung und Anwendung des chemischen Transportmodells REM/CALGRID. Modellierung und Prüfung von Strategien zur Verminderung der Belastung durch Ozon. Hrsg.: Umweltbundesamt (UBA), Berlin 2003.
https://www.umweltbundesamt.de/publikationen/entwicklung-anwendung-des-chemischen

Schneider, C., Pelzer, M., Toenges-Schuller, N., Nacken, M., Niederau, A.: ArcGIS basierte Lösung zur detaillierten, deutschlandweiten Verteilung (Gridding) nationaler Emissionsjahreswerte auf Basis des Inventars zur Emissionsberichterstattung. Hrsg. Umweltbundesamt (UBA), 2016.
https://www.umweltbundesamt.de/publikationen/arcgis-basierte-loesung-zur-detaillierten

Flemming, J., Stern, R.: Datenassimilation auf der Basis der Optimalen Interpolation für die Kartierung von Immissionsbelastungen. Hrsg. Umweltbundesamt (UBA), 2004.
https://www.umweltbundesamt.de/publikationen/datenassimilation-auf-basis-optimalen-interpolation

Thürkow, M., Schaap, M., Kranenburg, R., Pfäfflin, F., Neunhäuserer, L., Wolke, R., Heinold, B., Stoll, J., Lupascu, A., Nordmann, S., Minkos, A., & Butler, T. M. (2024). Dynamic evaluation of modeled ozone concentrations in Germany with four chemistry transport models. The science of the total environment, 906: 167665. doi:10.1016/j.scitotenv.2023.167665.

APPENDIX 7

Spatial Representativeness study for Belgium, Croatia, Ireland and Slovakia.

Annex to the report of FAIRMODE Working Group 8

January 2025

Vision on technology for a better world

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Spatial Representativeness study for Belgium, Croatia, Ireland and Slovakia.

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Table of contents

1 Introduction

The EU Ambient Air Quality Directive (AAQD) and its provisions require EU Member States to assess air quality throughout their whole territory. For this purpose, they define criteria for siting of air quality monitoring stations, such as in areas where the highest concentrations occur and in other areas which are *representative* of the exposure of the general population. At the core of this criteria is the ***spatial representativeness*** and ***coverage*** of the stations across the whole territory.

The definition of the spatial representativeness of a monitoring station has been under debate for a very long time within the EU air quality community as the AAQD definition is relatively broad. There is no standard approach and thus it can be loosely interpreted. Over the past few years, the European Commission - DG Environment has initiated studies to harmonize the methodologies for the definition of spatial representativeness in the context of air quality. This has resulted in the establishment of a FAIRMODE Working Group who are currently assessing the latest agreed approach that has been suggested by its members.

VITO have tested this latest methodology on the air quality networks of Belgium, Croatia, Ireland and Slovakia. For the analysis of the Belgian network the yearlong modelling work done by VITO and IRCELINE-CELINE (Belgian Interregional Environment Agency)[6] was used.

In the case of Croatia, the Croatian Meteorological and Hydrological Service have contracted VITO to implement specific modules of the ATMOSYS air quality modelling system to their requirements. This contract is being carried out within the framework of the 'AIRQ project'[7] to support and improve their own air quality modelling capabilities for adhering to the ambient AQ directive. Among others, historical air quality maps for Croatia, with a street level zoom over Zagreb, were produced. The analysis on the Irish network was done within the LIFE Emerald project[8]. The air quality maps created with VITO's ATMO-Street model during this project were used for this analysis. Between 2019 and 2021 VITO implemented its air quality tools at the Slovak Hydrometeorological Institute (SHMÚ)[9]. On the air quality maps resulting from this project a spatial representativeness analysis was performed for Slovakia.

All results were shared with the FAIRMODE Working Group 8[1] and separate presentation workshops were given to the air quality modelling experts of the Irish, Croatian, Slovak and Belgian environmental agencies to discuss the results and the recommendations to FAIRMODE.

In this report the presentations given to the air quality services of the four countries are brought together.

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[6] https://www.irceline.be/nl
[7] https://www.airq.hr/en/about-the-project/
[8] https://www.epa.ie/environment-and-you/air/life-emerald/
[9] https://atmosys.vito.be/en/slovak-hydrometeorological-institute

2. Results for Ireland

2.1 Input data for the Spatial Representativeness Study

2.1.1 Air quality station locations

The EPA provided the locations of the air quality stations in Ireland. To calculate the Spatial Representativeness Area (SRA) the following information is needed:

- The station location (latitude and longitude). With the location, the modelled concentration at the station can be retrieved from modelled air quality maps. The location determines in which Air Quality Zone (AQZ) the station lies.
- Station type (traffic, industrial, background). Some definitions of spatial representativeness use the station type.
- Station area (rural, suburban, urban). Some definitions of spatial representativeness use the station type.
- Pollutants measured. The spatial pattern of the concentration of a pollutant can be rather flat (e.g., Ozone, particulate matter) or show high spatial variability (e.g., NO_2, ultra fine particles). Hence, the spatial representativeness of a pollutant will also depend on the pollutant.

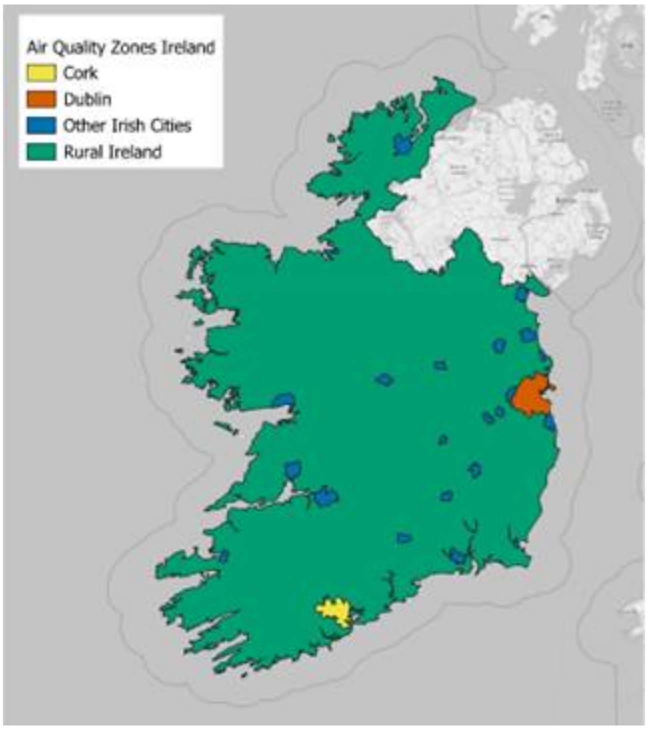

Figure 1: Air Quality Zones in Ireland

2.1.2 Air Quality Zones (AQZ)

Ireland has four AQZs: Dublin, Cork, other cities, and rural Ireland. The geometries of these zones were retrieved from the EEA website[10]. To speed up the calculations about 4000 little islands were removed, and the contours were simplified with a tolerance of 100 meters. Otherwise, it is very time-consuming to calculate which points of the air quality map lie inside each AQZ. This simplification has no impact on the results, 99.5% of the total area was preserved. A fifth zone covering the whole of Ireland was also considered. This was done because for rural background stations there is a proposal to lift the restriction that an SRA must lie within an AQZ.

2.1.3 Air quality maps

The high-resolution air quality maps created with the ATMO-Street model during the LIFE Emerald project are used. Maps are available the following pollutants: NO_2, $PM_{2.5}$, PM_{10} and O_3. Each map is available for the years 2021 and 2022.

2.2 Spatial Representativeness Area (SRA) definitions

The definition of a Spatial Representativeness Area (SRA) is still under discussion in the FAIRMODE Working Group 8 on Spatial Representativeness. The definition proposed now is as follows:

1. The SRA of an air quality station for a pollutant and year is an area <u>within the AQZ</u> in which the station is located.
2. A point in the AQZ belongs to the SRA of the station if the modelled concentration lies within an interval around the modelled concentration at the air quality station. Hence, high-resolution modelled concentrations are necessary.
3. The lower and upper bound of this interval are determined with the following formula:

$$\left[\min\left(C - cut\_off,\ C\left(1 - \frac{tol}{100}\right)\right); \max\left(C + cut\_off,\ C \times \left(1 + \frac{tol}{100}\right)\right)\right]$$

where *C* is the modelled concentration at the station location, tol and *cut_off* are a tolerance and cut-off value that depend on the pollutant and station type. The tolerance and cut-off are listed in the table below. In the further analysis we refer to this definition as *Tol=10or20%*: tolerance 10 or 20% with cut-off 2 µg/m^3.

[10] https://discomap.eea.europa.eu/map/FME/AQZones/

Pollutant	Station type	Tolerance	Cut-off
NO_2, O_3, $PM_{2.5}$, PM_{10}	Traffic, Industrial	20%	2
	Background	10%	2
Benzo-a-pyrene	Traffic, Industrial	20%	0.2
	Background	10%	0.2

Table 1: station type and pollutant dependent tolerance and cut-off of the SRA 'Tol=10or20%'.

An example:

- The modelled NO_2-concentration in a traffic station is 36.2 µg/m³. The interval is [28.96; 43.44]. For higher values the tolerance determines the size of the interval (36.2*0.8 = 28.96). All points inside the AQZ with a modelled concentration in this interval belong to the SRA of the station.
- The modelled NO_2-concentration in a background station is 8.1 µg/m³. The interval is [6.1; 10.1]. For smaller values the cut-off determines the size of the interval.

An alternative definition does not make a distinction between different station types and always uses a tolerance of 15%. The cut-off remains the same (see Table 2). For this definition SRAs were calculated as well. In the further analysis we refer to this definition as *Tol=15%*: tolerance 15% with cut-off 2 µg/m³.

Pollutant	Tolerance	Cut-off
NO_2, O_3, $PM_{2.5}$, PM_{10}	15%	2
BaP	15%	0.2

Table 2: station type and pollutant dependent tolerance and cut-off of the SRA definition 'Tol=15%'.

2.3 Results

2.3.1 Spatial representativeness areas

The number of combinations of station, pollutant, year, and SRA-definition leads to hundreds of SRA-plots. A selection of plots is shown below to illustrate the application of the current definitions of SRA for Ireland. Figure 2 shows the SRA of the suburban traffic station IE001AP (Dublin Inchicore Davitt Road) for NO_2 in 2022 according to two definitions. Because in definition *Tol=10or20%* a tolerance of 20% is used, the SRA covers 11.9% of the Dublin AQZ. With the smaller tolerance of 15% only 6.4% is covered. The station is representative for most major roads in Dublin.

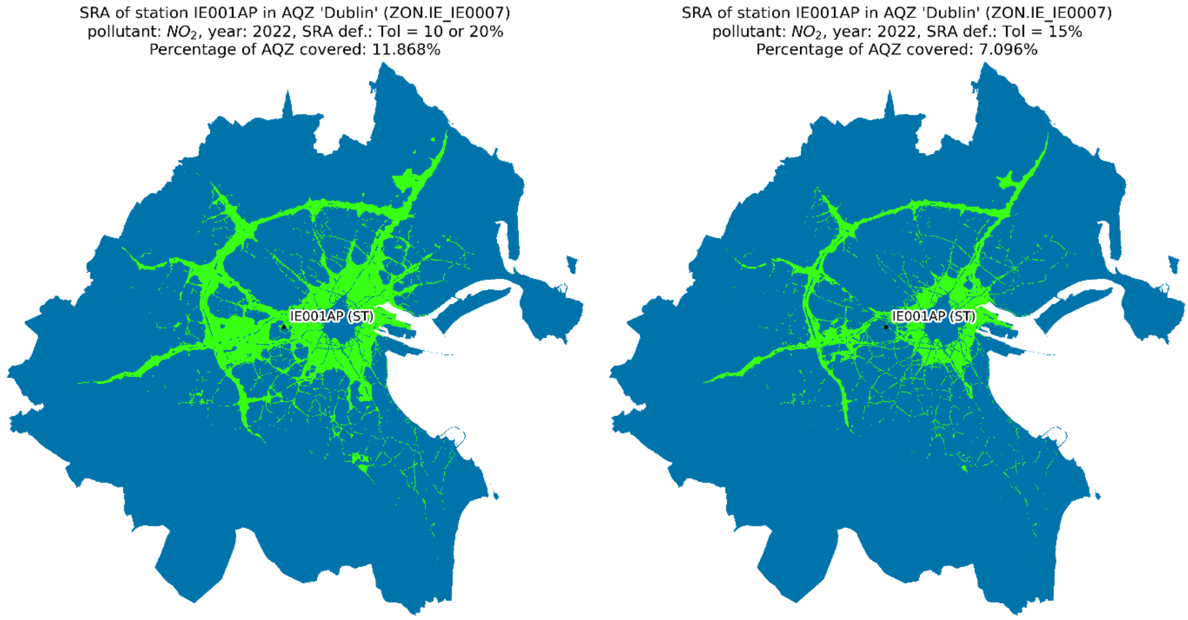

Figure 2: SRA of the suburban traffic station IE001AP (Dublin Inchicore Davitt Road) for NO_2 in 2022 according to two definitions. The SRA of the station is shown in green, the station is not representative for the area in blue.

