Deliverable D34 (D4.13)

Synthesis of RI-URBANS pilot actions, sustainability and importance on upscaling

RI-URBANS

Research Infrastructures Services Reinforcing Air Quality Monitoring Capacities in European Urban & Industrial AreaS (GA n. 101036245)

By

UHEL, CSIC, CNRS, FMI, UOB, UU, ISGlobal, PSI, KNMI & INOE

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Deliverable D34 (D4.13): Synthesis of RI-URBANS pilot actions, sustainability and importance on upscaling

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1. About this document

This report "*Synthesis of RI-URBANS pilot actions, sustainability and importance on upscaling*" (D34, D4.13) offers a summary of the synthesis of the pilot studies and includes integration of WP4 ("*Pilot Implementations for Testing and Demonstrating Services*") results to support the roadmap for interoperable services concerning air quality (AQ) enhanced observations, modelling, health effects, urban mapping of nanoparticles, hotspots (industrial, harbour, airport and traffic hotspots), participation of small/medium-sized enterprises (SMEs), and other relevant issues. Report also shows strategical analysis to link Air Quality Monitoring Networks (AQMNs) and European Research Infrastructures (RIs) such as the ACTRIS (The Aerosols, Clouds and Trace gases Research Infrastructure Network), ICOS (Integrated Carbon Observation System), IAGOS (In-service Aircraft for a Global Observing System) as well as nationally operated AQ supersites. Report also includes a coherent summary of the piloted actions and their benefits to the local AQMNs. All these supports the roadmap for Service Tools (STs) upscaling in WP5 ("*Strategic Guidance for Upscaling RI-URBANS STs*").

This is a public document that will be distributed to all RI-URBANS partners for their use and submitted to the European Commission as a RI-URBANS Deliverable D34 (D4.13). This document can be downloaded at https://riurbans.eu/work-package-4/#deliverables-wp4.

2. Summary synthesis of the WP 4 pilots

This section includes short summaries of each Pilot (P1-P5) activities in the Pilot Cities of 9 European metropolitan areas (ATH – Athens, Greece; BCN – Barcelona, Spain; BIRM – Birmingham, UK; BUC – Bucharest; Romania; HEL – Helsinki, Finland; MIL – Milano, Italy; PAR – Paris, France; ROT – Rotterdam, The Netherlands; and ZUR – Zurich, Switzerland) – extracted from the RI-URBANS completed relevant deliverables/reports. Table 1 associates the pilot cities with the pilot studies.

Table 1. RI-URBANS pilots and participating European cities. "X" indicates planned pilot contribution, and "F" indicates a follower-activity (table from Milestone M28 (M4.12)).

Pilot - Task City	ATH	BCN	BIRM	BUC	HEL	MIL	PAR	ROT	ZUR
P1 - T4.1 - NRT aerosols	X	F		F	X	X	X		X
P2 - T4.2 - NRT nanoparticles		X	X		X + F				F
P3 - T4.3 - Urban fine scale mapping	X		X	X	F		X	X	
P4 - T4.4 - Novel health indicators	X	X					F		X
P5 - T4.5 - Pollution hotspots				X	F	X		X	

2.1 Near-real-time source apportionment

To employ Near Real Time (NRT) – Source Apportionment (SA) tools for the ACSM (Aerosol Chemical Speciation Monitor) for carbonaceous particles (organics, OM, sulphate, SO_4, nitrate, NO_3, ammonium, NH_4, and chloride, Cl), and multi-wavelength Aethalometer (BC) data in order to allow uniform view on the sources of aerosol particles across European urban environments. The pilots in European urban areas/ cities (in supersites of Athens, Greece; Helsinki, Finland; Milan and Bologna, Italy; Paris, France; and Zurich, Switzerland) are in focus. The work done includes: (1) on a monthly basis, to automatically transfer from pilot sites measured carbonaceous particles and BC concentrations for reporting, visualisation, analysis and interpretation (D22 (D4.1)); (2) each pilot city, in addition to online SA, performed manual SA for quality control purposes (D23 (D4.2)); and (3) as the final product a synthesis of the NRT-SA results and benefits for the Air Quality Measurement Networks (AQNMs) in Europe (D24 (D4.3)).

The Deliverable D22 (D4.1) "*Monthly reports of concentration levels and PMF for each city during the pilots*" (https://riurbans.eu/wp-content/uploads/2024/04/RI-URBANS_D22_D4_1.pdf) summarises aspects of monthly reporting and visualization system of ACSM (Aerosol Chemical Speciation Monitor) for carbonaceous particles (organics, OM, sulphate, SO_4, nitrate, NO_3, ammonium, NH_4, and chloride, Cl) & multi-wavelength Aethalometer for black carbon (BC) measurements. These measurements are done at 13 stations (12 pilot sites and 1 follower site) situated in different environments (traffic – 2, urban – 9, suburban – 1, and regional – 1) in 8 cities. The data are transferred from pilot sites to the server, for further reporting (utilizing template) and visualisation, analysis, and interpretation. Results can be presented as an hourly, daily, monthly average values, as statistics, as time-series of concentrations of individual compounds, or compounds stack, etc. The Near Real Time (NRT) – Source Apportionment (SA) ACSM's and Aethalometer's data are successfully running, and results are available for Air Quality Measurement Networks (AQNMs). See these above in more details in D22 (D4.1).

The Deliverable D23 (D4.2) "***Comparison of NRT source apportionment and manual PMF in the pilot cities***" (https://riurbans.eu/wp-content/uploads/2024/05/RI-URBANS_D23_D4_2.pdf) summarises purposes of comparing SA outputs and needs of harmonization manual SA analyses by designing and sharing a unique protocol; feasibility of upgrading process in NRT demonstrated "offline" in Chen et al. (2022) using a combination of rolling Positive Matrix Factorization (PMF) and Chemical Mass Balance (CMB) models; constrains, a-values, number of factors run parameters, and criteria. Identified reasons for discrepancies include wrong input data lead to wrong SA output, input data consistency, gaps in data, optimizing NRT-SA parameters, external tracers. Results from the pilot phase show that consistency of NRT- SA results and the manual offline SA can be reached as long as the whole chain is operational, and prior evaluation was performed. Site-to-site discrepancies were observed, highlighting that some key parameters still need to be framed and harmonized. See these above in more details in D23 (D4.2).

The Deliverable D24 (D4.3) "*Summary: source apportionment pilots, sustainability and associated benefits*" (https://riurbans.eu/wp-content/uploads/2025/01/RI-URBANS_D24_D4_3.pdf) summarises the Pilot Phase, summary of main findings, recommendations, next steps of future of upscaling Near Real Time (NRT) – Source Apportionment (SA) tools. Before the pilot phase, all stations started the measurements and established the dataflows to servers. During the pilot year (2023) the stations ensured that measurements are running and dataflows work. After the pilot year the stations conducted offline source apportionment for ACSM data using seasonal and rolling Positive Matrix Factorization (PMF) analysis. Detailed description of the pilot sites, instruments operated, and software tools needed for NRT-SA. The strengths for **conducting organic aerosols NRT-SA based on ACSM data** include automatization of process with minimization of the user influence; provision results to user in real time; availability in easily understandable format in real time to anybody. The challenges are that experienced users with long-term experience on ACSM measurements and SA are preferred; knowledge about sources and source profiles are essential; correct measured input data are required; changes in particle sources found over time are problematic; optimizing the parameters, disruption in measurement, and validation results are essential; software is not open access yet. The strength for **conducting NRT-SA based on BC data** include mature measurement technique easy to run continuously, soot photometers producing data as a compact .txt files, easy to automate and produce reliable results, software mad in the projects and openly accessible. The challenges are that a priori knowledge of sources is preferable; amount of information produced can be limited; naming convention: “liquid” and “solid” nomenclature does not explicitly refer to pollution sources. A set of recommendations for both above mentioned SAs is given based in the instrument providing the data & it is summarised in the Chapter “Summary and Recommendations”. See these above in more details in D24 (D4.3). For harmonized real time SAs the following aspects were considered: reliability and trustability of the results; traceability of the process; fairness and open source; standardization; PM source apportionment; connection between different source apportionment analysis. Harmonization, sustainability and upscaling for SAs are summarized in the Chapters “Sustainability” and “Upscaling”.

Finally, the techniques and procedures developed and utilized are suggested in Service Tools of RI-URBANS - ST10: “Source apportionment of PM based on offline and online PM speciation” (https://riurbans.eu/wp-content/uploads/2025/02/ST10.pdf) & ST11: “Source apportionment of UFP, BC, OP and VOCs using receptor modelling” (https://riurbans.eu/wp-content/uploads/2025/02/ST11.pdf).

2.2 Near-real-time aerosol number size distribution

To carry out harmonised nanoparticle/particle number size distribution (PNSD) measurements at urban supersites in order to ensure their compliance with PNSD ACTRIS requirements. The pilots in European urban areas/ cities (Barcelona, Spain; Birmingham, UK; Helsinki, Finland; and Kasrene-Zurich, Switzerland) are in focus. The work done includes: (1) to make instrumental setups/checks with regards to performance, sampling protocols, best practices, sample drying, instrument maintenance, size classification, and standard operating procedures based on the operational ACTRIS standardised NRT data provision tool for sub-micron PNSD (developed in Copernicus project CAMS-21a); (2) to apply this to existing European urban PNSD systems from different cities in Europe, harmonizing measurements and providing NRT data to the end-users enabling contrasting data analysis between city environments and background sites; and (3) to show benefits of PNSD at pilot cities to AQMNs, and to include pilot cities as part of ACTRIS network (depending on national support).

