National Physical Laboratory

NPL REPORT EAS (RES) 001

AUDIT REPORT ON BREATHE LONDON FIXED NETWORK QUALITY ASSURANCE AND QUALITY CONTROL PROCEDURES

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NPLML - COMMERCIAL

OCTOBER 2020

Audit report on Breathe London fixed network quality assurance and quality control procedures

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1. Introduction

The Breathe London project[1] aims at underpinning air quality monitoring by deploying an innovative fixed network of low cost monitors. This dense fixed network consists of over 100 AQMesh sensor systems for the measurement of atmospheric parameters such as pollutants concentrations, temperature, humidity and air pressure.

Air quality data produced by the network undergoes strict quality assurance and quality control procedures, which aim at ensuring the highest level of confidence on the network performance. Near real time results then become available to the public on the Breathe London project website[2].

As part of NPL's contribution to the successful fulfilment of the objectives of Breathe London, all quality assurance procedures have been independently audited, and the methodology and findings are reported hereafter.

2. Objective

This report describes the detailed methodology and findings of NPL's independent audit on quality assurance procedures carried out during the Breathe London project.

3. Methodology

3.1.1. Breathe London Data Quality Assurance and Control Procedures

The document 'AQMesh Fixed Sensor Network Data Quality Assurance and Control Procedures' (QA/QC)[3] outlines all requirements for data management and processing into five stages (from 0 to 4), which can be described as follows:

- Stage 0 concerns factory settings and describes how raw measurement data are generated by the AQMesh monitors (also referred to as 'pods'), processed to reflect metadata information and made available to the consortium;
- Stage 1 concerns empirical verification of the pod performance carried out by the application of different calibration approaches:
    - Sub-stage 1.1 concerns confirming pre-scaled data without applying scaling factors;
    - Sub-stage 1.2 concerns scaling raw data by applying scaling factors provided by co-location with reference grade instruments;
    - Sub-stage 1.3 concerns scaling raw data by applying scaling factors provided by co-location with transfer standard 'gold pods' (essentially, regular pods whose performance has been assessed by co-location with reference instruments);

[1] Funded by Children's Investment Fund Foundation (CIFF), C40 Cities, and Clean Air Fund (CAF).
[2] https://www.breathelondon.org/methodology/ (last access: 11/09/2020)
[3] Breathe London AQMesh Fixed Sensor Network Data Quality Assurance and Control Procedures

  - Sub-stage 1.4 concerns scaling of raw data by applying scaling factors provided by a network calibration method based on an innovative algorithm developed for the purposes of the project;
- Stage 2 comprises of manual quality assurance procedures and involves credibility checks on a number of parameters, e.g. concentration levels, validity periods for calibrations, baseline concentrations, maintenance services or any other technical issues identified with the pods;
- Stage 3 concerns automated revision of results against pre-set concentration limits and the identification of ozone depletion episodes;
- Stage 4 comprises of special issues that need to be addressed before the end of the project, such as ratification of reference instrument results, ozone interference effects and any further procedure required to account for unexpected events.

A complete description of all procedures and processes employed can be found in the aforementioned document. Appendix A provides a table which summarizes the key information for these requirements.

3.1.2. Audit methodology

The audit adopted the QA/QC document as the reference and starting point for collecting evidence that all its processes and requirements were adhered to. The initial roll of activities focused on interviewing the key project partners. Online meetings and written communications were consistently held for that purpose during July and August 2020. Partners' adherence to the requirements was verified, as well as the associated data management and communication processes across the consortium. Subsequently, the partners were requested to provide official documentation in which records of actions could also be verified. These documents mainly consist of digital files containing spreadsheets of results and metadata about the network operation.

In addition to partners' interviews and document provision, relevant digital files were acquired independently. For example, the data set made available to the general public on the Breathe London website[4], as well as files from partner's platforms[5] and cloud storage[6], to which access was granted for the purposes of the audit. Appendix A presents a table of detailed information about this initial phase of the audit, containing the indexed list of collected documents which unique audit labels have been assigned, contents, origin of documents and the partners who took part in the interviews.

Later phases of the audit relate to the collection of evidence of conformity and nonconformity with the reference procedures (QA/QC)[7]. These activities involved a thorough revision of every indexed document in order to identify records of data processing which indicate either adherence to (conformity) or deviation from (nonconformity) every procedure described in the QA/QC document and Appendix A.

[4] https://www.breathelondon.org/methodology/ (last access: 11/09/2020)
[5] www.airmonitors.net (last access: 11/09/2020)
[6] https://docs.google.com/spreadsheets/d/1S8p7WKWnP0fvL7-H9ZNCki_kyQRHXMtC1wJaQ1xWc3o/edit?ts=5f46716d#gid=0 (last access: 11/09/2020)
[7] Breathe London AQMesh Fixed Sensor Network Data Quality Assurance and Control Procedures

Appendices B and C present tables with a complete description of all examples of conformity and nonconformity, respectively, to which unique audit labels have also been assigned for referencing purposes. The audit's findings are presented and discussed below.

4. Findings and discussion

The findings and discussion regarding conformity and nonconformity evidence are presented separately below. Both subjects are divided into sections which correspond to the QA/QC document.