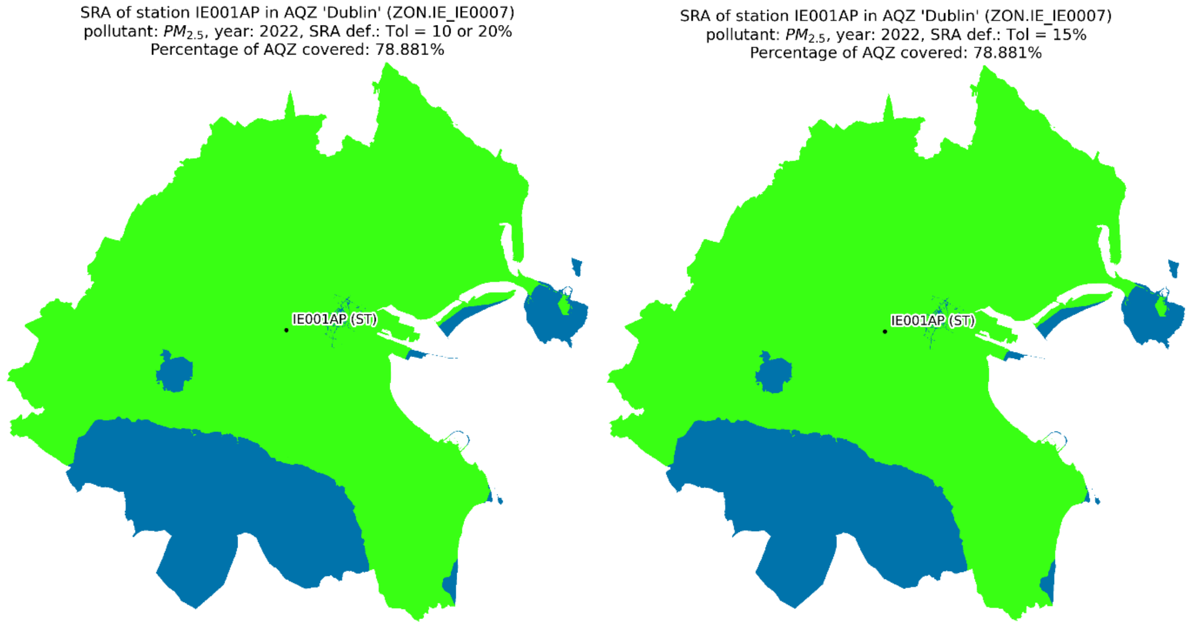

Figure 3: SRA of the suburban traffic station IE001AP (Dublin Inchicore Davitt Road) for $PM_{2.5}$ in 2022 according to two definitions. The SRA of the station is shown in green, the station is not representative for the area in blue.

Figure 3 shows the SRA of the same station but for $PM_{2.5}$. Because the concentration of $PM_{2.5}$ shows less spatial variability the coverage is bigger for both definitions (79.9%). There is no difference between the definitions because the cut-off value is used to determine the concentration bounds.

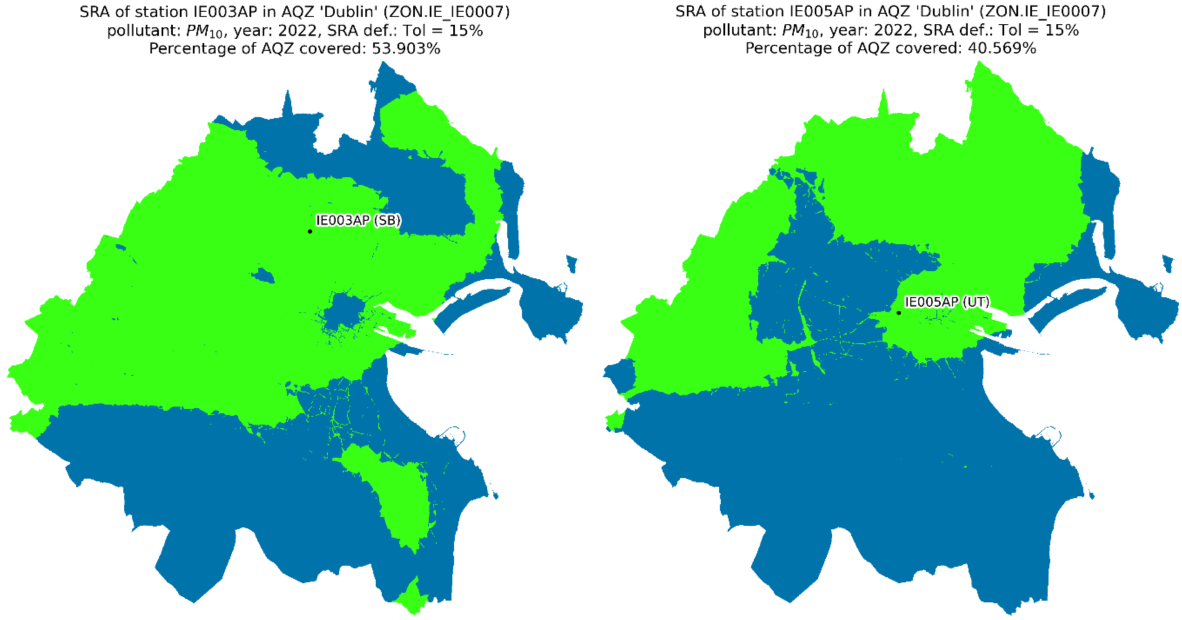

Figure 4: The SRA of two PM_{10} stations: the suburban background station IE003AP (Dublin Finglas Mellowes ROAD) and the urban traffic station IE005AP (Dublin Kilmainham St. John's Road West). The SRA of the station is shown in green, the station is not representative for the area in blue.

Figure 4 shows the SRA of two PM_{10} stations. Because the PM_{10} concentrations shows less spatial variability than NO_2, the SRA of both traffic and background stations is quite extensive.

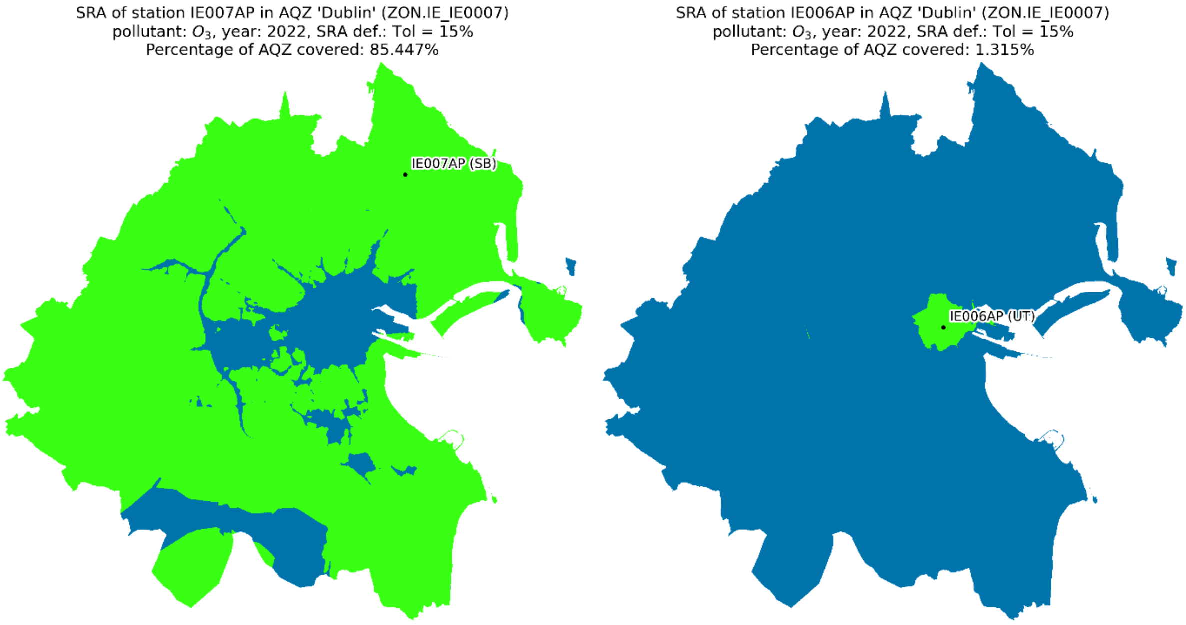

Figure 5: SRA of two ozone stations: the suburban background station IA007AP, Dublin Airport (left) and the urban traffic station IE006AP, Dublin Pearse street (right). The SRA of the station is shown in green; the station is not representative for the area in blue.

Figure 5 shows the SRA of two ozone stations. The SRA of the suburban background station covers 76% of the AQZ. The SRA of the traffic station is much smaller. Due to NOx emissions of traffic the ozone concentration is lower in the city centre while it is rather uniform and higher in the suburbs of Dublin.

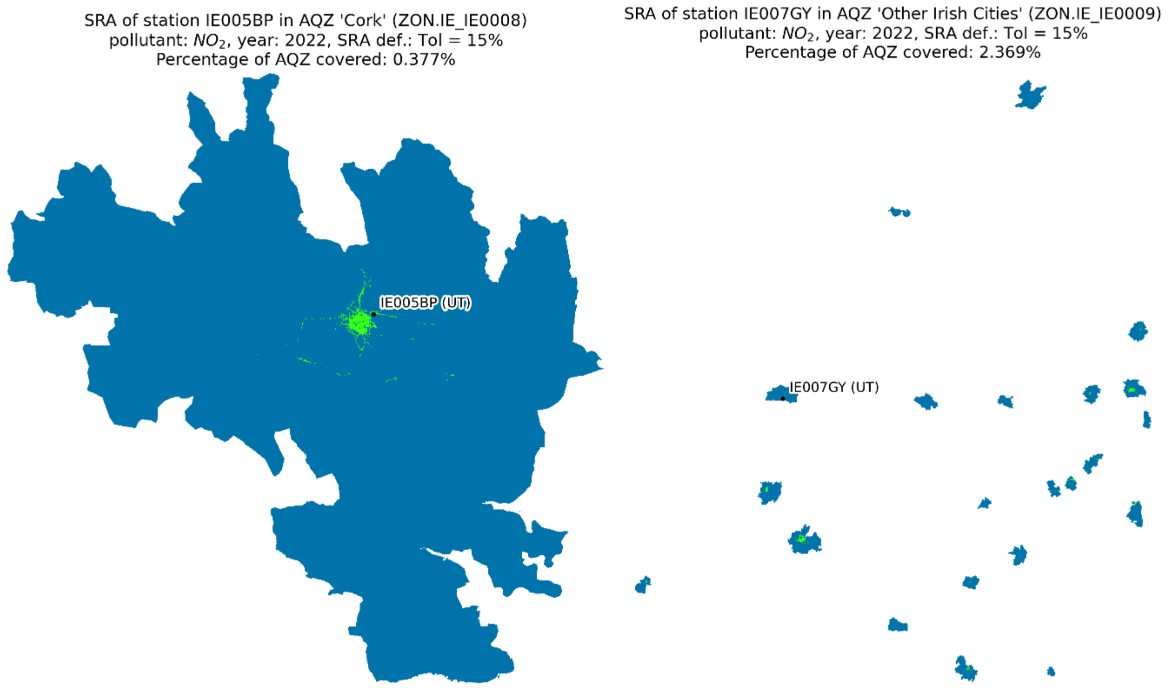

Figure 6: SRA of two NO_2 urban traffic stations: the station IA005BP in the Cork AQZ (left) and the station IE007GY (Galway Eyre Square) in the Other Irish Cities AQZ (right). The SRA of the station is shown in green; the station is not representative for the area in blue.

Figure 6 illustrates the SRA of urban traffic stations outside Dublin for NO_2. The traffic station in Cork proofs representative for only the busy roads in the heart of the city. Outside of the urbanized city centre we have significantly lower NO_2 concentrations. In the ‘other Irish cities’ zone a traffic station in Galway proofs representative for traffic locations in other Irish cities.

2.3.2 Coverage of air quality zones

In this paragraph, the coverage of the AQZs by the SRAs of stations inside the AQZ is examined. A coverage map is obtained by overlaying the SRAs of all stations measuring a pollutant in an AQZ. This is illustrated by Figure 7 for the Cork AQZ for NO_2 in 2022 with definition *Tol=15%*. The three stations cover parts of the city centre but don’t cover the rural areas outside the city. This is a pattern seen for NO_2 in other Irish cities and in similar analysis in other EU countries.

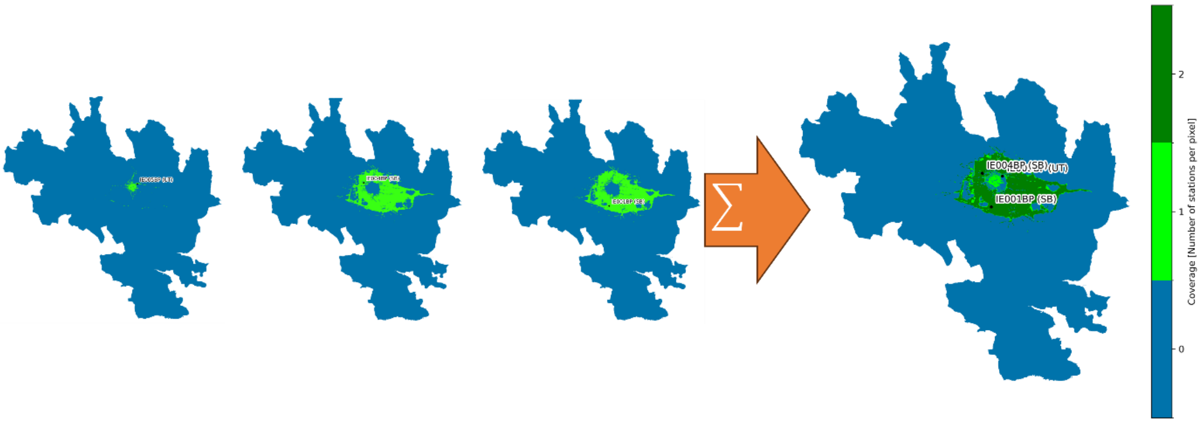

Figure 7: The coverage map of the Cork AQZ for NO_2 in 2022 with definition Tol=15% is the sum of three SRAs: IE001BP, IE004BP and IE005BP.