The Deliverable D25 (D4.4) “*Nanoparticle concentration levels in the pilot studies*” (https://riurbans.eu/wp-content/uploads/2024/01/RI-URBANS_D25_D4_4.pdf) summarises nanoparticle number size distribution (PNSD) measurements with a mobility particle size spectrometer (MPSS) at selected pilot cities and results (PNSD levels). At Helsinki, the PNSD measurements are obtained from the SMEAR-III (Station for Measuring Ecosystem–Atmosphere Relations) urban background station, and from the Mäkelänkatu street canyon site (Helsinki urban area); at Barcelona - from the Barcelona urban background station; and similarly at Birmingham. All results are presented as time-series of PNSD between 10 and 800 nm. Nanoparticle concentrations in the above mentioned three pilot cities were calculated for the total concentration (10 – 800 nm) as well as for the nucleation (10 – 25 nm), Aitken (25 – 100 nm) and accumulation (100 – 800 nm) modes. The five-point summary statistics showed that the Helsinki urban background site has the lowest concentrations across all modes. The Mäkelänkatu street canyon site showed the 2nd lowest median concentrations across all modes, except accumulation mode. The Birmingham site showed the 2nd largest median total concentrations as well as nucleation and Aitken mode concentrations. The Barcelona site showed the largest overall median concentrations across all modes. Barcelona site showed the highest average particle number concentration (PNC), followed by Birmingham, and Helsinki sites. Analysis revealed common features between all these urban locations, but also some differences in concentration levels and diurnal variation related to unique location of each site. These results in general were consistent with earlier analyses of PNSD in urban sites (e.g., Trechera et al. 2023). The harmonization of measurement protocols and instrumentation within RI-URBANS and ACTRIS will make future comparison studies more straightforward. See these above in more details in D25 (D4.4).

The Deliverable D26 (D4.5) "*Nanoparticle aerosol pilots, sustainability, associated benefits for AQMNs and AQ policy*" (https://riurbans.eu/wp-content/uploads/2025/01/RI-URBANS_D26_D4_5.pdf) summarises main achievements of PNSD measurement at 5 pilot sites included upgrade to ACTRIS standard, calibration, implementation of NRT and operationalisation of NRT with data capture; and also demonstrated the NRT open information of these measurements, whose data are sent in a NRT way to EBAS (ACTRIS Data Centre). Each measurement site (mentioned in D4.4) including Zurich-Kaserne has unique characteristics, surroundings, instrumentation, list of measured chemical species and aerosols, etc. See these above in more details in D26 (D4.5). The answers on three strategic questions with regards to implementation and continuation the NRT operations at the sites are summarized in the Chapter "Sustainability". These questions concern upgrading to ACTRIS standards, implementing of NRT, and interests/commitment to continue NRT provision to EBAS. The associated benefits for AQMNs and AQ policy are summarized in the Chapter "Summary and Recommendations".

Finally, the recommendations of the RI-URBANS Service Tool ST1: "Ultrafine (=nano)-Particle Number Size Distributions (UFP-PNSD)" (https://riurbans.eu/wp-content/uploads/2025/04/ST1.pdf) guided and contributed to improved and advanced PNSD measurements at the pilot cities.

2.3 Air quality mapping

The two RI-URBANS deliverables using described modelling tools, mobile measurements of nanoparticles, BC and PM mid-cost sensors, novel dispersion measurements, and participation of networks of citizens and new innovative instruments by SMEs, allows RI-URBANS to reproduce high pollutant concentrations in the streets, hourly maps required for summer and winter at spatial scales less than 100 metres helping to describe the variability of outdoor exposure of nanoparticles and other pollutants. Seasonal measurement campaigns (at fixed stations, mobile - car, cycling, walking) in the pilot cities and dispersion modelling activities at finest scales contributes to mapping of the air quality in the pilot cities which are located in European urban areas/ cities (Athens, Greece; Bucharest, Romania; Paris, France; Birmingham, UK; Paris, France; Rotterdam, The Netherlands; and Helsinki, Finland).

In particular, **the Deliverable D27 (D4.6): "*Air pollution variability in the pilot studies*"** (https://riurbans.eu/wp-content/uploads/2024/03/RI-URBANS_D27_D4_6.pdf) summarises piloted mapping of air pollution in European urban areas/ cities (Athens, Greece; Bucharest, Romania; Paris, France; Birmingham, UK; and Rotterdam, The Netherlands) including innovative modelling, monitoring, and crowdsourcing. For that an advantage of developed Service Tools (STs) is used to describe the variability of outdoor exposure of ultrafine particles (UFP) and other pollutants using modelling tools, mobile measurements of UFP, black carbon (BC) and mid-cost sensors for measuring atmospheric particulate matter (PM), novel dispersion measurements, and the participation of networks of citizens and new innovative instruments by SMEs.

In cities, the urban background concentrations are often simulated with chemical transport models (CTM), which typically have horizontal resolutions coarser than 1 x 1 km, and they cannot capture the city heterogeneities. Variability along traffic axes and streets is particularly important for NO_2, BC, UFP represented by the number of particles, $PM_{2.5}$ and PM_{10}. This variability may differ depending on season, and a resolution finer 100 m may be necessary to characterise them. Depending on the pilot city, two main approaches are used to represent these heterogeneities: (1) Deterministic models with a multi-scale and multi-pollutant (NO_2, $PM_{2.5}$, PM_{10}, BC, Number concentrations) approach (Paris, Birmingham, and Athens); (2) Analysis of mobile monitoring and/or citizen observations using Land Use Regression (LUR) modelling (Rotterdam and Bucharest) to map Number, $PM_{2.5}$, PM_{10}, NO_2 concentrations. To characterise the air pollution variability in the pilot cities, concentrations are mapped and compared for winter and summer periods (see in details for each pilot city listed above in the RI-URBANS D27 (D4.6)). A summary of results obtained from these pilots is the following:

The concentrations for NO_2 were higher in winter than summer in Birmingham, and in the urban background of Paris and Athens. However, they are similar at traffic sites in Paris and Athens. The higher urban background NO_2 in Athens and Paris may be linked to lower boundary layer (BL) height during winter than summer, decreasing the volume in which city emissions are diluted. The influence may not be seen at traffic stations, because NO_X emissions are for a large part emitted by traffic and as NO. The NO emissions are transformed into NO_2 locally by photochemistry. Photochemistry is higher in summer than winter, leading to higher local-NO_2 production in summer. However, concentrations in streets are also influenced by the urban background. Hence, the higher local-NO_2 production in summer is counterbalanced by the higher urban background NO_2 in winter. In Rotterdam and Bucharest, NO_2 concentrations tend to be similar in winter and summer, probably because the measurements are performed using localized sensors, which may better represent the local scale than urban background variations. For particle mass, BC and $PM_{2.5}$, concentrations are higher in winter than in summer in all cities probably because of lower BL height, and residential heating emissions. For particle number (PN), concentrations are higher in winter in Paris, Birmingham and Bucharest, but these are similar in winter and summer in Rotterdam.

RI-URBANS utilised several techniques in the mapping. The concentrations mapped using the different approaches are compared to measurements performed at fixed stations. Averaged concentrations are compared at urban background sites and traffic sites when possible. For cities using the mixed-LUR approach, such as Bucharest and Rotterdam, the comparison focuses on mean concentrations and their variations. For cities using deterministic modelling, more detailed statistics of comparisons, as daily concentrations were computed. The model performance goal of Boylan and Russell (2006) was met over Paris for NO_2, $PM_{2.5}$, BC and PN, except for BC in winter. For all pollutants in all seasons, the FAC2 (measures the fraction of estimates within a factor of two of the observations & should be as close to 1 as possible) is high, e.g. closer to 0.88-1.00. Note that there is no traffic station to evaluate PN concentrations in winter. For Birmingham, the mean concentrations compare well to the measurements, the Mean Fractional Bias (MFB) are low for NO_2 and $PM_{2.5}$, and the FAC2 is high: 77-82 for NO_2, 76-86 for $PM_{2.5}$, 61-69 for PN. However, there is no traffic station to evaluate PN and only one urban background station for PN. Over Athens, the model performance goal is met in summer for NO_2 and $PM_{2.5}$, but NO_2 is underestimated in the winter and in the urban background in summer. There is no urban background measurement of $PM_{2.5}$ in winter.

The variability of concentrations, the range of average values for the Normalised Standard Deviation (NSD) of NO_2, BC and $PM_{2.5}$ tends to be similar between different cities, indicating that the variations of the concentrations are of the same order. In Paris, Birmingham and Athens, it is lower for $PM_{2.5}$ than for NO_2, indicating that the variations within the city of NO_2 are higher than those of $PM_{2.5}$. In Paris, the NSD is also high for BC compared to $PM_{2.5}$. This is because NO_2 and BC are largely emitted by traffic, whereas the sources of $PM_{2.5}$ and pathways of formation are more diverse. For NO_2, the average NSD ranges are: 0.14-0.27 over Paris, 0.14-0.36 over Birmingham, 0.16-0.19 over Athens, 0.11-0.20 over Rotterdam, 0.10-0.18 over Bucharest. For $PM_{2.5}$, the average NSD ranges are: 0.06-0.07 over Paris, 0.05-0.09 over Birmingham, and 0.09-0.17 over Bucharest. It is 0.01 in Athens, but with large variations within the city. Similar NSD ranges for $PM_{2.5}$ and NO_2 in Bucharest may indicate that the traffic sources significantly contribute to $PM_{2.5}$ emissions in Bucharest. For BC, the average NSD is about 0.27 in Paris, and it ranges between 0.11 and 0.17 in Rotterdam. The higher NSD observed in Paris than in Rotterdam could be related to differences in the traffic fleet. For PN, the NSD ranges are: 0.25-0.29 in Paris, 0.026 -0.060 in Birmingham, 0.12-0.25 in Rotterdam, 0.132-0.209 in Bucharest. The NSD values are lower by a factor, at least 10, in Birmingham than in Paris and Rotterdam, probably because aerosol dynamics (condensation/ evaporation and coagulation) was not considered in Birmingham. These processes may be partly responsible for the large PN variability observed. The large NSD in Paris, Rotterdam and Bucharest indicates the large variability of PN and the probably fairly strong influence of traffic sources. The NSD detailed above are averaged over cities, but they can reach higher values, especially in districts where there are large roads. The large values simulated for NO_2, BC and PN show that the concentrations of these pollutants vary largely within cities. Variations of $PM_{2.5}$ are lower.

The ratio of NO_2, BC and BC, PN, to analyse further the variability of pollutants, were computed in Paris and Rotterdam based on quantile division. In Paris, low NO_2, BC and PN were observed in areas far from the roads. In Rotterdam, high NO_2 concentrations were more restricted to the city centre, UFP was most pronounced on the major roads and BC was relatively elevated in the suburbs. In Birmingham, higher ratios between predicted NO_2 and $PM_{2.5}$ or PN were more restricted to the city centre and areas near motorways, which were more influenced by higher traffic induced NO_2. In Athens, $NO_2/PM_{2.5}$ were predicted high mainly over the road network. The Normalised Mean Bias (NMB), which quantifies the differences between the sub-grid variability and the regional-scale urban background concentrations simulated with a Chemistry-Transport Model (CTM) of 1 x 1 km resolution, is higher over Paris for NO_2, BC, PN (between 36-87%) than $PM_{2.5}$ (about 9%), in agreement with the higher NSD. It is the highest for BC (between 75-87%).

To estimate the population exposure to air pollution over Paris, the MAJIC database (Letinois, 2014) was used to estimate the number of inhabitants in each building. People living in a building that is on the main street are assigned to that street concentration. People living in a building that does not open directly onto the street are assigned to urban background concentrations. The Exposure Scaling Factor (ESF) is defined as the ratio of the population weighted concentration (PWC) to the regional scale concentration. The ESF is the highest for NO_2, BC, PN, and $PM_{2.5}$ in order, and the average ESF in Paris is higher than 1 for all pollutants in both summer and winter. The ESF is the highest (about 1.3) for BC, indicating that outdoor population exposure is under-estimated by as much as 30% when considering urban background concentrations with a resolution of 1 x 1 km. The ESF is the closest to 1 for $PM_{2.5}$ (1.03 to 1.04). Over Athens, the exposure is determined using 100 m^2 spatial resolution for the population and for the model sub-grid representation. The domain-averaged ESF value is equal to 1 for $PM_{2.5}$, as the variability of $PM_{2.5}$ is low within the city. However, an ESF value lower than 1 is obtained for NO^2. The main difference between Paris and Athens lies in the representation of the sub-grid variability. As a Gaussian-based approach is superimposed to the road network, the sub-grid (100 m^2) concentrations can be lower than the main grid (1000 m^2) concentrations. In the Eulerian street-network approach used in Paris, sub-grid local-scale concentrations are not averaged over 100 m^2 grid cells, but local-scale concentrations are averaged within each street segment, leading to local-scale street concentrations always higher than background concentrations and ESF values much higher than 1 for NO_2, BC and PN.

The Deliverable D28 (D4.7): "Summary: mapping procedures, sustainability and applicability for upscaling" https://riurbans.eu/wp-content/uploads/2025/01/RI-URBANS_D28_D4_7.pdf) summarises pilot studies (including methods, results, validation and required resources) in European urban areas/ cities (Athens, Greece; Bucharest, Romania; Paris, France; Birmingham, UK; Rotterdam, The Netherlands; and Helsinki, Finland). RI-URBANS adopted two approaches in the pilot studies to develop high spatial resolution maps of outdoor air pollutants across cities. The first approach involves statistical models (Land Use Regression, LUR) derived from measured concentrations. The second approach involves high-resolution dispersion modelling. The pollutants covered in the pilots include UFP, BC, NO_2, particle mass concentrations (PM), $PM_{2.5}$, PM_{10}. The D28 (D4.7) takes advantage of developed Service Tools and summarises variability of outdoor exposure of nanoparticles and other pollutants using modelling tools, mobile measurements of nanoparticles, BC and PM mid-cost sensors, novel dispersion modelling. Note, Deliverable D13 (D2.5) underlines critical importance of improved spatiotemporal resolution of multi-component air quality (AQ) data for better understanding of the connection between AQ parameters, human exposure and consequent health effects. Advances in sensor technologies and the availability of portable and sensing devices give rise to new opportunities for mobile monitoring and denser fixed sensor networks, compared to the current spatially sparse, temporally rich routine monitoring. More specifically, summarized complementary approaches to traditional AQMS in order to derive high-resolution exposure maps based on monitoring data. These monitoring approaches were subsequently tested in the RI-URBANS pilot cities: Birmingham, Rotterdam, and Bucharest. The lessons learned from these pilot city initiatives are presented in Deliverable D14 (D2.6). Deliverable D27 (4.6) described some results of the pilot studies focusing on variability of concentrations between seasons and variability within 1 x 1 km areas.

In this D28 (D4.7), for mapping part with modelling, for Birmingham, the Gaussian-based dispersion modelling approach with the ADMS urban model was developed in which street-scale dispersion was given with an ultimate resolution of 10 x 10 m, validated using data from a dense local sensor network supplemented with citizens monitoring for $PM_{2.5}$, BC, NO_2 and nanoparticles. For Paris, the Eulerian multi-scale modelling approach with CHIMERE coupled with street scale model MUNICH (for NO_2, $PM_{2.5}$, PM_{10}, nanoparticles, BC, inorganic and organic aerosols) and a hybrid approach with CHIMERE coupled with ADMS with data assimilation (for NO_2, PM_{10}, BC) were elaborated and applied. The pilots partly address different issues and use different approaches. See in details pilot cities listed above in the RI-URBANS D28 (D4.7). A summary of results obtained from these pilots is the following:

For the Birmingham pilot, (see more details in D28 (D4.7)), the monitoring and dispersion modelling were performed. Monitoring included citizen-involved approaches using low-cost sensors (LCS). The air quality assessment at neighbourhood scale included monitoring at 6 static measuring points (incl. Birmingham Air Quality Supersite, BAQS, as a background site) which allowed evaluation of long-term LCS performance vs. research grade instruments for air pollution monitoring, to take into account local sources of pollution, temporal variations of pollutants and finer scales. The street level air quality assessment and pollution source apportionment included monitoring as walking sessions (in total, 51) and cycling sessions (34) with involvement of UB students. This allowed to calculate effect of both regional and local sources in fine details (about 100 x 100 m). Furthermore, the extent of the effect of point sources provided valuable information for potential public health studies of hyperlocal sources of pollution. The prediction $PM_{2.5}$ concentrations through the monitoring a combination of collected data with additional traffic count, topography and demographist data were processed to create a model which be used to fill data gaps and predict PM concentrations when measured data is not available (Baruah et al., 2024). The local scale ADMS-Urban Gaussian plume air dispersion model has been developed to generate high resolution air quality datasets for NO_2, $PM_{2.5}$ and PNC. The modelled concentrations satisfy the strictest performance criteria for NO_2 and $PM_{2.5}$ at both background and traffic stations in winter and summer, and the less strict performance criteria for particle number concentration (PNC) at the background station. The average NO_2 concentrations range is 13 and 29 µg m^3, and it is lower than in Paris, but higher than in Athens. Average concentrations of between 7 and 14 µg µg m^3 for $PM_{2.5}$ were lower than Paris and Athens (in summer), but equal to Athens in winter. The average PNC are, at least, 5 times lower than in Paris: the average ranges between 2,100 #particles cm^3 and 2,900 #particles cm^3.