Table and Figure 8 examine the coverage situation in Cork for NO_2 in 2022 with definition Tol=15% in more detail. There are 3 stations with their respective modelled concentration, and lower and upper bound according to the definition. Each concentration bound represents a line in Table . The bounds are ordered from small to large. In the first column there is the station ID, if available for the bound. The second column contains the modelled concentration at the station. The column *bound* is a lower or upper bound. The value in column *up_down* is 1 or -1 for a lower and upper bound, respectively. The column *coverage* is the cumulative sum of column *up_down* and gives the number of stations that cover the interval [*bound, next_bound*]. E.g., the third row represents the interval between 11.8 µg/m^3 (lower bound of station IE004BP) and 15.8 µg/m^3 (upper bound of station IE001BP). There are 325551 10-by-10-meter cells in this interval. The three intervals marked in blue are without coverage:

- [0, 11.6]: the low concentrations in the countryside around Cork
- [16, 19]: middle concentrations in the centre
- [25.6, max]: the highest concentrations in the centre

StationId	Concentration	bound	next_bound	up_down	coverage	pts_in_interval
	-	0.0	11.6	0	0	3385055
IE001BP	13.7	11.6	11.8	1	1	90244
IE004BP	13.9	11.8	15.8	1	2	325551
IE001BP	13.7	15.8	16.0	-1	1	15339
IE004BP	13.9	16.0	19.0	-1	0	19301
IE005BP	22.3	19.0	25.6	1	1	17998
IE005BP	22.3	25.6	Inf	-1	0	1964

Table 3: Overview table of the coverage in Cork for NO_2 in 2022 with definition Tol=15%. Each row represents a concentration bound for a station (3 stations, 6 bounds). The blue rows are not covered, the green ones are covered by one or two stations.

In Cork there are two stations with similar modelled concentration and by consequence similar intervals: IE001BP [11.6, 15.8] and IE004BP [11.8, 16.0]. Figure 8 shows the coverage map for Cork (left) and on the right the information of the table as a frequency histogram; on the x-axis the NO_2 concentration bounds, on the y-axis the point density. Uncovered intervals have a blue fill.

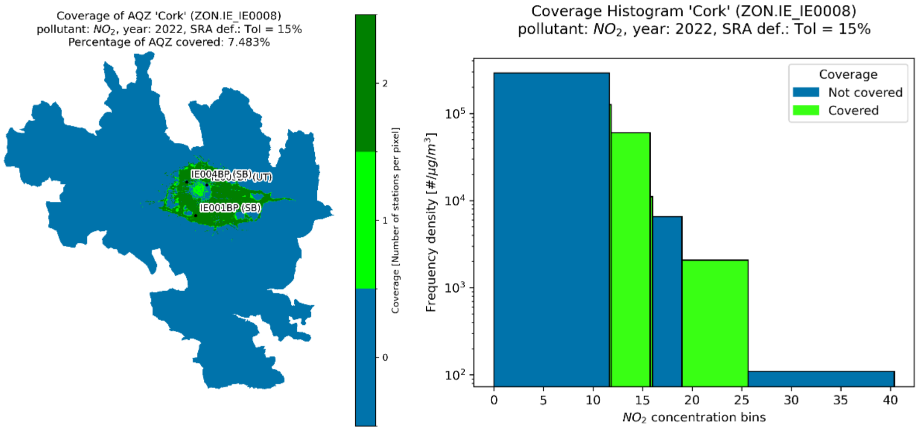

Figure 8: left: The coverage map of the Cork AQZ for NO_2 in 2022 with definition Tol=15%, right: Coverage histogram with the frequency density (number of 10-by-10-m cells per concentration)

Figure 10 and Table 4 illustrate the coverage situation for NO_2 in Dublin in 2020 with definition Tol=15% (left). The city of Dublin is very well covered, except the very centre, while the rural surroundings within the AQZ are not well covered. The under-covered surroundings, with concentrations between 0 and 10.3 µg/m^3, would be better covered by stations in the AQZ Rural Ireland. However, since the definition limits the SRA to the AQZ, the rural surroundings are not covered in the Dublin AQZ. Therefore, the restriction of the AQZ might be dropped for rural stations. This is still under discussion in FAIRMODE WG 8. The uncovered interval in the centre is rather wide: 24.8 to 31.0 µg/m^3. This is the blue patch in the centre in Figure 10. Concentrations above 49.5 µg/m^3 hardly occur (42 10-by-10-meter cells).

StationId	Concentration	bound	next_bound	up_down	coverage	pts_in_interval
	-	0.0	10.3	0	0	2593149
IE0140A	12.3	10.3	12.6	1	1	1157190
IE0136A	14.8	12.6	12.8	1	2	388108

IE0036A	15.1	12.8	12.8	1	3	409300
IE0132A	15.1	12.8	14.3	1	4	1254545
IE0140A	12.3	14.3	14.6	-1	3	422781
IE007AP	17.2	14.6	15.8	1	4	1135139
IE0131A	18.6	15.8	15.9	1	5	485728
IE0028A	18.7	15.9	16.7	1	6	708525
IE001AP	19.7	16.7	17.0	1	7	248539
IE0136A	14.8	17.0	17.0	-1	6	257318
IE004AP	20.0	17.0	17.3	1	7	52672
IE0036A	15.1	17.3	17.4	-1	6	61983
IE0132A	15.1	17.4	18.3	-1	5	177761
IE009AP	21.5	18.3	19.7	1	6	152405
IE007AP	17.2	19.7	21.4	-1	5	126106
IE0131A	18.6	21.4	21.6	-1	4	17918
IE0028A	18.7	21.6	22.6	-1	3	41664
IE001AP	19.7	22.6	23.0	-1	2	19899
IE004AP	20.0	23.0	24.8	-1	1	23057
IE009AP	21.5	24.8	31.0	-1	0	52915
IE0029D	36.4	31.0	31.2	1	1	3886
IE005AP	36.7	31.2	41.9	1	2	13313
IE0029D	36.4	41.9	42.0	-1	1	388
IE006AP	49.5	42.0	42.2	1	2	76
IE005AP	36.7	42.2	56.9	-1	1	2003
IE006AP	49.5	56.9	Inf	-1	0	42

Table 4: Overview table of the coverage in Dublin for NO_2 in 2022 with definition Tol=15%. Each row represents a concentration bound for a station (13 stations, 26 bounds). The green rows represent concentration intervals covered by one or more stations. The blue rows represent concentration intervals without coverage.

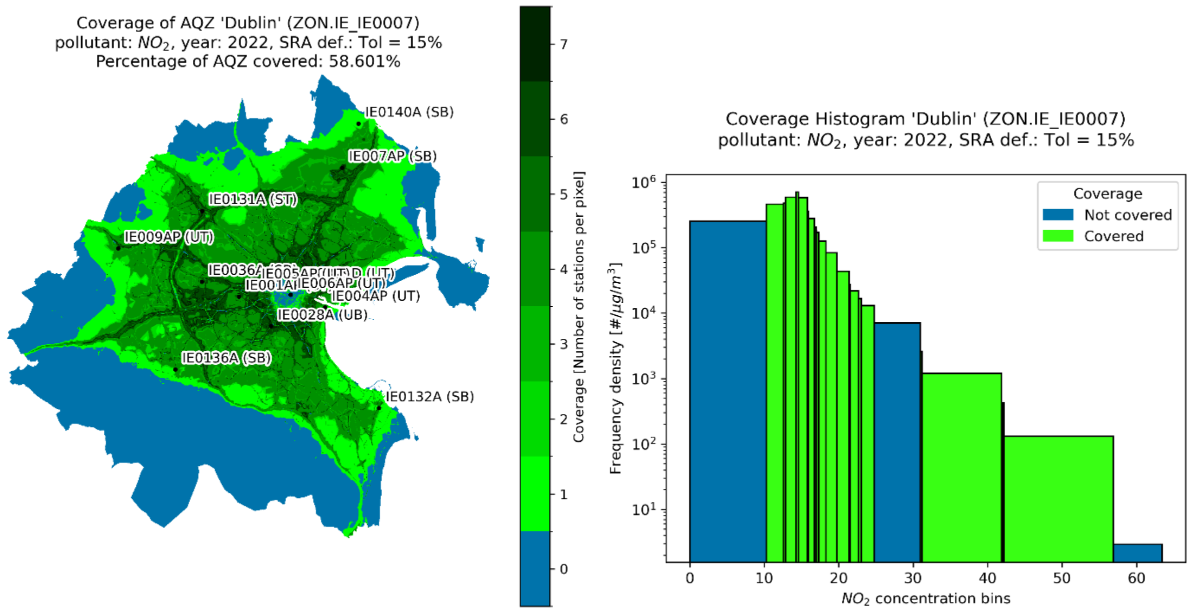

Figure 9: Left: The coverage map of the Dublin AQZ for NO_2 and $PM_{2.5}$ in 2022 with definition Tol=15%. Right: the corresponding coverage histogram.

For $PM_{2.5}$ the coverage in Dublin is complete (Figure 10). Also, in the AQZ Rural Ireland the coverage is complete Figure 11).

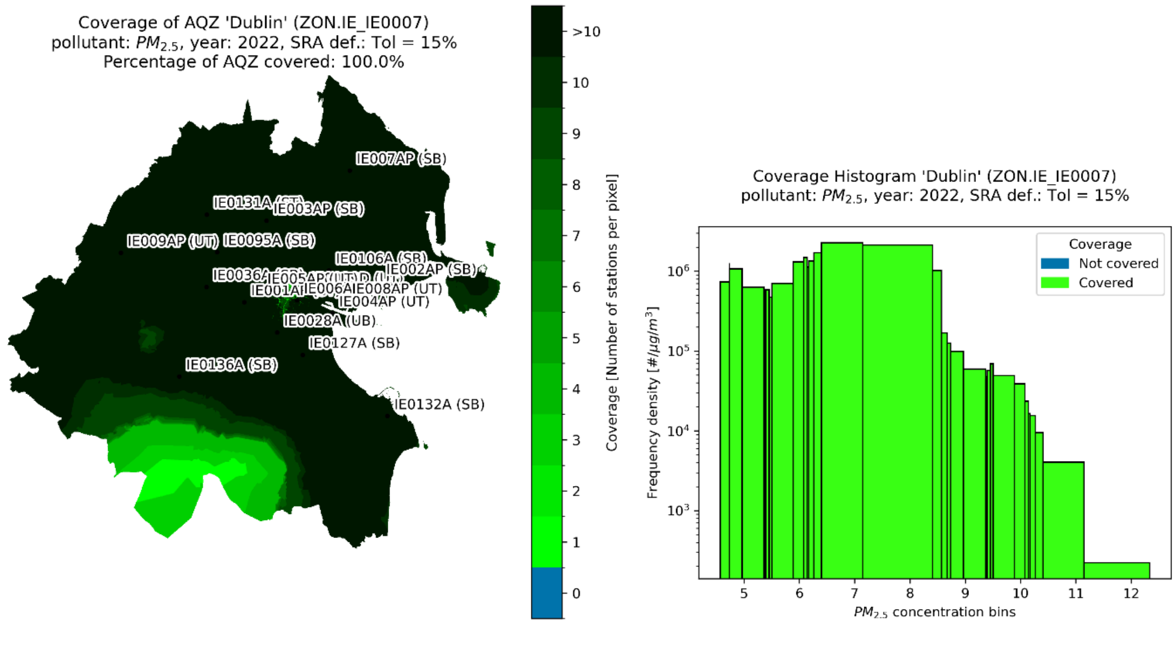

Figure 10: The coverage map of the Dublin AQZ for $PM_{2.5}$ in 2022 with definition Tol=15%.