For the Rotterdam pilot, (see more details in D28 (D4.7)), the citizen-based mobile monitoring, following methods developed by van den Bossche (2015), including sampling whilst commuting (to/from work) with potable instruments for black carbon (BC) to map exposure and derive representative long-term average air quality maps during commuting hours in winter and summer. Note, that similar hourly concentration variability was observed at fixed sites of AQMN as from mobile BC. An additive or multiplicative normalization procedure was applied for mobile data to derive representative spatial maps of BC exposure. The car-based mobile monitoring was also implemented. A car to measure the ambient concentrations of NO_2, BC and UFP was used. The selected area was divided into 8 polygons, each containing a part of the city centre and residential areas as to randomize road characteristics at much as possible in each polygon. The collected measurements allow to produce mixed-effect model predictions for air pollutants levels or long-term average air pollution concentration maps for the Rotterdam metropolitan area, by the means of LUR-models, and where it is possible, to investigate if the industrial sources (mainly port activities) could be adequately captured in the mobile monitoring campaign. The pilot was successful – in producing plausible maps of the individual pollutants, less successful – in the interpretation rested upon monitoring data directly. The ratios between the pollutants offer new insights into the source contribution of the pollutants. UFP is often elevated near airports, whereas BC and NO_2 are not. With a systematic mobile monitoring in areas of interest, generating sufficient repetitions the mobile approach could have been more successful in mapping specific source areas.

For the Bucharest pilot, (see more details in D28 (D4.7)), mobile measurements campaigns without citizens' involvement for UFP, different particle matter fractions (PM_1, $PM_{2.5}$, and PM_{10}) and gaseous compounds (NO_2) were measured along the routes (incl. heavy traffic roads, inside the city, residential, industrial, commercial, sub-urban areas) as well as the ESCAPE Land Use Regression (LUR) models together with PyLUR tool and QGIS were implemented. Maps based on car measurements showed that the UFP sources seem to be well distributed during summer, while winter is characterized by more homogeneous sources. Significantly elevated concentrations are found mainly on the industrial area and urban agglomerations, but also on some important traffic routes. The average UFP number concentration along the mobile route presents a large spatial gradient mostly during summer, with differences up to a factor of 2 in the mean. The NO_2 concentration showed sharper gradients during summer, when the concentrations are higher on the main roads. On both seasons the main streets, including the Bucharest ring road, represented the main NO_2 source. Also, the city centre roads are highlighted, where the intensity of the traffic persists for the entire day. The model performance (obs/mod) showed for NO_2 (12.58/20.35 ppb for summer and 15.98/17.17ppb – for winter) and for PM_{10} (24.64/22.94 µg m^3 – for summer and 26.33/27.81 µg – for winter). Overall, the model performed well, although NO_2 values are overestimated, while PM_{10} levels are slightly underestimated. As the model was trained with mobile on-road data, it is not surprising that it overestimated NO_2 exposures.

The normalised standard deviation (NSD) computed for all pollutants to access spatial sub-grid variability (within 1 x 1 km) showed that higher variability of pollutants concentrations was observed during summer, in winter important variation is highlighted mostly on the ring road areas. Similar variability patterns are observed for the particle's concentrations. UFP and NO_2 mean NSD were higher during summer. The seasonal difference of the pollutants corresponding to daytime working days are highlighted. The PM and NO_2 concentrations were very dependent on the season and city area (industrial, residential, or background areas). Campaigns and the model outputs extend the data available routinely for the city both in time and space, fostering a better assessment of seasonal and spatial pollutants variability. The model output maps are validated for PM_{10} and NO_2 concentrations, and although modelled for UFP, but not validated due to the lack of other independent measurements for the rest of pollutants.

For the Paris pilot, (see more details in D28 (D4.7)), techniques based on deterministic modelling provided high-resolution outdoor exposure city maps.

The first, Eulerian multi-scale modelling approach with CHIMERE coupled with street scale model MUNICH (for NO_2, $PM_{2.5}$, PM_{10}, nanoparticles, BC, inorganic and organic aerosols) showed that the modelled concentrations satisfy the strictest performance criteria for all modelled pollutants (NO_2, BC, $PM_{2.5}$ and UFP) at both urban background and traffic stations in winter and summer. The both observed/modelled mean concentrations at traffic sites are higher than the concentrations at urban background stations: for NO_2 – 41.2/38.8 µg m^3 compared to 15.0/14.5 µg m^3 (in summer) and 43.4/52.1 µg m^3 compared to 25.1/25.2 µg m^3 (in winter); for BC – 2.8/2.6 µg m^3 compared to 0.9/0.7 µg m^3 (in summer) and 3.2/3.7 µg m^3 compared to 1.3/1.5 µg m^3 (in winter); for $PM_{2.5}$ – 11.2/9.9 µg m^3 compared to 6.9/6.8 µg m^3 (in summer) and 17.2/22.0 µg m^3 compared to 12.1/13.2 µg m^3 (in winter).

The second, hybrid approach with CHIMERE coupled with ADMS with/without data assimilation (for NO_2, $PM_{2.5}$, BC) also showed that the modelled concentrations satisfy the strictest performance criteria for modelled pollutants (NO_2, BC, $PM_{2.5}$ and UFP) at both urban background and traffic stations in winter and summer. With data assimilation (DA), improves systematically the Mean Fractional Error (MFE). Moreover, bias is higher for BC at traffic stations. The both observed/modelled (without | with DA) mean concentrations at traffic sites are higher than the concentrations at urban background stations: for NO_2 – 41.2/(37.8|34.1) µg m^3 compared to 15.0/(19.8|16.8) µg m^3 (in summer) and 44.6/(50.7|40.8) µg m^3 compared to 26.9/(33.0|28.4) µg m^3 (in winter); for BC – 2.8/(2.9|2.7) µg m^3 compared to 0.86/(1.0|0.6) µg m^3 (in summer) and 3.1/(3.8|2.7) µg m^3 compared to 1.4/(1.2|0.9) µg m^3 (in winter); for $PM_{2.5}$ – 11.2/(11.6|11.5) µg m^3 compared to 6.9/6(6.6|6.9) µg m^3 (in summer) and 17.3/(23.9|17.0) µg m^3 compared to 12.5/(16.3|12.4) µg m^3 (in winter).

For the Athens pilot, (see more details in D28 (D4.7)), the concentration variability and outdoor population exposure to air pollution in Athens was assessed using the multi-scale numerical atmospheric model system CAMS/ WRF/ EPISODE-CityChem. Results showed that NO_2 concentrations tend to be higher along streets with high traffic in both seasons. The spatial distribution of both pollutants is similar with higher NO_2 than $PM_{2.5}$ values at the inner-city centre. The concentrations are higher in winter than in summer, especially for $PM_{2.5}$ (and for background NO_2). The contributions of residential emissions from heating tend to increase particle concentrations during wintertime. NO_2 photochemistry is enhanced in Athens during summer, which is partly the reason for higher NO_2 concentrations at the traffic sites. Other reasons for seasonal differences include the lower boundary layer during wintertime and the stronger dispersion phenomena during summertime, which affect concentrations, mainly downwind the road network.

The simulated concentrations (100 m cells) showed that for both pollutants the mean concentrations compare well with observations satisfying the model performance criteria and goal of the Boylan and Russell (2006) in most cases. The both observed/modelled mean concentrations at traffic sites are higher than the concentrations at urban background stations: for NO_2 – 59.6/44.0 µg m^3 compared to 19.5/13.5 µg m^3 (in summer) and 51.6/41.4 µg m^3 compared to 26.0/14.3 µg m^3 (in winter); for $PM_{2.5}$ – 15.0/15.1 µg m^3 compared to 12.6/15.3 µg m^3 (in summer) and -/- (no obs.) µg m^3 compared to 23.1/17.6 µg m^3 (in winter).

For the Helsinki pilot, (see more details in D28 (D4.7)), a suite of intensive campaigns was carried out in the RI-URBANS, a summary of the Kumpula campus campaign measurements of BC (Elomaa et al. 2024) and mobile bike-based measurement campaign (Kleemola et al. 2024) are given in this D28 (D4.7). In urban area, on the Kumpula campus the measurements were conducted at the SMEAR-III station as urban background environment (Järvi et al. 2009) and at the Mäkelänkatu supersite as the urban street canyon (Barreira et al., 2021). A network of four types of small-scale filter-based BC sensors was deployed with the objective to evaluate these sensors for monitoring ambient BC concentrations and to study variations in high resolution. Sporadic and transient high values were observed both with sensors and with the reference instruments indicating spatially and temporally varying BC sources in the area. Results showed that the BC concentration reached occasionally concentrations up to 2000 ng m^3 while during most of the time the concentrations remained within 100-800 ng m^3. The sensor data correlated relatively well against the reference and the Pearson correlation coefficient was 0.78-0.84. The highest concentrations are associated with emissions from local traffic and the signature of the arterial road from Helsinki city centre to Lahti, Kustaa Vaasantie in south-east direction provides a significant contribution to the observed BC concentrations. The local emissions from the traffic in the campus, including the city buses are clearly indicated by the wind-rose. The highest concentrations are in the ground level and roof level near the Physicum building (campus) and lower concentrations prevail further away from the bus lines.

The mobile bike-based $PM_{2.5}$ measurements were also performed in Helsinki, where instrumentation was constructed on a bike and connected to cloud-services for data access. Sampling was done on a route that connected areas with high variability in aerosol number concentration and two air quality supersites, namely SMEAR-III and Mäkelänkatu supersite. Results showed that the correlation was modest. As expected, the highest concentrations were observed near traffic and considerably smaller concentrations were observed in the park areas. The transient nature of the number concentrations is seen very well in Mäkelänkatu, where the mobile measurements indicated a gradient between the sides of the street canyon, which is in line with earlier studies with mobile measurements (Pirjola et al. 2012). Within the street canyon the number concentrations are elevated by the local wind patterns inside the street canyon on the leeward side of the prevailing wind due to local wind structures withing street canyon (Dos Santos-Juusela et al. 2013).

The lessons learned from AQ mapping activities (on example of Helsinki) are summarized in the Chapter "Summary and Recommendations". The potential for sustainability and upscaling in cities including added value of fine resolution monitoring and modelling beyond as complementary tools to data from fixed regulatory AQMNs based on the pilot studies are summarised in Chapters "Sustainability" and "Upscaling".

Finally, the methods of spatial air quality mapping utilized are suggested as one of the Service Tools of RI-URBANS - ST13: "Mapping ultrafine particles and citizen science" (https://riurbans.eu/wp-content/uploads/2025/02/ST13.pdf) & ST12: "Deterministic urban modelling of fine PM and PNC" (https://riurbans.eu/wp-content/uploads/2025/02/ST12.pdf).

2.4 Novel health indicators

To elaborate novel health indicators of nanoparticles and PM components and source contributions, the RI-URBANS validated measurement techniques and approaches in order to assess health effects by complementing existing AQ policies with measures directly targeting novel AQ metrics and health-relevant emission sources. Different temporal resolutions are used for all health indicators, from hours to daily averages. The pilots in European urban areas/ cities (Athens, Greece; Barcelona, Spain; Paris, France, and Zurich, Switzerland) are in focus. The work done includes: (1) an epidemiological evaluation of the health effects of the novel AQ metrics (D29 (D4.8)); (2) OP of PM components and source contributions from novel pilot city data were analysed to evaluate long-term variations (D30 (D4.9)); and (3) as the final product a summary of novel health indicators, their sustainability and benefits for the AQMNs and AQ policies (D31 (D4.10)).

The Deliverable D29 (D4.8): "*Summary: health effects of novel AQ metrics, source contributions: epidemiology*" summarises the results of an epidemiological analysis using quasi-Poisson regression models, aimed to estimate the short-term effects of both novel unregulated and regulated pollutants on mortality in RI-URBANS pilot cities – Athens, Greece; Barcelona, Spain; Paris, France, and Zurich, Switzerland. Air quality data was obtained following common measurement protocols, and the period of analysis was about 3 years, taking place between 2018 and 2023, depending on the city and pollutant. In total, 97 variables were evaluated, including PM fractions, sources, constituents, oxidative potential (OP), and particle number size distribution (PNSD) modes. Single and two-pollutant models were used to associate pollutant concentrations and daily mortality counts on the same day of exposure and up to 7 days after (lags 0-7). Cumulative lags to study the cumulative effects of exposure were also evaluated (lags 0-1, 0-2, 2-3, and 4-7) for variables that were measured daily. The study developed in two phases. First, the associations between air pollutants and mortality were estimated in each city individually. Second, the results were combined by random effect meta-analysis. All the models were adjusted for the effects of air temperature, relative humidity, days of the week, bank holidays, and long-term trends and seasonality. In two-pollutant models the associations between the pollutant concentrations and daily mortality were adjusted for the effects of either NO_2, $PM_{2.5}$ or PM_{10}, depending on the pollutant.

Based on single and two-pollutant models, consistent associations were found between increased Aitken, Accumulation and N25_800 modes concentrations and mortality at lags 4 to 7. More immediate associations (lags 0 to 3) were found between Regional 2, a PNSD source that is influenced by ammonium sulphate and organic aerosols, and mortality. Associations were also found between NH^{+4} (lag 7), Ca (lags 1, 2, 3, and 7), and Ca^{+2} (lag 1), Fe, Mg, Mn, and Ti (lag 2) and mortality at different lags. Equivalent black carbon (eBC) and black carbon from residential and commercial sources (eBRC) were also associated with mortality. The study found inconsistent associations with mortality of secondary organic aerosols from α-pinene, OP, and primary organic aerosols.

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This study had the advantage of using measurements that were conducted following the same protocols, and were analysed by the same laboratories, which increases comparability across the cities. However, the study was also limited in some aspects. For example, since the study was based on recent years, and official mortality data is often released with delay of, at least, one-year, all-cause mortality, burial data and natural mortality data were used depending on the city. The use of different types of mortality data may have impacted the associations and comparability. Another limitation of this study was that it included a period that was affected by the COVID-19 pandemic. As an attempt to avoid the impacts of COVID-19 on both mortality and air quality, the study excluded the year 2020 from the analysis, however, the effects of the pandemic on the years following 2020 cannot be ruled out. Other limitations include the use of short-time series, which reduces statistical power to detect associations, and the analysis of a large number of pollutants, which increases the chance of finding associations. Despite of the above-mentioned limitations, the epidemiological RI-URBANS pilot studies demonstrated the feasibility and the potential of using common measurement protocols to collect long-time series that are comparable across cities, which can enhance epidemiological models. This step is essential to obtain consistent epidemiological results and, consequently, motivate the creation of effective air quality regulations.

See these above in more details in D29 (D4.8).

The Deliverable D30 (D4.9): "*Summary: OP of PM, PM components and PM source contributions*" (https://riurbans.eu/wp-content/uploads/2025/01/RI-URBANS_D30_D4_9.pdf) summarises analysis of novel air quality (AQ) metrics and source contributions at selected urban background locations in Europe. This includes emerging AQ metrics such as off-line particulate matter (PM) chemistry, equivalent Black Carbon (eBC), Particle Number Size Distribution (PNSD), PM's oxidative potential (OP). Based on the presented work, main conclusions on source contributions in urban environments in Europe are drawn. The report summarises: (i) Online measurement of novel metrics (eBC, UFP); (ii) Sampling and analytical strategies (PM composition and OP, total concentration of metals, water soluble ions and concentration of metals, organic (OC) and elemental (EC) carbon, brown carbon (BrC), organic tracers, non-targeted chemical characterization of water-soluble OA, mass closure / data treatment; and (iii) Source apportionment (SA) analysis (PM chemistry, non-targeted mass spectral analyses of water-soluble OC, PNSD of UFP, eBC, OP. Results from all completed analyses (available at https://www.healthpilot-riurbans.eu) includes sum-ups about PM composition, BrC, SA analyses based on PM chemistry, SA of OC via non-targeted mass spectral analyses, SA based on eBC data, OP and its sources, SA of UFP-PNSD.

See these above in more details in D30 (D4.9).

The Deliverable D31 (D4.10): "*Summary: novel health effect indicator pilots, sustainability, associated benefits*" is a deliverable still in progress and will present a summary of the main results of the D10 (D2.2) " Evaluation of new AQ metrics and health" and D29 (D4.8) "Summary: health effects of novel AQ metrics, source contributions: epidemiology", and compares the results obtained by using two different sets of air quality data: a long non-harmonised time-series (>3 years) vs a shorter harmonised time-series for the evaluation of short-term associations with mortality.

Additionally, the sustainability of the air quality data collection for their use in time-series epidemiological analysis (which generally require daily data) will be evaluated. For example, offline laboratory analysis of certain novel air quality metrics such as oxidative potential are often time consuming and costly, and therefore may be difficult to monitor on a daily basis. Moreover, in order to provide information on the health impact of novel air pollutants, we will share information and alternatives to the difficulties of obtaining official health data (e.g. daily death counts) for the application of epidemiological time-series approach to very recent air quality data.

2.5 Pollution hotspots

To quantify emission sources and concentrations in and near urban areas with intense traffic and/or industrial activities & to identify the contribution of these hotspots to air pollutant exposure. The pilots in European urban areas/ cities (Rotterdam, The Netherlands; Milan-Bologna, Italy; Bucharest, Romania) are in focus. The work done includes: (i) initial results from campaigns (with different type of observations ground-based, mobile and aircraft, satellite, etc. and modelling) in the pollution hotspots (harbour, industrial, plant, airport) (D32 (D4.11)); and (ii) detailed results from campaigns, including summary of the pilot activities addressing their sustainability and local/ regional benefits for the AQMNs (D33 (D4.12)).

The Deliverable D32 (D4.11): "*Initial analysis of the hotspot pilot results*" (https://riurbans.eu/wp-content/uploads/2024/04/RI-URBANS_D32_D4_11.pdf) summarises measurement campaigns initiated for the pilots on hotspots and mapping of pollutants in Rotterdam-Amsterdam (The Netherlands), Bucharest (Romania), and Milano-Bologna (Italy) pilot cities. Each campaign has detailed description of the pilot cities in the focus, description of campaigns itself, list of measurements with measured chemical species and aerosols (e.g., ground-based fine scale mapping of aerosols; aircraft; radar; mobile trailer; bicycle; remote sensing, etc.) and involvement of representatives from national and municipal air quality monitoring authorities for provision of data from national and municipal AQMNs and operational support.