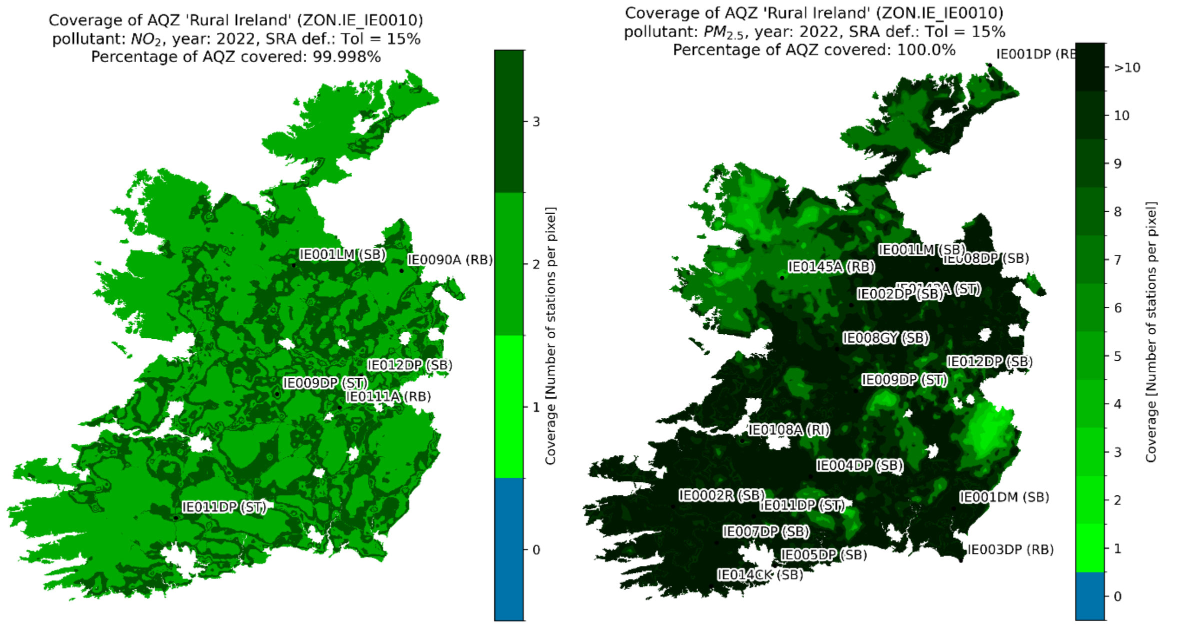

Figure 11: The coverage map of the Rural Ireland AQZ for NO_2 and $PM_{2.5}$ in 2022 with definition Tol=15%.

Figure 12 shows he whole of Ireland considered as a single AQZ, including the rural surroundings of Dublin and Cork. These rural surroundings are covered by a combination of stations, not only rural background stations. Figure 13 shows the SRAs of two rural background stations (IE0111A, Laois EmoCourt, and IE0090A, Monaghan Kilkitt Waterworks). Their areas do not represent the rural surroundings of Dublin and Cork. Figure 14 shows the SRAs of a suburban background (IE001CM Laois Portlaoise Dublin Road) and traffic station (IE009DP Offaly Birr). Their SRAs cover the surroundings of Dublin and Cork partially. Hence, to obtain full coverage for NO_2, not only for rural background stations, the restriction to the AQZ should be lifted.

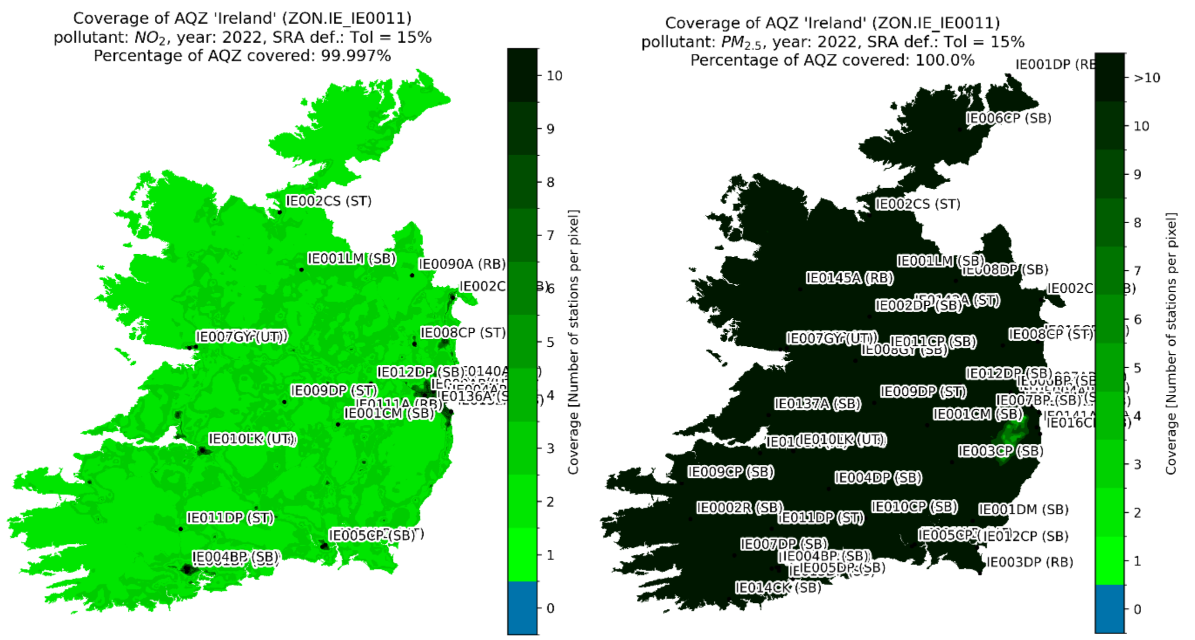

Figure 12: The coverage map of the whole of Ireland AQZ for NO_2 and $PM_{2.5}$ in 2022 with definition Tol=15%.

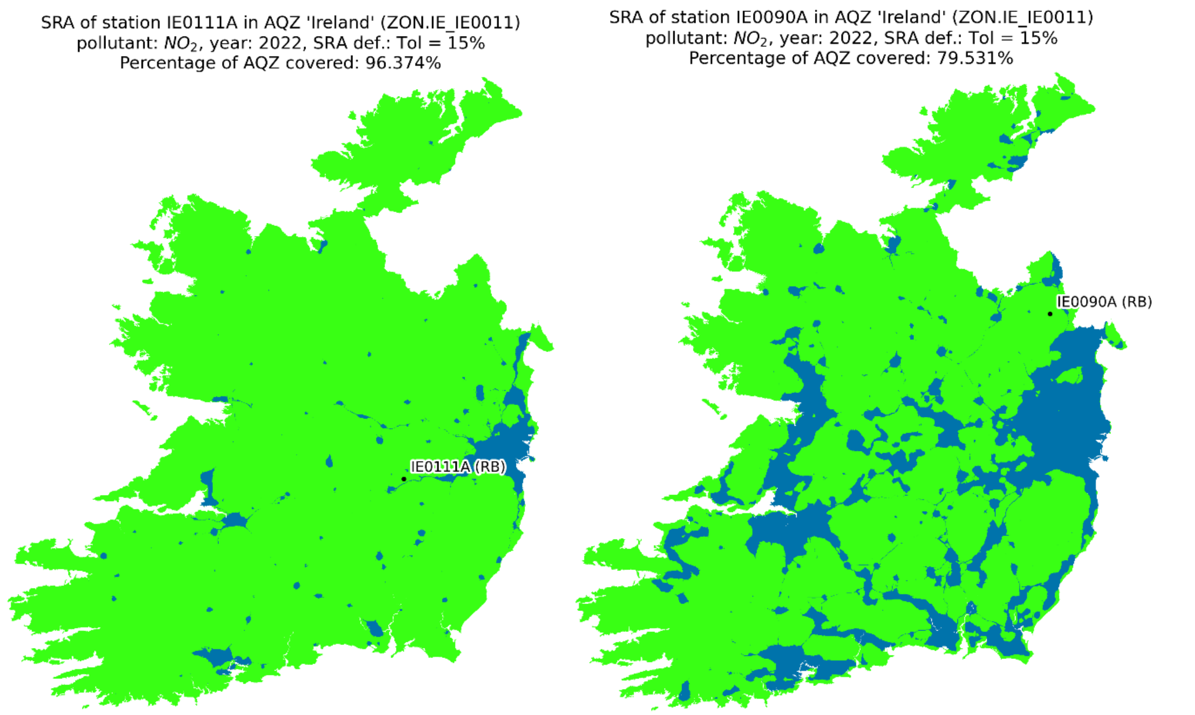

Figure 13: The SRAs of two rural background stations - IE0111A, Laois EmoCourt, and IE0090A, Monaghan Kilkitt Waterworks - considering the whole of Ireland as AQZ for NO_2 with definition

Tol=15%. Rural background stations alone are not enough to cover the rural surroundings of Dublin and Cork.

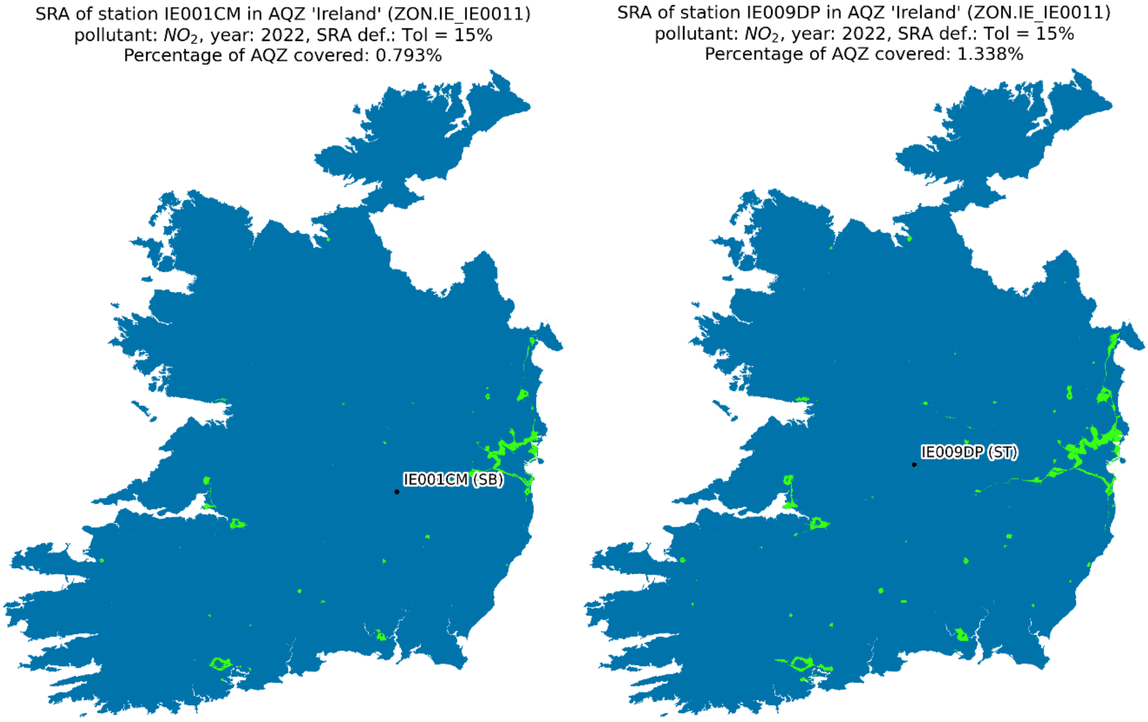

Figure 14: The SRAs of a suburban background - IE001CM Laois Portlaoise Dublin Road - and traffic station - IE009DP Offaly Birr - considering the whole of Ireland as AQZ for NO_2 with definition Tol=15%. These stations partially cover the rural surroundings of Dublin and Cork.

Table 5 summarizes the results of the coverage calculations. It shows for the year 2022 and the definition Tol=15% the percentage of each air quality that is not covered or covered by 1, 2 or more stations. The least covered AQZs are Cork, Dublin and Other Cities for NO_2. But when the AQZ for the whole of Ireland is considered the coverage for NO_2 is complete.

% AQZ covered by 0, 1, 2 or >2 stations	0	1	2	>2
ZON.IE_IE0007 (Dublin)				
NO2	41.4	16.9	2.1	39.6
O3	0.2	5.4	5.3	89.2
PM10	9.9	2.9	1.6	85.6
PM2.5	0.0	1.9	0.1	98.0
ZON.IE_IE0008 (Cork)				
NO2	92.5	1.1	6.4	
O3	1.3	43.1	19.7	35.8
PM10	3.1	10.4	1.7	84.9
PM2.5	0.1	0.0	0.3	99.6
ZON.IE_IE0009 (Other Cities)				
NO2	76.3	0.0	4.0	19.6
O3	5.1	7.3	1.3	86.3
PM10	0.0	3.5	6.6	89.9
PM2.5	0.0	0.0	0.1	99.9
ZON.IE_IE0010 (Rural)				
NO2	0.0	0.0	69.0	31.0
O3	0.0	0.0	0.8	99.2
PM10	0.5	6.8	1.0	91.7
PM2.5	0.0	0.0	0.4	99.6
ZON.IE_IE0011 (Ireland)				
NO2	0.0	0.0	67.6	32.4
O3	0.0	0.0	0.0	100.0
PM10	0.5	0.1	5.7	93.7
PM2.5	0.0	0.0	0.0	100.0

Table 5: The percentage of the AQZ that is not covered or covered by 1, 2 or more stations for the year 2022 and definitions Tol=15%.

2.4 Conclusions for Ireland

The current EU proposals for a definition of SRA have been applied to the Irish monitoring network. The analysis targeted NO_2, PM_{10}, $PM_{2.5}$ and O_3 for each AQZ in Ireland. The following conclusions and observations can be made.

- The whole Irish territory is well covered by air quality stations for all pollutants.
- All plots of SRAs and AQZ coverage maps have been created and analysed at network level.
- This analysis was presented to FAIRMODE WG 8 in a webinar on 14 December 2023.
- Compared to other EU AQ monitoring networks, Ireland has a dense monitoring network resulting in high coverage of the AQZs for each pollutant.[11]
    - The exception are the rural surroundings of Dublin and Cork. These parts are not covered for NO_2 but would be covered by rural, suburban, and urban stations outside of the respective AQZs. The FAIRMODE requirement that an SRA lies within an AQZ might need to be dropped and be replaced by a distance criterion for rural stations. This is still under discussion in FAIRMODE WG 8 on Spatial Representativeness.
- It is still unclear what the implications of the Spatial Representativeness will be for network design.
    - Does the whole AQZ have to be covered? E.g., It would not make much sense to put stations in the rural areas around Dublin. But it could be useful to add/move a station to the very centre of Dublin that is not covered for NO_2.
    - What happens if an AQZ is overcovered?
- A next step could be rerunning the analysis based on the final FAIRMODE definition. This will probably have a single tolerance of 15%, a cut-off of 2 µg/m^3. For rural stations the SRA might not be restricted by the AQZ but by distance from the station.

[11] https://fairmode.jrc.ec.europa.eu/Activity/CT8/Show/20231214

3 Results for Belgium

3.1 Spatial representativeness Area of a station over time

For NO_2 the spatial representativeness area (SRA) can vary considerably from one year to the next. Figure 15 shows the SRA of station Belliard Street (street canyon) in Brussels in 2015, 2016, 2019, 2020 and 2021. Because the contribution of road traffic to NO_2 becomes smaller over the years (see concentration maps in Figure 16) the SRA of this traffic stations expands beyond the street canyons in the city.

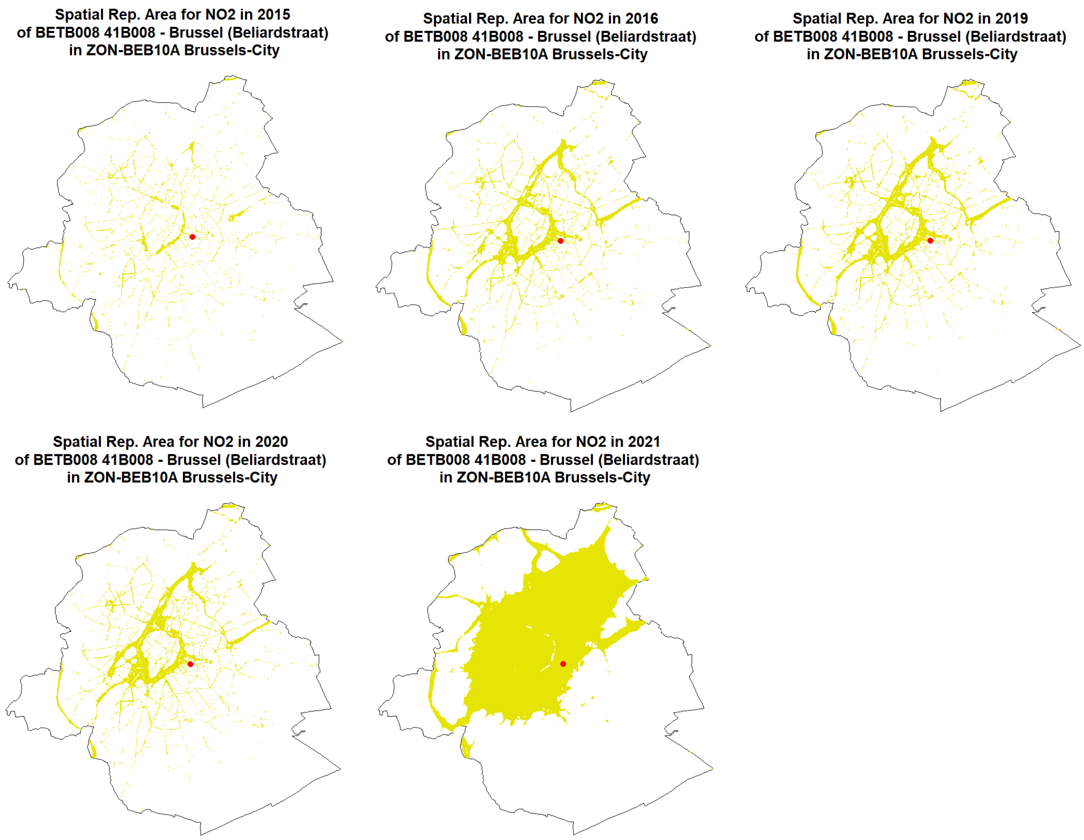

Figure 15: Spatial representativeness area of station Belliard Street (street canyon) in Brussels in 2015, 2016, 2019, 2020 and 2021.

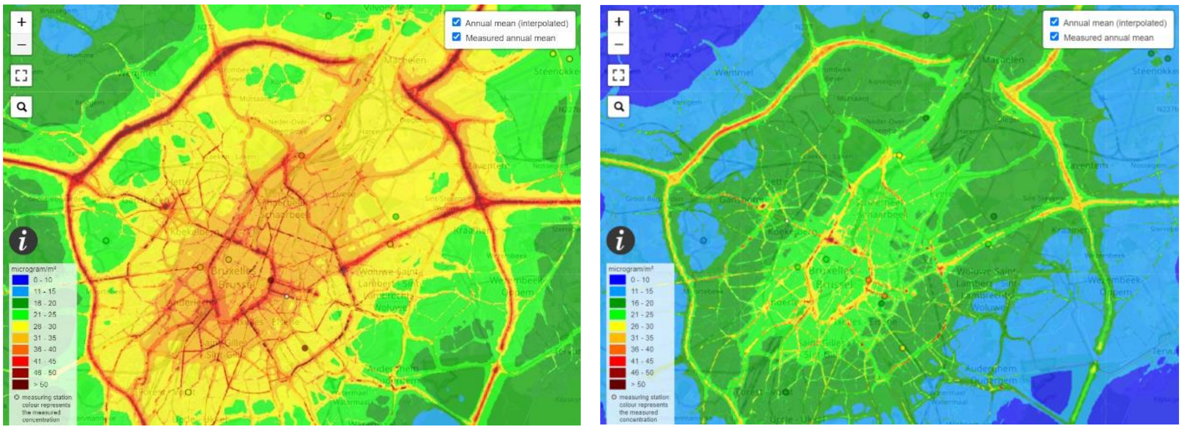

Figure 16: NO_2 concentration over Brussels in 2017 and 2020.

For O_3, $PM_{2.5}$ and PM_{10} the coverage is high and less variable over time. As an example Figure 17 shows the SRA of the station Meudon in Brussel for $PM_{2.5}$. Figure 18 shows the annual average $PM_{2.5}$ concentration over Brussels in 2017 and 2020.

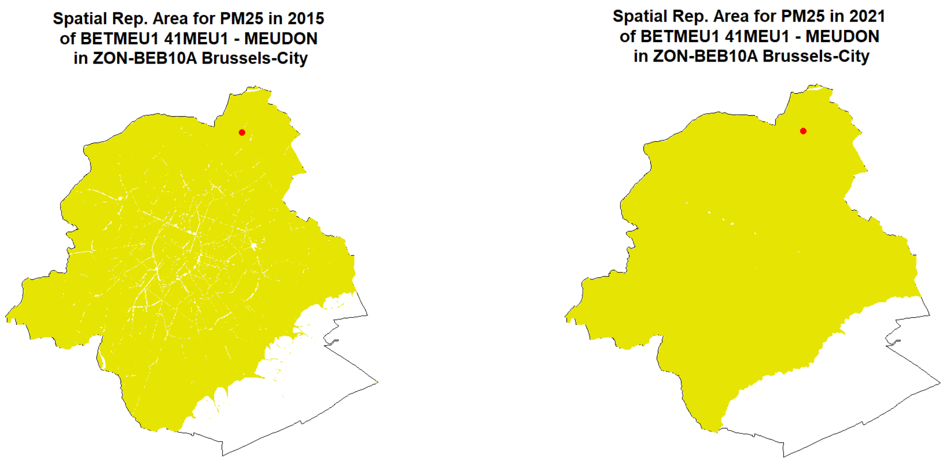

Figure 17: Spatial representativeness area of station Meudon (Urban background) in Brussels in 2015 and 2021.

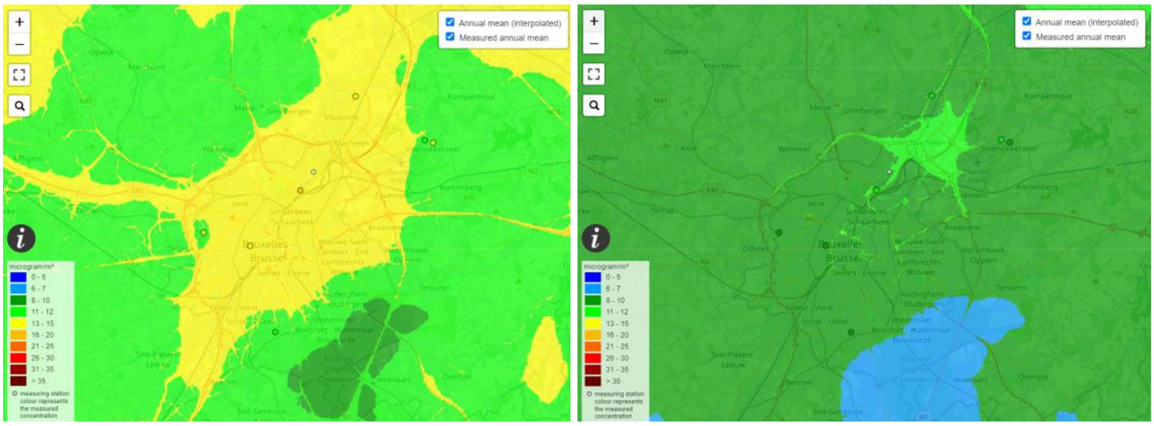

Figure 18: Annual average $PM_{2.5}$ concentration over Brussels in 2017 and 2020.

3.2 Coverage of the air quality zone

Impact of the tolerance; 15 % for all station types or differentiating between stations (10 % for rural and 20 % for traffic and industrial) doesn't make a big difference. This is illustrated by Figure 21. The uncovered area (red) in the south-east is a forest. Concentrations there are too low to be covered by the stations in the build-up area. This is a recurrent issue in the rural surroundings of cities (see also Figure 21).

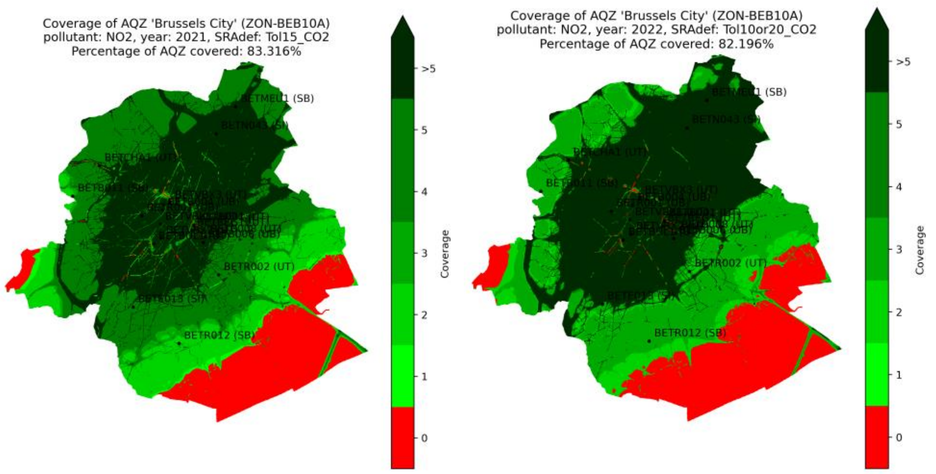

Figure 19: Coverage of Brussels for NO_2 in 2021 for different tolerance levels; 15 % for all stations vs 10 or 20 % depending on the station type.

The coverage over time doesn't change much for NO_2 in Brussels.

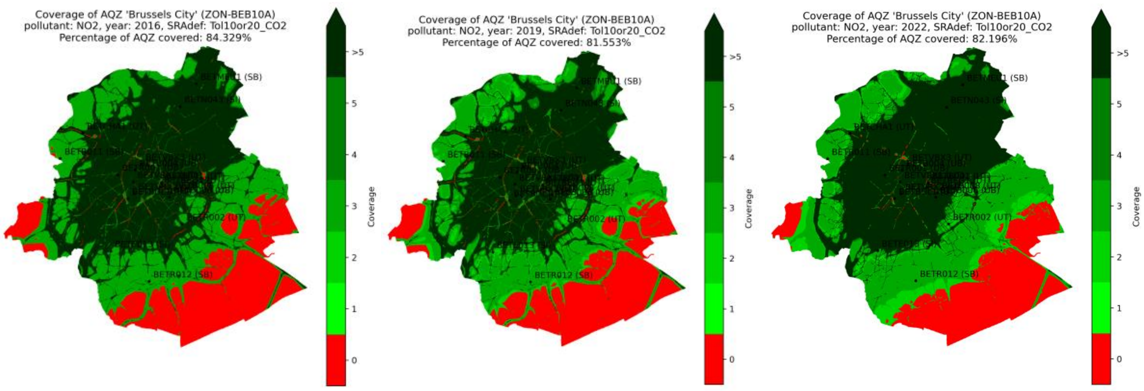

Figure 20: Coverage of Brussels for NO_2 over time: 2016, 2019 and 2022.