For Rotterdam (hotspot – harbour and industrial emissions as a hotspot of pollution), the applied methodology included observations from permanent stations, mobile, bicycle, airborne, and mobile trailer observations as well as modelling. Campaign approach is to use stationary as well as mobile observations to map out the air pollution, incl. meteorological observations and vertical profiling of wind and aerosols. High resolution modelling within the urban canopy was applied to connect the observations to understanding of the existence of hotspots and the dispersion of air pollution away from the sources of emission in a complex environment as a city with a neighbouring harbour and industrial area.

For Budapest (hotspot – CET West power plant as a hotspot of pollution), the applied methodology included observation strategy, background reference and temporary sites, fine mapping with LUR-model, comparison between districts of the city and between the two measurement sites, power plant contribution to the pollution at near surface, typical air mass circulations, mixing layer height.

For Milano (Po Valley; hotspot – Milano Linate international city airport as a hotspot of pollution), the applied methodology included observation strategy, background reference site (the area CNR-Milano Pascal-Uni Milan), urban spatial mapping, data acquisition and time series analysis, comparison between measurements sites and seasonality, diurnal variability and source apportionment, diel profiles variability with variability boundary layer height, impact from flights, mapping the spatial variability of pollution.

See these above in more details in D32 (D4.11).

The Deliverable D33 (D4.12): "Summary of AQ hotspot pilots, sustainability and associated benefits" (https://riurbans.eu/wp-content/uploads/2025/04/RI-URBANS_D33_D4.12-1.pdf) summarises the results of the pilot studies (Rotterdam, Milan, Bologna, Bucharest), including methods, results, maps, required resources, overall assessment; as well as potential for upscaling and sustainability for pilot cities. Results of finalized measurement campaigns, followed elaborated methodologies (in D32 (D4.11)), for the pilots on hotspots and mapping of pollutants in Rotterdam-Amsterdam (The Netherlands), Bucharest (Romania), and Milano-Bologna (Italy) pilot cities are summarized. In Rotterdam, mobile monitoring was done using a car measuring nanoparticles, BC, NO_2, $PM_{2.5}$ and CO_2, in addition to a network of stationary citizen NO_2 and $PM_{2.5}$ sensor measurements. Remote sensing techniques were applied and provided valuable results. Models and observations were compared to demonstrate the ability for upscaling in other cities. In Milan, an urban pollution maps were created with special attention to heavy traffic roads, while in Bologna focus was on the airport. Mapping was carried out with mobile sensors for gases, PM and BC. A comparison of measurements with urban scale LUR and DALES models and microscale chemical transport models was made. In Bucharest, an observation site was established in a highly polluted area around one of the most important power plants in the city. In-situ and remote sensing observations near the pollution source and at the background reference site were used to quantify nanoparticles, $PM_{2.5}$ and reactive trace gases (NO_2, SO_2, O_3), mini-DOAS, ceilometer and a scanning LIDAR.

The new Ambient Air Quality Directive (EU) 2024/2881 is requiring that the highest pollution hotspots should be identified, and air quality measurements carried out there, with a ratio urban background/hotspot ratio not higher than 2. The methods used are valid for this identification, not only for new pollutants but also for criteria pollutants. In this sense the mapping of pollutants at urban scale is a very powerful tool for implementing this new directive.

See these above in more details in D33 (D4.12).

Finally, several Service Tools of RI-URBANS are in support of the RI-URBANS Deliverables on hotspots areas of the pilot cities: ST7: “Measurements of boundary level height” (https://riurbans.eu/wp-content/uploads/2025/02/ST7.pdf); ST8: “Measurements of vertical profiles of aerosols” (https://riurbans.eu/wp-content/uploads/2025/02/ST8.pdf); ST9: “Measurements of IAGOS vertical profiles by commercial aircrafts” (https://riurbans.eu/wp-content/uploads/2025/02/ST9.pdf).

3. Sustainability of the pilot actions

A summary of sustainability of the pilot actions for the pilots for the near-real-time source apportionment, the near-real-time aerosol number size distribution, the air quality mapping, the novel health indicators, and the pollution hotspots is presented in this Chapter.

P1: For NRT SA Measurements (see more details in D24 (D4.3)), with regards to implementation and continuation of the NRT operations at the sites beyond the project lifetime, a summary is the following with respect to running a centralized SA in a way that all results are available in real-time is a big effort, and therefore:

- The **expertise and good skills** are needed from users to work with a variety of software, data transmission and servers.
- The **observed results** are strongly dependent on the correct input data and used SA tools, and impact of the results depends on capability to visualize and make the results available for end-users.
- The used **SA method/tool for black carbon**, the Aethalometer model, is well-established and widely used, and non-complex approach & it is easily automated and run in real time with modest dataflows and with results easy to visualize and understand.
- The used SA, in some conditions dividing the sources only to BC emissions from liquid and solid fuel combustion, is problematic and does not provide reliable results (especially, when there was only one very dominating source, e.g. in a traffic environment).
- The used **SA ACSM method/tool** (combining PMF and CMB models) **for carbonaceous particles** needs very experienced users to setup, previous knowledge on sources and SA software to run it as well as it produces a very large and complex dataset (for that a separate tool was developed to transfer) to transfer the needed data to the server (establishes dataflows from all polit sites was challenging).
- The used SA ACSM needed significant amounts of information about sources, including source profiles, constraints, etc. however, significantly more information is provided that could be further utilized in the emission mitigation, future emission limits and city planning.

- **Both SA tools** (for black carbon and for carbonaceous particles) are useful, however, further development is needed in order to produce tools that can be easily adapted to AQMNs as a part of daily routine work.
- **NRT data produced by both SA** tools can be utilized in the air quality related applications, services, and dissemination, and moreover, in the NRT data validation when the results are visualized and communicated in a real-time.

P2: For NRT PNSD Measurements, (see more details in D26 (D4.5)), with regards to implementation and continuation of the NRT operations at the sites beyond the project lifetime, a summary is the following with respect to upgrades to ACTRIS standards, implementation of NRT, and provision of NRT MPSS data long-term dataflow to EBAS from the pilot sites.

- **How easy/difficult the upgrade to ACTRIS standards?** All sites: (i) Technical upgrade to ACTRIS standards was easy (due to experienced personnel working with the instrumentation, support from manufacturer, previous positive experience on ACTRIS standards); (ii) TSI instruments MPSS update to ACTRIS standards is required to be able to work with positive voltage; DMA3083 needed to be purchased which covered the 10-800 nm size range; CPC used with the SMPS and standalone CPC are required to be recalibrated to a lower size limit of 10 nm; (iii) TSI AIM software require updates to be able to export data in a format ready for the NRT (experienced users are needed, or otherwise, upgrade could become challenging); (iv) ACTRIS Central Facility (e.g., aerosol in-situ calibration centre) ought to be ready to deal with differences in the technical readiness levels of observation sites.
- **How easy/difficult the implementation of NRT?** All sites: (i) The implementation of the NRT software should not have mixed messages, e.g., exact clarification on steps in implementation is needed, it takes a while to see the NRT data in the ACTRIS data server; (ii) Updates and upgrades of the NRT software/ version control are not optimally progressing; (iii) It would be recommended that personnel at both the ACTRIS Central Facility and the ACTRIS Data Centre will be available to speed up the implementation of NRT data delivery; (iv) working knowledge of PYTHON, script and a familiarity of the Command Prompt is useful; (v) to understand the return messages and if the process is working or in troubleshooting mode, an interpretation for the inexperienced user is needed.
- **Provision of NRT MPSS data long-term dataflow to EBAS?**
  - Birmingham site: interested to continue with NRT MPSS data long-term, but (i) with possibility of extending this to other instruments, (ii) limitation for personnel to deal with increase in difficulties that arise as additional instruments put online.
  - Barcelona site: will continue to provide NRT MPSS data long-term, but also requires (i) more user-friendly software, (ii) more support to avoid problems if something changes in software/firmware or other errors occur.
  - Helsinki site (SMEAR-III): can continue to provide NRT MPSS data long-term, but also requires (i) to have more support if something changes in software/firmware or other errors occur; (ii) to ensure data delivery and data processing chain after software/firmware/hardware upgrades; (iii) to ensure needs of specific interaction between the data providers, Central Facility and Data Centre having clear responsibilities; (iv) to put automated procedure/mechanism to more efficiently flag, when data is not being submitted to EBAS.
  - Zurich site (Kaserne & Duebendorf; in addition to 3 listed above): plans to provide NRT MPSS data long-term.

P3: For Air Quality Mapping, (see more details in D28 (D4.7)), with regards with implementation and continuation with respect to mobile monitoring, modelling activities, and engagement with citizens at the sites beyond the project lifetime, a summary is the following:

- **Mobile monitoring**: (i) links well to the past practice and expertise of some network agencies, that used mobile monitoring with reference-grade instruments in large vans; (ii) supported by adequate QA-QC, a sufficient number of repetitions and a targeted design, monitoring agencies can operate mobile monitoring systems; (iii) investment cost is high, easily exceeding 100 KEuro, which suggests that it is only feasible in larger networks; (iv) operating costs are moderate to high as a driver is needed; (v) measurement car was developed in such a way that the least amount of manual interference is needed with the system; (vi) a challenge for sustainable implementation is the time of day of monitoring (weekend and evening monitoring is challenging).
- **Modelling**: (i) easier to implement, if a prior expertise already exists and input data on emissions are available; (ii) challenge may be the requirements of regulatory modelling, limiting the flexibility of model choice; (iii) applies less to unregulated pollutants such as UFP.
- **Engagement with citizens**: (i) improved because of low-cost sensor (LCS) networks by citizens, supported by network agencies; (i) LCS monitoring is promising to refine spatial resolution and identifying hotspots, provided that quality is controlled & it is cheaper and easier to implement than mobile monitoring; (iii) more qualified personnel is needed to process the data and calibrate instruments prior to deployment and on a regularly basis, thereby taking into account threats to quality; (iv) the most robust LCS remain the passive samplers for especially NO_2, that have proven to be very useful for assessing spatial variation of average exposures (1 week or longer); (v) for many applications long-term average exposure maps are sufficient.

P4: For Novel Health Indicators, (see more details in D31 (D4.10)), the sustainability of the assessment of the health associations for the novel health indicators is feasible and recommended given the need of harmonised long time-series for a better health impact evaluation. One of the main points to consider includes the need to obtain very recent health data (i.e. daily death counts). Official records usually have 1 or 2-year delay, therefore access to this data may delay the obtention of results. Alternatives to the official mortality records could be considered, for instance the use of the city burial registries.

P5: For Pollution Hotspots, (see more details in D33 (D4.12)), with regards with implementation and continuation with respect to different types of monitoring for hotspots beyond the project lifetime, a summary is the following:

- **New AQ Directive**: As the new Ambient Air Quality Directive (EU) 2024/2881 requires that the highest pollution hotspots should be identified and air quality measurements carried out there, with a ratio urban background/hotspot ratio not higher than 2. The methods used here are valid for such identification, and not only for new pollutants, but also for criteria pollutants.
- **Mapping pollutants**: As the mapping of pollutants at urban scale is a very powerful tool for implementing this new directive. The pilot studies performed for characterisation of pollution hotspots in the framework of the RI-URBANS project in the cities of Rotterdam, Bucharest and Milano have shown that advanced observations have added value to the understanding of exposure to air pollution in general and UFP in particular.
- **Mobile monitoring**: As mobile observations provide great insight in characterisation of pollution hotspots. Once existing or new instrumented vehicles are available, they can be continued to be deployed in the RI-URBNS pilot cities as well as in all kinds of cities. However, sustainability of such operations/ campaigns depends on circumstances to be carefully considered as these are laborious and costly.

- **Bicycle monitoring**: As bicycle measurement approach demonstrated that mobile measurement campaigns combined with citizen participation are an effective method to obtain detailed urban air quality data and offers the potential to validate urban air quality models, they can be continued to be deployed in the RI-URBNS pilot cities as well as in other cities, with logistical support for a clearly defined measurement route and support from local organisations or universities being essential.
- **Citizen involvement**: Active citizen participation is crucial, requiring adequate information/communication and motivation to participate in the experiment. Following RI-URBANS experience it can be continued in the pilot cities as well as such experience extended to other cities.

4. Upscaling

A summary of upscaling for the pilots for the near-real-time source apportionment, the near-real-time aerosol number size distribution, the air quality mapping, the novel health indicators, and the pollution hotspots is presented in this Chapter.

P1: For NRT SA Measurements (see more details in D24 (D4.3)), the upscaling of SA to many sites will likely be seen in future, because the SA provides important data that would be beneficial to authorities, city planning, general public. In order to reach harmonized real time SA, following aspects need to be considered and improved prior upscaling:

- **Reliability and trustability** of the results.
- **Traceability** of the process shall be achieved by the determination of harmonized submission procedures.
- **Fairness and open source** when optimally the SA tool would be openly accessible and available freely for other users and for further developments.
- **Harmonization** of terms used for the sources needs to be done, so that the results between different stations are comparable.
- **PM source apportionment** improvement for different needs of end-users may have different needs.
- **Connection between different SA analysis** for a comprehensive view on the sources influencing air quality.

P2: For NRT PNSD Measurements, (see more details in D26 (D4.5)), the upscaling to many sites will likely be seen in future, because the measurements provide important data that would be beneficial to authorities, city planning, general public. In order to reach harmonized real time procedure, following aspects need to be considered and improved prior upscaling:

- **Reliability and trustability** of the results.
- **Traceability** of the process shall be achieved by the determination of harmonized submission procedures.
- **Fairness and open source** when optimally the tool would be openly accessible and available freely for other users and for further developments.
- **Harmonization** of terms used for the sources needs to be done, so that the results between different stations are comparable.
- **PM source apportionment** improvement for different needs of end-users may have different needs.
- **Connection between different analysis** for a comprehensive view on the sources influencing air quality.

P3: For Air Quality Mapping, (see more details in D28 (D4.7)), for upscaling the mapping for air quality to existing and new identified hotspots in the cities or other urban areas, a summary is the following:

- **Fine/High resolution monitoring** for RI-URBANS pilot cities was important for mapping air quality, and it can be upscaled to other cities as well as to regulatory AQMNs that can be added value to the project and approach for monitoring.
- **Mobile sensing platforms and fixed sensor networks** based on low-cost sensors can be used to obtain more fine-spatial resolution pollution data across the city than obtained from routine monitoring stations. Such data are critically important for more accurate mapping.
- **The approaches to develop maps** across the cities worked well and were useful for a general assessment. Utilising monitoring data based on a sufficiently large number of repetitions across the city was useful to identify locations in which current models under- or overestimate concentrations.
- **Dispersion modelling** can be upscaled to other cities as it was found to be useful and agreed well with measurement data from the often few regulatory monitoring stations. Such type of modelling is probably closer to expertise of network operators, though typically using these models that are applied for regulatory purposes.

P4: For Novel Health Indicators, (see more details in D31 (D4.10)), the upscaling is a possibility as long as there exists a relatively long (e.g. 3-4 years) time series of air quality data. Importantly, it would be valuable that the air quality data is collected in a harmonized way across all the locations for which the associations with mortality or any other outcome will be evaluated. Further details will be provided in the upcoming D4.10, which is currently under development.

P5: For Pollution Hotspots, (see more details in D33 (D4.12)), with regards for upscaling the monitoring to existing and new identified hotspots in the cities or other urban areas, a summary is the following:

- **New AQ Directive**: As the new Ambient Air Quality Directive (EU) 2024/2881 requires that the highest pollution hotspots should be identified and air quality measurements carried out there. The methods used are valid for such identification, and not only for new pollutants, but also for criteria pollutants.
- **Mapping pollutants**: the RI-URBANS mapping of pollutants at urban scale, following new AQ Directive, in pilot studies for characterisation of pollution hotspots can be upscaled to new pilot cities and their hotspots because advanced observations have added value to the understanding of exposure to different air pollutants
- **Mobile monitoring**: the RI-URBANS mobile observations provided great insight in characterisation of pollution hotspots, and can be upscaled to new instrumented vehicles as well as to new identified hotspots in other cities/ countries, although it will depend on consideration of labour, instruments, logistics, etc. costs.
- **Bicycle monitoring**: the RI-URBANS bicycle observations demonstrated that such campaigns combined with citizen participation are an effective method to obtain detailed urban air quality data and to offer the potential to validate urban air quality models, and can be upscaled to new instruments mounted on bikes as well as to new identified hotspots in other cities/ countries, although it will also depend on consideration of labour, instruments, logistics, etc. but of lower costs compared with mobile monitoring.
- **Remote sensing**: concentration maps of chemical species/aerosols provide insights that can be very useful for understanding specific cases, since the instrumentation is not fully mature and only campaign-based observations are feasible.
- This could be interesting to apply in other cities to get a better understanding of, for instance, the changes in terrain on the dispersion of air pollution from the hotspots of RI-URBANS pilot cities as well as other cities.
- **Citizen involvement**: active citizen participation is crucial, requiring adequate information/communication and motivation to participate in the experiment. Following RI-URBANS experience it can be continued in the pilot cities as well as such experience extended to other cities.

- **Combined use of various techniques**: RI-URBANS hotspots showed that in-situ and remote sensing will gain the most complete dataset to address the pollution studies for a particular city, especially in cases of complex (orographic) terrain, or large/mega cities with very complex building structures.

5. Summary and Recommendations

Summary and recommendations for the pilots for the near-real-time source apportionment, the near-real-time aerosol number size distribution, the air quality mapping, the novel health indicators, and the pollution hotspots are presented in this Chapter.

P1: For NRT SA Measurements (see more details in D24 (D4.3)), the running a centralized SA with all results produced in real time is a serious effort with commitment at all pilot sites. Clearly, expertise as well as good skills from users are required, including work with software packages required for SA, data transmission and servers as results observed depend on correct/valid input data and specifics of applied SA tools. Although some SA tools (for example, for SA for BC) are well-established and widely used, relatively easy to apply and handle, the other tools as SA ACSM for aerosols are more complex to apply and handle.

In RI-URBANS, both SA tools were found useful, however further development is recommended in order to produce tools that can be easily adapted to any air quality network as a part of daily routine work.