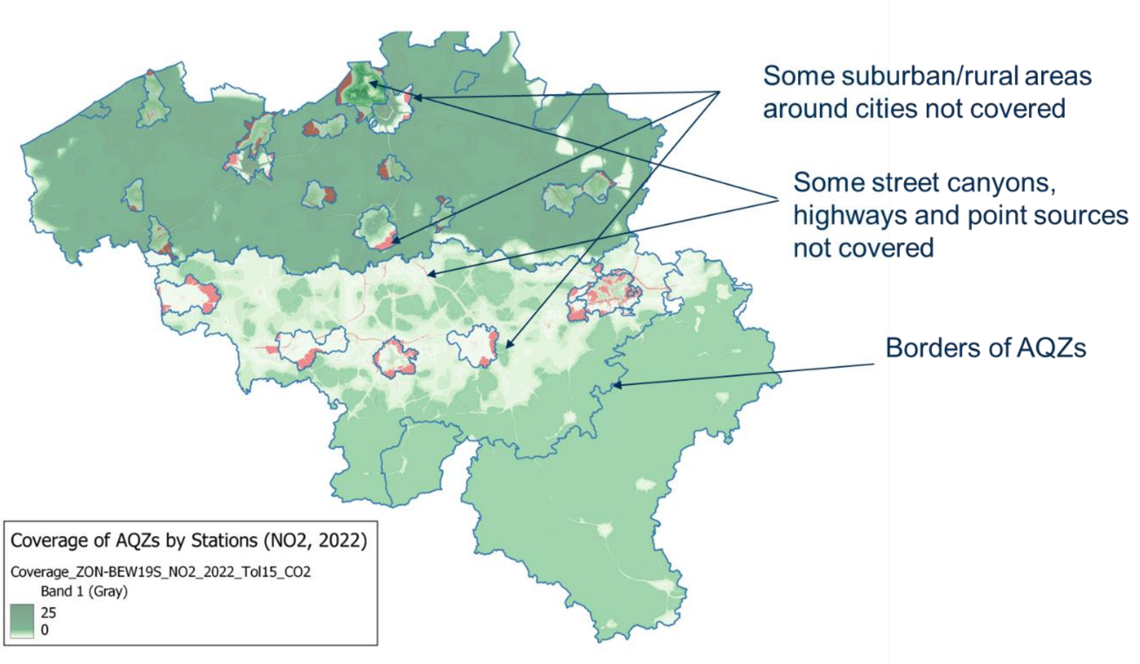

Figure 21: NO_2 coverage in Belgium in 2022, all AQZs together

3.3 Conclusions for Belgium

- In cities some canyons with high concentrations are not covered.
  - Not much of a problem in Belgium.
- Suburbs of cities not covered belong more to countryside AQZs: not covered inside the AQZ but by a station outside.
  - Solution: Drop restriction to AQZ for Background stations.
  - Rural regions: large areas not covered (especially for NO_2) because stations are in cities, not in the countryside. There is usually one (continental) background station per country, not per region. This leads to low coverage (except if there is an overall AQZ like in SK).
  - Not the case in Belgium
- The definition of SRAs can have an impact on the network design
  - Very big AQZ ➔ high coverage ➔ reduce stations?
  - To avoid misinterpretation the SRA definition should be provided as code, not in words.

4 Results for Croatia

4.1 Input data

- Air Quality Stations:
  - Location (from e-Reporting)
  - Station type (traffic, industrial, background). Some SRA definitions use the type.
  - Station area (rural, suburban, urban). Some proposed definitions treat rural stations differently)
  - Pollutants measured
- Air Quality zones
- Air Quality maps > ATMO-Street 10m-resolution maps

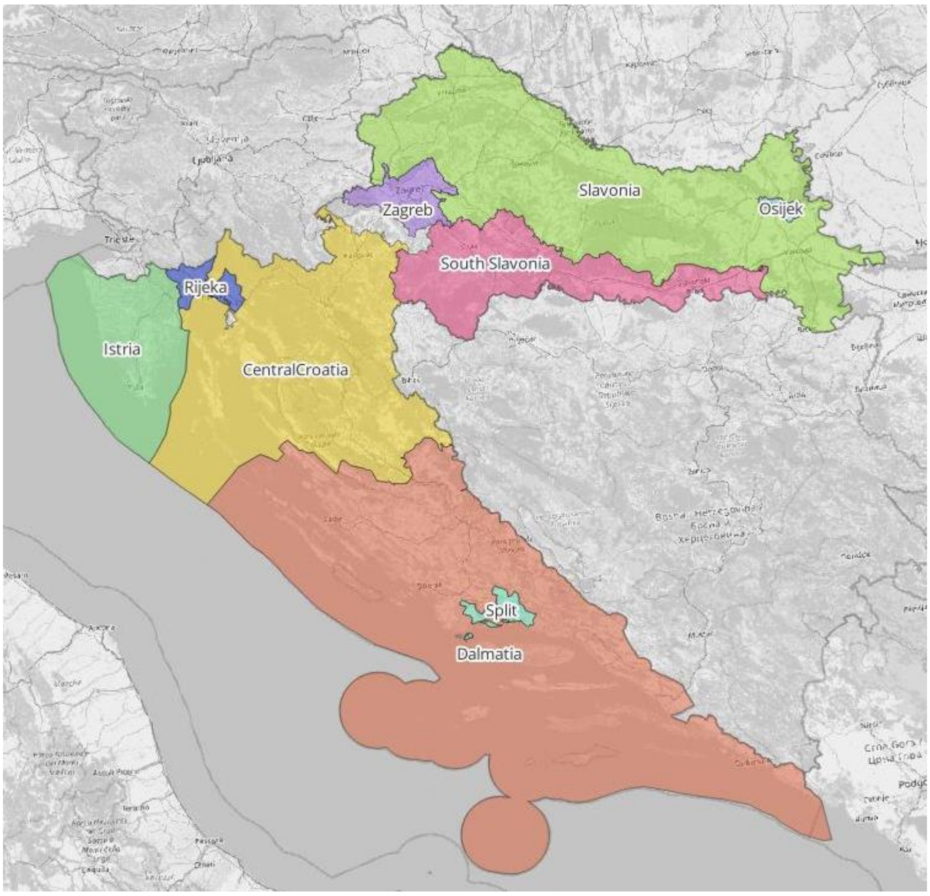

Figure 22: Air quality zones in Croatia, 9 non-overlapping zones.

There is some impact of the definition on the size of the spatial representativeness area (SRA). Figure 23 shows the SRA for NO_2 of an urban background station in Zagreb (HR0009A). The coverage is 6.3% for definition *Tol10or20_CO2 (left) and 9*.1% for definition *Tol15_CO2 (right).*

The high spatial variability of NO_2 leads to small SRAs.

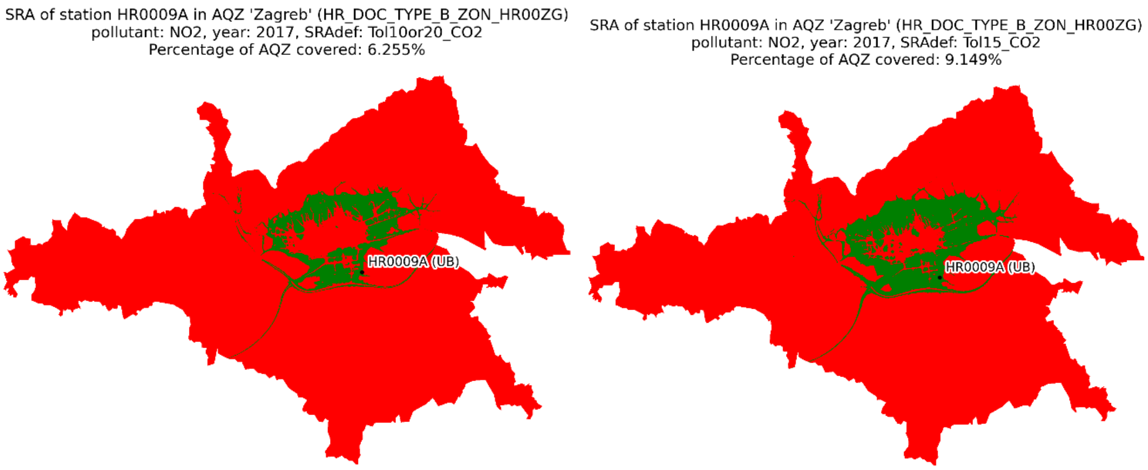

Figure 23: SRA of an urban background station in Zagreb (HR00ZG) according to both definitions; 10 or 20 % tolerance or 15 % tolerance.

The low spatial variability of $PM_{2.5}$ leads to large SRAs, as shown in Figure 24:

- Rural background station HR0013A in Central Croatia (left)
- Rural background station HR0017A in Dalmatia (right

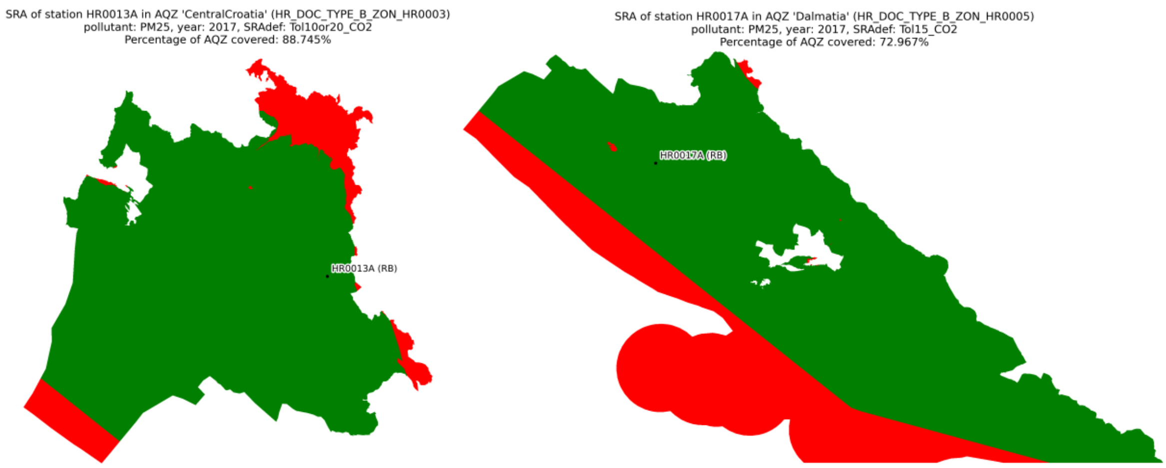

Figure 24: SRA for $PM_{2.5}$ of two rural station in Croatia.

4.2 Coverage

Figure 25 shows the coverage of the Zagreb AQZ for NO_2 and PM_{10}.

- NO_2 coverage (left): rural areas around the city not covered, very centre not covered, most of the city very well covered
- PM_{10} coverage (right): the city centre is well covered, rural areas around Zagreb are not covered.

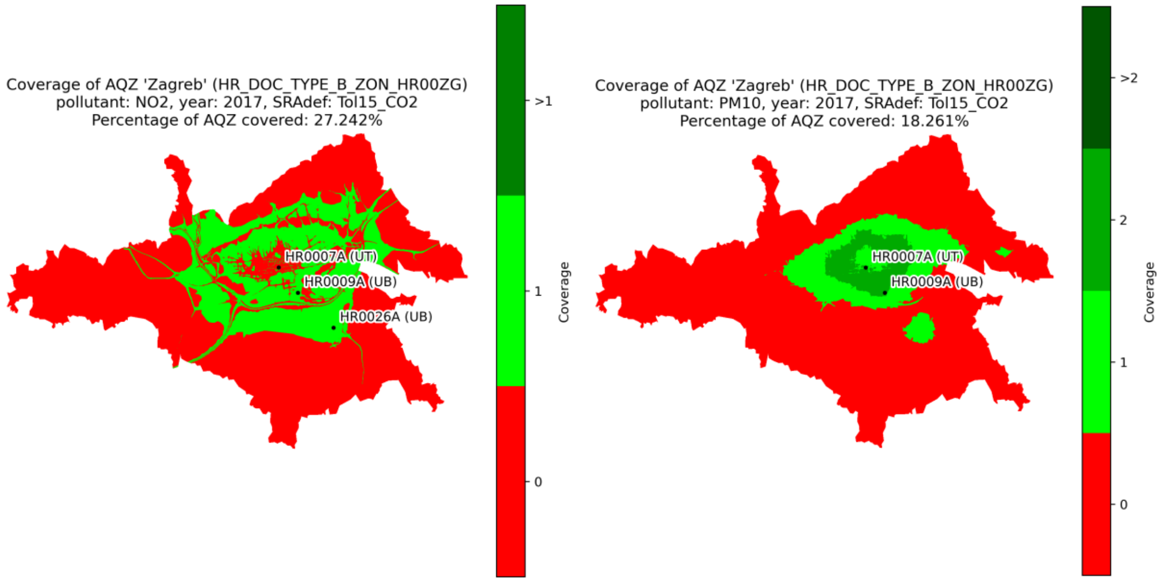

Figure 25: Coverage of the Zagreb AQZ for NO_2 and PM_{10} (15 % tolerance definition).