Among these recommendations, there are the following:

For source apportionment of organic aerosols (ACSM) to ensure: (i) controlling quality of the input data used for the source apportionment; (ii) robustness of data transfer system to avoid data gaps; (iii) optimizing the source apportionment parameters; (iv) quality assessment/ quality control (QA/QC) of output data.

For source apportionment of black carbon (BC) to ensure: (i) using the latest software and firmware versions in the measurements and instruments; (ii) including all necessary information in metadata in order to harmonize the parameters between instruments if data from several measurement locations are used; (iii) controlling quality of input data; (iv) documenting all changes and observations to the measurement diary for traceability of the results in case of doubt; (v) conducting quality assurance for SA e.g., against other co-existing measurements for correct operation of both instrument and SA.

P2: For NRT PNSD Measurements, (see more details in D26 (D4.5)), let's consider associated benefits for AQMNs and AQ policy. The new European Ambient Air Quality Directive (2024/2883/CE) requires the establishment of supersites with the ability to measure UFP and PNSD. It has been shown that experienced personnel can establish the measurement capability for UFP-PNSD and can implement the EBAS NRT software effectively. The demonstrates the capacity for AQMNs to establish their own capability, possibly with use of expert assistance in the set-up. Subsequent operation should be well within the capability of AQMN personnel.

Once this has been established, several benefits follow such as:

(i) Cities will gain knowledge of their own status in terms of UFP concentrations and the likely exposures of their citizens & They will be able to view this in the context of other cities across Europe; (ii) The data generated will be a valuable asset in the development of city-wide numerical models of UFP exposures; (iii) If regulatory standards or guidelines are developed for UFP, the data from the AQMNs will allow an assessment of local compliance, and an evaluation of the magnitude of possible mitigation measures needed if high concentrations occur & additional value would arise from identification of new UFP hotspots, which are required to be monitored by the AQ Directive; (iv) The data generated will be essential to establishing trends in UFP concentrations and evaluation of the impacts of control measures; and (v) The NRT capability will be a great asset if short-term mitigation measures are needed for the protection of public health during episodes.

In terms of policy development, a reliable, quality assured monitoring capability as established in the pilots is an essential component in the provision of evidence needed in any strategy for air quality improvement.

P3: For Air Quality Mapping, (see more details in D28 (D4.7)), the lessons learned from the pilot are the following: (i) Quality control against the reference instruments is essential. The intercomparison should be done in an ideal case both before and after the campaign. In case of mobile measurements, the intercomparison is recommended during the campaign as well; (ii) Near-Real-Time (NRT) data delivery to the data cloud increases the value and usability of the data. In this manner, the pilot data were connected to operational air quality modelling (e.g. ENFUSER, Johansson et al. 2022), which allowed novel insights into the spatial variability of emerging air pollutants; (iii) Particularly UPF concentrations are highly variable in the urban environment. Reducing pedestrian exposure to UFPs can be achieved with small changes in their routes through the city.

P4: For Novel Health Indicators, (see more details in D31 (D4.10)), the main recommendation would be to highlight the importance of harmonized air quality datasets, ensuring full comparability across the different locations for which the health impacts are going to be evaluated.

P5: For Pollution Hotspots, (see more details in D33 (D4.12)), let's consider outcomes of several campaigns in selected pilot cities considered as hotspots.

Rotterdam pilot city included the extensive suite of observations that were made during the campaign addressing the hotspots. From the overview of processed data that is obtained from the experiments it is expected that the intended results can be obtained. That is, using the fixed and mobile observations in and around the city, the influence and the extend of the hotspots can be analysed. We expect that the results from the Rotterdam campaign are sufficient to make a significant step in the modelling of the hot spots in state-of-the-art high-resolution models. This analysis is currently ongoing and further work will focus on interpretation and modelling.

Bucharest pilot city presented findings (based on observations analysis) regarding the potential adverse effect of the hotspot (CET West power plant, PP) on the population living in the nearby residential area. As such, decoupling the impact of PP from the impact of other sources is not completely possible, for 2 reasons: (i) measurements and measured-based modelling embed contributions from all sources – separation can only be qualitatively made; and (ii) publicly available emission inventories for Bucharest are not trustable, e.g. constantly underestimating traffic, and therefore, the inventory-based modelling gives unrealistic outputs. The expectations that PP could be affecting the air quality in the residential areas nearby is not confirmed. The only pollutant, which can localize PP as a source is NO_2, mostly during winter only affecting the very small region around PP, which is not a significant source of particles, not even UFP. Higher concentrations of PM_{10} and $PM_{2.5}$ have been measured near PP, but the differences to other districts are not sufficiently large to allow a clear identification of the source. Road dust produced by agriculture and construction activities and transported by traffic is always present, hiding the contribution of PP up to a point. The fact that the differences to other districts are higher during the cold season may indicate that PP is a constant source of particles in the region (PP increases its operations during winter). However, it does not mean that people living northeast of PP are affected by it. The only situation which would favour the transport of pollutants from PP to the residential area is during winter night-time, when the planetary boundary layer is very low, the pollutants are injected above and transported by mid-tropospheric winds. The minimum mixing layer height is reached during night-time (23 – 05 UTCs), and it is below 400 m (the measurement limit of the ceilometer). Tilted lidar measurements are recommended.

Milano pilot study showed consistently higher eBC mass concentration and total PNC measured at the hotspot (airport) site than at the background site where eBC, PNC, PNSD, and NO_2 were measured. Higher concentrations were observed during winter than summer, which is in line with previous measurements conducted in Milan and other urban sites in Europe. The SA on eBC revealed that residential heating and traffic contributed equally during winter at the background site, while fossil fuel combustion is the dominant source at the hotspot site in winter and summer, as well as the dominant source at the background site in summer. This finding confirms what previous SA studies at urban and background-urban sites in Milan reported. Additionally, our findings indicate that airport is both concentration and traffic hotspots in any season. The diel variability of eBC and PNC is largely explained by the traffic rush hour peaks in the mornings and evenings, and the atmospheric dilution effect due to the increase in the boundary layer height during daytime. In addition, bike campaign conducted during two seasons showed higher BC than the background and the hotspot site during winter, and comparable concentrations with the hotspot site during autumn. It is recommended to finalize analysis of NO_2 and UFP in order to have a complete overview of the data measured at the hotspot; to compare the size distribution of the two sites (for studying the influence of high emissions on the New Particle Formation (NPF) events and SA production; to evaluate the impact from flight emissions on all the measured pollutants compared to the other pollution sources from the city; to use the observed temporal and spatial variability of BC and how it is dispersed in the metropolitan area.

As overall summary, the preliminary and intermediate results from the hotspots campaigns (using different approaches) conducted in Rotterdam, Bucharest, and Milano showed that fine final analysis and modelling efforts are recommended with a phase of integration in order to upscale the approaches used, and the lessons learned can be taken along to be implemented in other metropolitan and urbanized areas.

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Deliverable D22 (D4.1): Monthly reports of concentration levels and PMF for each city during the pilots

https://riurbans.eu/wp-content/uploads/2024/04/RI-URBANS_D22_D4_1.pdf

Deliverable D23 (D4.2): Comparison of NRT source apportionment and manual PMF in the pilot cities

https://riurbans.eu/wp-content/uploads/2024/05/RI-URBANS_D23_D4_2.pdf

Deliverable D24 (D4.3): Summary: source apportionment pilots, sustainability and associated benefits

https://riurbans.eu/wp-content/uploads/2025/01/RI-URBANS_D24_D4_3.pdf

Deliverable D25 (D4.4): Nanoparticle concentration levels in the pilot studies

https://riurbans.eu/wp-content/uploads/2024/01/RI-URBANS_D25_D4_4.pdf

Deliverable D26 (D4.5): Nanoparticle aerosol pilots, sustainability, associated benefits for AQMNs and AQ policy

https://riurbans.eu/wp-content/uploads/2025/01/RI-URBANS_D26_D4_5.pdf

Deliverable D27 (D4.6): Air pollution variability in the pilot studies

https://riurbans.eu/wp-content/uploads/2024/03/RI-URBANS_D27_D4_6.pdf)

Deliverable D4.7: Summary: mapping procedures, sustainability and applicability for upscaling

https://riurbans.eu/wp-content/uploads/2025/01/RI-URBANS_D28_D4_7.pdf

Deliverable D29 (D4.8): Summary: health effects of novel AQ metrics, source contributions: epidemiology

(there is no link available yet)

Deliverable D30 (D4.9): Summary: OP of PM, PM components and PM source contributions

https://riurbans.eu/wp-content/uploads/2025/01/RI-URBANS_D30_D4_9.pdf

Deliverable 4.10: **Summary: novel health effect indicator pilots, sustainability, associated benefits**

(there is no link available yet)

Deliverable D32 (D4.11): Initial analysis of the hot spot pilot results

https://riurbans.eu/wp-content/uploads/2024/04/RI-URBANS_D32_D4_11.pdf

Deliverable D33 (D4.12): Summary of AQ hotspot pilots, sustainability and associated benefits

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Milestone M28 (M4.12): Pilot studies finished in 9 cities

https://riurbans.eu/wp-content/uploads/2024/11/RI-URBANS_M28.pdf