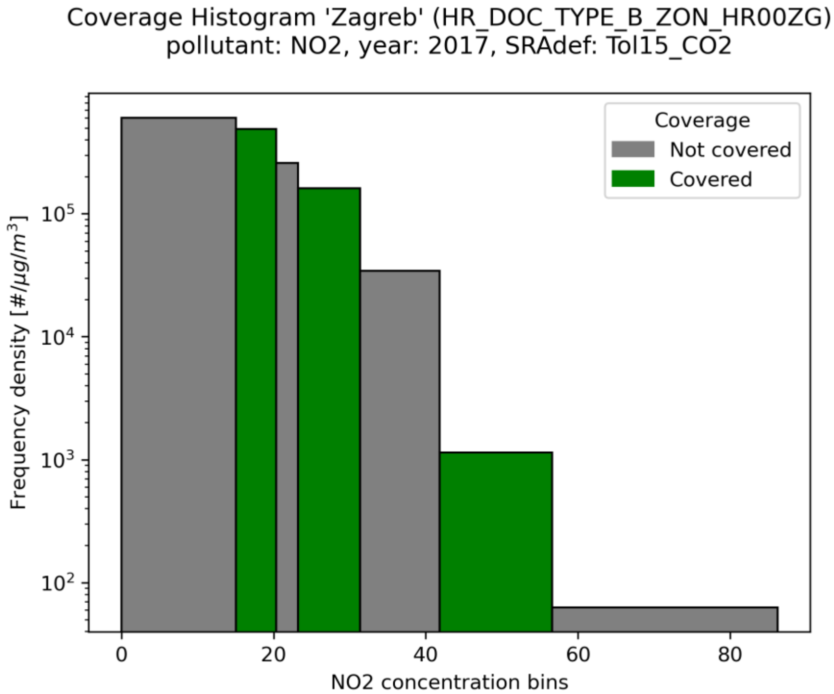

Figure 26: Coverage histogram of the Zagreb AQZ for NO_2

Figure 26 shows the coverage histogram for NO2 of the Zagreb AQZ. This histogram is made as follows:

1. Three NO_2 stations in Zagreb ➔ three concentrations at stations ➔ three lower and upper bounds
2. Sort the bounds from small to large
3. Count the number of 10-by-10-meter cells in the concentration map inside each interval between bounds and divide by the interval width ➔ Frequency density of the NO_2 concentration in coverage intervals

Uncovered intervals

- [0, 15.0]: rural surroundings of Zagreb
- [20.3, 23.2]: band with locations in the centre
- [31.4, 41.8]: wide band with locations in the centre
- [56.6, max]: very few locations in the centre (street canyons)

Figure 27 shows the coverage of the Central Croatia AQZ and neighbouring Dalmatia for NO_2.

- NO_2 coverage in Central Croatia is 86.2% (green areas), in neighboring Dalmatia 0%. But Dalmatia would be covered by station HR0013A in Central Croatia. Hence, lifting the restricting that an SRA lies inside the AQZ would solve this. There is a proposal to do this for rural stations if it makes sense geographically.

- The same is true for rural areas around cities (e.g., Zagreb)

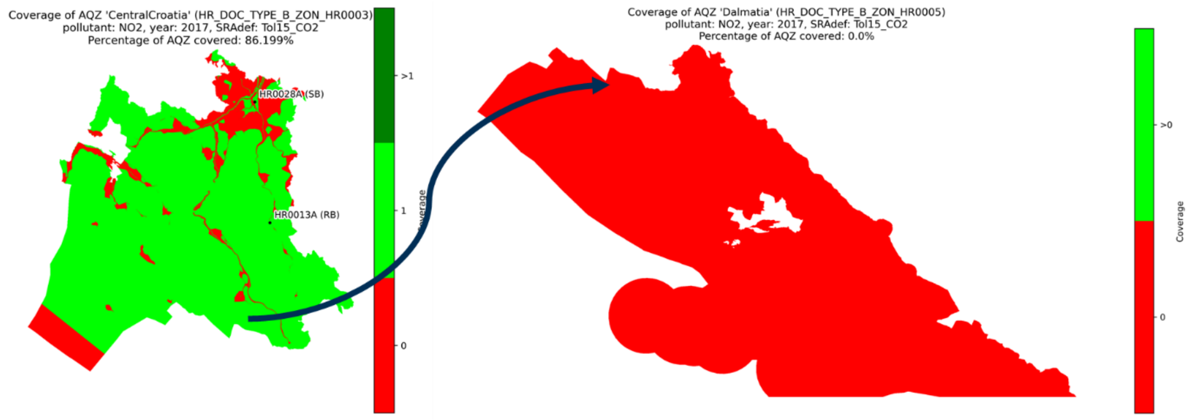

Figure 27: Coverage of the AQZs Zagreb and Dalmatia.

4.3 Conclusions for Croatia

- Many AQZs are not covered. This is due to the layout of AQZs in Croatia: one per region and some cities. AQZs without rural stations have a low coverage but would be covered by a station in a neighbouring AQZ.
- The rural surroundings of cities are not covered for NO_2 but would be covered by rural stations. ➔ The requirement that an SRA lies within an AQZ might be dropped and replaced by a distance criterion for rural stations. (under discussion in FAIRMODE WG 8)
- All plots of spatial representativeness areas and air quality zone coverage maps can be provided.
- This analysis was presented to FAIRMODE WG 8 in a webinar on 14 December 2023 together with similar analysis for Belgium, Ireland and Slovakia.
- Implications for network design are still unknown:
    - Does the whole AQZ have to be covered?
    - What if the AQZ is overcovered? ➔ remove stations?
- A next step could be rerunning the analysis based on the final definition. This will probably have a single tolerance of 15%, a cut-off of 2 $\mu g/m^3$. For rural stations, the SRA might not be restricted by the AQZ but by distance from the station.

5 Results for slovakia

5.1 Input data

The following data were used for the analysis:

- Air Quality Stations:
  - Location (from e-Reporting)
  - Station type (traffic, industrial, background). Some SRA definitions use the type.
  - Station area (rural, suburban, urban). Some proposed definitions treat rural stations differently)
  - Pollutants measured
- Air Quality zones (Figure 28):
  - Some overlapping zones: ZON-SK-BA01.1 'Outside Bratislava' overlaps with all other zones except ZON-SKBA01.1 'Bratislava City'
- Air Quality maps: ATMO-Street 10m-resolution maps

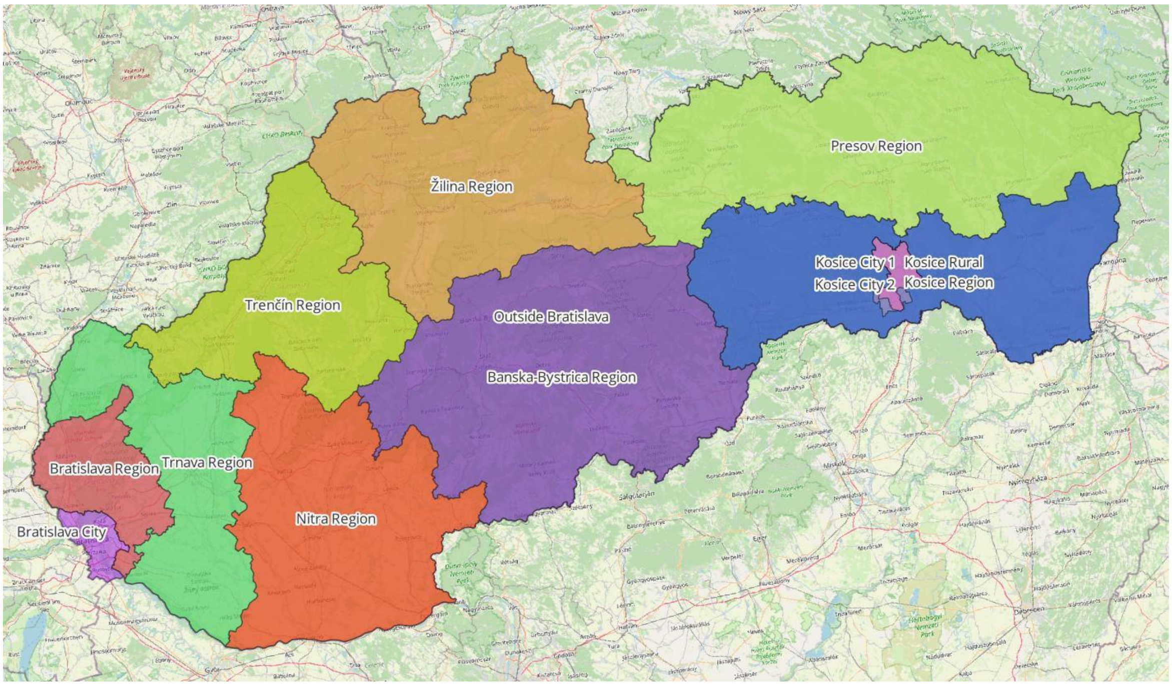

Figure 28: Air Quality Zones in Slovakia, except the one 'Outside Bratislava' which covers the whole country except the zone 'Bratislava city'.

5.2 Spatial representativeness areas according to both definitions

Figure 29 shows the SRA of an urban traffic NO_2 station in Bratislava (SK0061A) for two definitions:

- 13.1 % coverage for definition *Tol10or20_CO2 (left)*

- 9.8 % coverage for definition *Tol15_CO2 (right)*

High spatial variability of NO_2 leads to small SRAs.

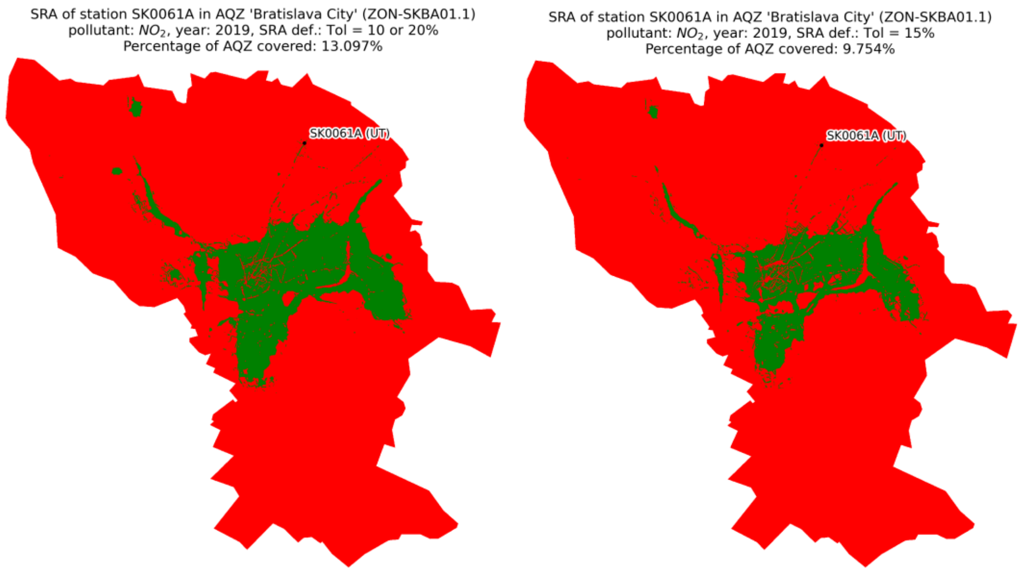

Figure 29: SRA for an urban traffic NO_2 station in Bratislava (SK0061A) for two definitions: 10 or 20 % tolerance (left) or 15 % tolerance (right).

Figure 30 shows the SRA of an urban background $PM_{2.5}$ station in Bratislava (SK0004A). In this case map is the same for both definitions (66.5 %) because cut-off of 2 ug/m^3 is used.

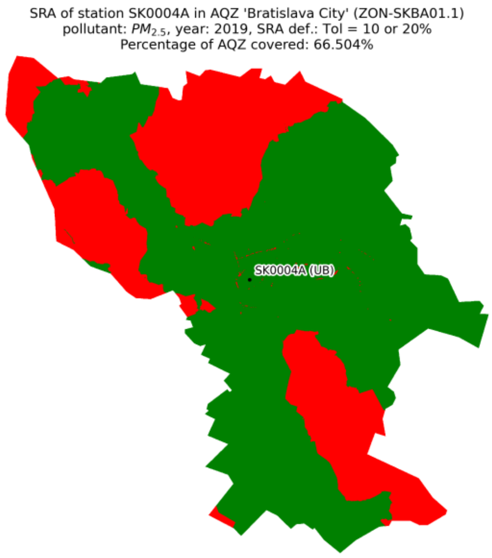

Figure 30: SRA for an urban traffic $PM_{2.5}$ station in Bratislava (SK0004A) for two definitions: 10 or 20 % tolerance (left) or 15 % tolerance.

Figure 31 shows the SRA of an urban traffic $PM_{2.5}$ station in Bratislava (SK0002A). The SRA covers 0.67 % of the AQZ with the definition using a15% tolerance and covers 9.6 % using the 20% tolerance.

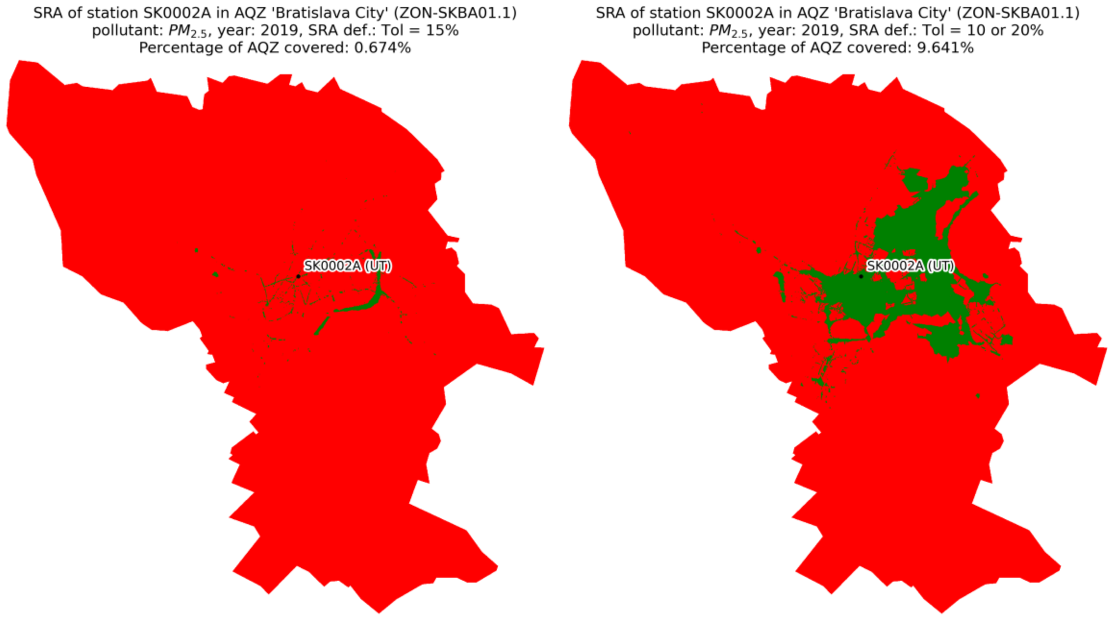

Figure 31: SRA for an urban traffic $PM_{2.5}$ station in Bratislava (SK0002A) for two definitions: 10 or 20 % tolerance (left) or 15 % tolerance (right).

5.3 Coverage

5.3.1 Coverage of the Bratislava-City AQZ

Figure 32 (left) shows the coverage for NO_2 of the 'Bratislava-City' AQZ. Most of the city very well covered. However, rural areas around the city are not covered because the concentration is lower than the lower bound of the lowest station. Some roads in the centre not covered because the concentration exceeds the higher bound of the highest measured value.

Figure 32 (right) shows the coverage for PM_{10}. The city centre is well covered, rural areas around Bratislava are not covered.

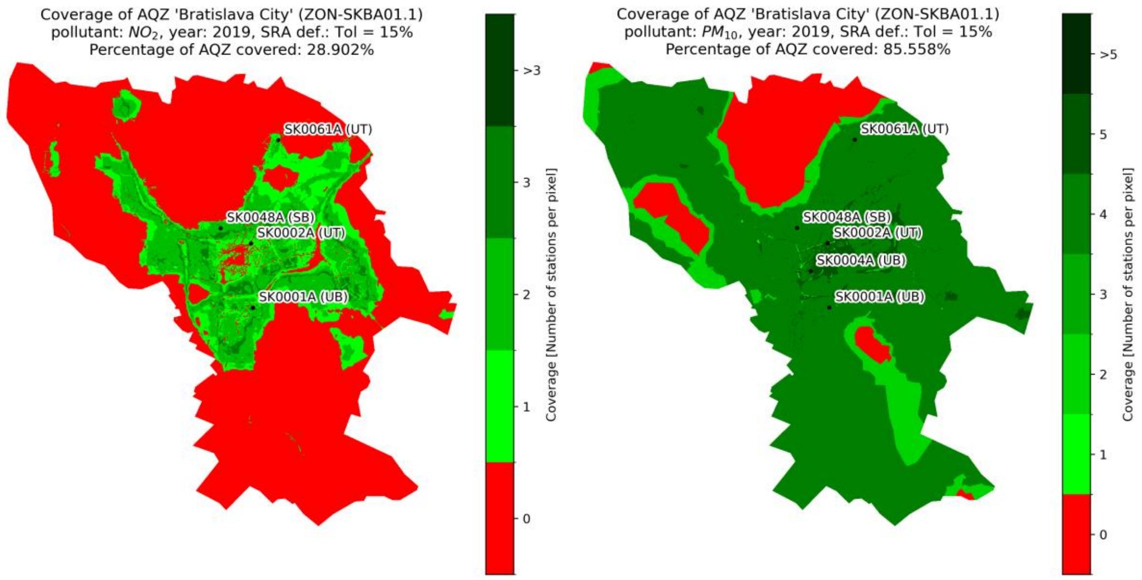

Figure 32: Coverage of the 'Bratislava-City' AQZ for NO2 (left) and PM10 (right).

Figure 33 shows a coverage histogram for the 'Bratislava-City' AQZ for NO_2. The histogram is mad as folows:

1. Four NO_2 stations in Bratislava ➔ Four concentration values at the stations ➔ Four lower and upper bounds.
2. Sort the 8 bounds from small to large.
3. Count the number of 10-by-10-meter cells in the concentration map inside each interval between bounds and divide by the interval width ➔ Frequency density of the NO_2 concentration in coverage intervals

This analysis shows that there are some uncovered concentration intervals:

- [0, 15.8]: rural surroundings of Bratislava
- [28, 39]: band with locations in the centre
- [45.8, max]: very few locations in the centre (street canyons)

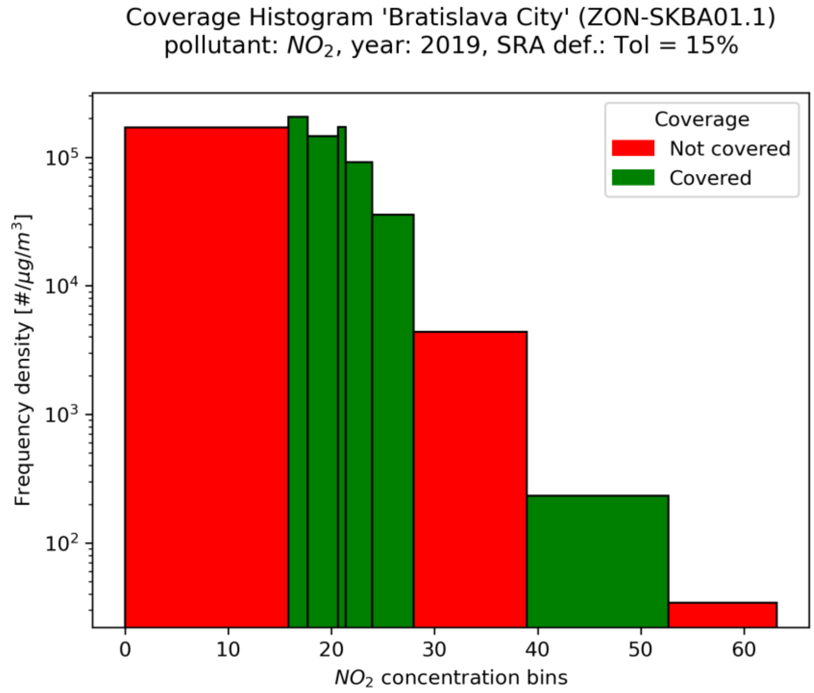

Figure 33: Coverage histogram of the 'Bratislava-City' AQZ for NO_2.

5.3.2 Coverage of AQZ Rural Areas

- NO_2 coverage in the all-but-Bratislava AQZ is 100%, in the Bratislava-city AQZ it is only 28.9% but the rural regions would be covered by stations outside the Bratislava AQZ ➔lifting the restricting that an SRA lies inside the AQZ would solve this. There is a proposal to do this for rural stations if it makes sense geographically.
- The same is true for rural areas around cities (e.g., Kosice)

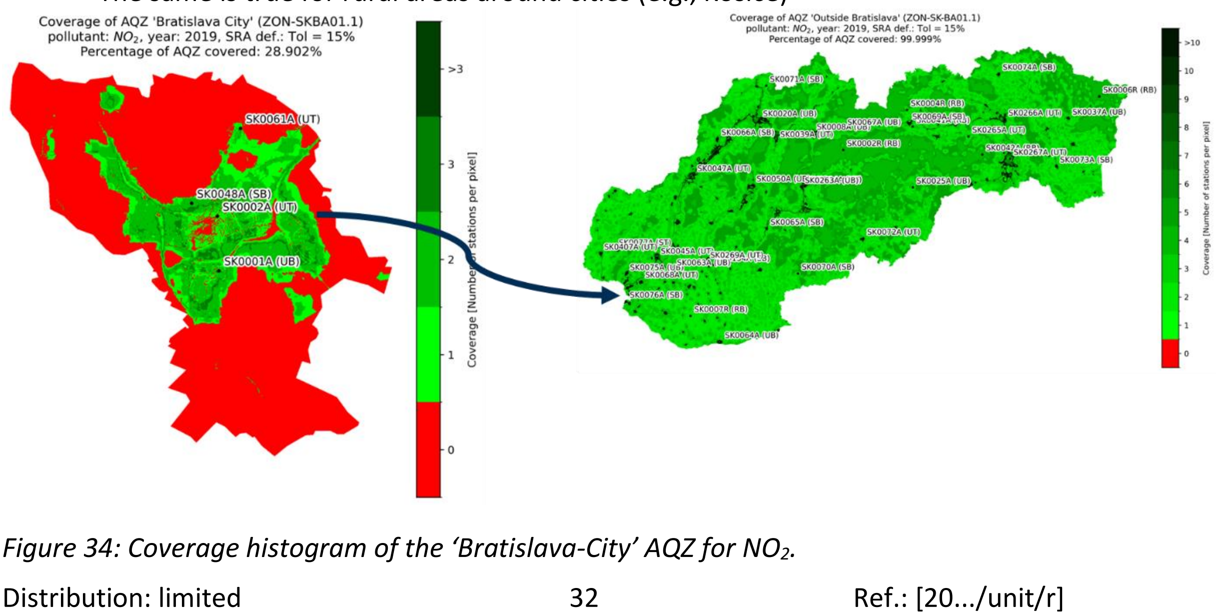

Figure 34: Coverage histogram of the 'Bratislava-City' AQZ for NO_2.

Is a distance limit required?

One can argue if a rural station on Chopok (SK0002R) or an urban background station in Jelšava (SK0025A) is representative for areas up to 400 km to the East or West. Rather geography and not just distance will determine how big an SRA is.

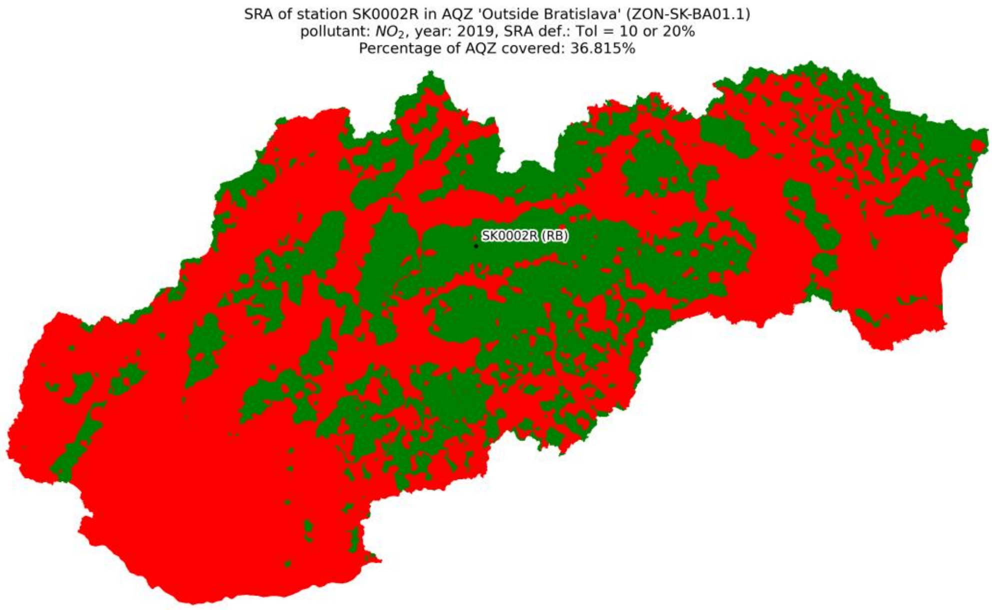

Figure 35: SRA of the Chopok Station for NO_2 in the AQZ 'Outside Bratislava'.

Conclusion

- Many provincial AQZs are not covered but in the all-but-Bratislava AQZ coverage is complete.
- Other countries don't have such extensive AQZ ➔ rural areas around cities not covered.
    - The requirement that an SRA lies within an AQZ might be dropped and replaced by a distance criterion for rural stations. (under discussion in FAIRMODE WG 8)
    - In SK this is only relevant for the Bratislava AQZ.
- All plots of spatial representativeness areas and air quality zone coverage maps can be provided (~700 plots and tables).
- This analysis was presented to FAIRMODE WG 8 in a webinar on 14 December 2023 together with similar analysis for Belgium, Ireland and Croatia.
- Implications for network design are still unknown:
    - Does the whole AQZ have to be covered?
    - What if the AQZ is overcovered? ➔ remove stations?
- A next step could be rerunning the analysis based on the final definition. This will probably have a single tolerance of 15%, a cut-off of 2 µg/m^3. For rural stations, the SRA might not be restricted by the AQZ but by distance from the station.

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