4.1. Conformity evidence

4.1.1. Stage 0 – Factory settings

The initial conformity evidence relates to QA/QC stage 0 – Factory settings. To achieve that purpose, data sets and additional information were downloaded directly from the Air Monitors platform[5], which generated the documents DC19 to DC23, as described in Appendix A. Metadata and monitoring results were acquired for the randomly selected time periods and pods. Conformity evidence CE01 to CE05 demonstrate adherence with QA/QA requirements for the operation of pod 1245 during the period of 03rd to 04th of January of 2020. Pre-scaled (raw) results for NO_2 and $PM_{2.5}$ were extracted successfully and documented as pieces CE01 and CE02. However, results for all air quality parameters during the particular pod/period were available and can be further verified in the same document (DC19). Document DC19 also provided evidence for the assignment of timestamps to each one minute reading (CE03) and fault code based flags to NO_2 and $PM_{2.5}$ results (CE04 and CE05, respectively), all flagged as 'Valid'.

Similar verifications were also conducted for the pods 5245 and 17245 during the time period of 01/08/2019 to 29/09/2019, which generated documents DC22 and DC23. Availability of pre-scaled (raw) measurement results and timestamp assignment requirements were also met in both cases. Moreover, pod 17245 provided CO_2 data flagged as 'Rebasing', resulting in an additional evidence item (CE06) for this particular requirement.

Beyond the evidence items selected and described, all documents relating to Stage 0 (including DC20 and DC21) provided a high volume of results and metadata, which reinforced the observed strong adherence of data management and processing for this particular group of QA/QC requirements. Therefore, the selected pieces of evidence are believed to be representative of these conditions and to provide sufficient confidence on the overall adherence to the Stage 0 procedures conducted by the project partners.

4.1.2. Stage 1 – Empirical verification

As mentioned above, the empirical verification stage of QA/QC relates to all the procedures conducted to address the evaluation of the performance of the pods. The main focus when auditing this stage was verifying documents which provide data on the various co-location studies, specifically regarding scaling factors available and correlated metadata. This includes, not only the records of verified actions taken, but also the consistency of data and results considering the communication processes between all project partners and the whole project timescale.

Examples of conformity evidence CE07 to CE10 relate to the first sub-stage 1.1 of processing and confirm that, based on the documentation available, hospital pods represent the only occurrence where pre-scaled data was published without the application of scaling factors. This evidence identifies records of the linear graph slope and offset for NO_2 and $PM_{2.5}$ results for pods 128245, 129245 and 372245. However, equivalent conditions were also observed for the following pods: 130245, 132245, 373245, 374245, 375245, and 376245. Most other valid results (and associated metadata) involve applying scaling factors to raw data prior to making them public.

Pieces of conformity evidence CE11 to CE13 provide details about co-locations with reference instruments, the subsequent stage of empirical verifications (1.2). Here, slope and offset scaling factors of 1.593 and 2.218, respectively, were confirmed for pod 37245, after a three day co-location evaluation between 6th and 8th of October of 2019. Acceptance criteria were met, as R^2 and normalized RMSE results for the same co-location were 0.8698 and 0.17, respectively. Although, this particular scaling method seemed to represent a minority of cases, because only five other pods (58245, 60245, 78245 and 82245) retained NO_2 scaling factors from reference instruments co-locations, according to the same document (DC15), as well as none of the pods retained equivalent scaling factors for $PM_{2.5}$.

Examples of conformity evidence CE14 to CE23 relate to co-locations with gold pods, the sub-stage 1.3 of empirical verifications. Scaling factors for pod 64245 were obtained by co-location with gold pod 2046150. The NO_2 slope and intercept results were 1.252 and 0.917, respectively, and these details are corroborated by documents DC15 and DC24 (CE14 and CE15). Adherence to the acceptance criteria was also verified for the same co-location. NO_2 R^2 and normalized RMSE results were 0.913 and 0.08, respectively, and $PM_{2.5}$ R^2 and normalized RMSE results were 0.948 and 0.06, respectively (CE19 and CE20). Additionally, adherence to duration related requirements were confirmed. Initial performance characterization of gold pod 2046150 was conducted during eighteen days between 4th and 22nd of April 2019 (CE22). Intermediate performance checks for the same gold pod occurred during eleven days between 17th and 28th of July 2019 (CE23) and the co-location of pod 64245 with the gold pod 2046150 for NO, NO_2, $PM_{2.5}$ and PM_{10} evaluations occurred between 6th and 18th of June 2019, for a period of twelve days (CE21).

Gold pod co-locations represent the prevailing scaling method for NO_2 performance evaluations. Up until August 2020, when the main documents and evidence collection was carried out, a total of 58 candidate pods were evaluated by this method (DC15). In comparison, gold pod co-locations were only occasionally employed for $PM_{2.5}$

evaluations, with four pods (14245, 23245, 58245 and 87245) retaining results from such scaling method by September 2020 (DC25). Examples of conformity evidence CE24 to CE29 present findings regarding the application of the cloud-based network calibration scaling method, the sub-stage 1.4 of empirical verifications. Concerning $PM_{2.5}$, this scaling method represented the majority of empirical verifications, being applied to 78 pods up until August 2020 (DC16). Slope and intercept results (1.266 and 0.685, respectively) from network calibrations were applied to pod 45245 (CE27 to CE29), information that was confirmed by the review of multiple documents collected from different project partners (DC3, DC11, DC16 and DC25). Even though the network calibration was not as extensively employed for NO_2, a considerably large volume of data was verified for that purpose. Representing this scaling method for NO_2, slope and intercept results (1.084 and -1.605, respectively) from network calibrations were applied to pod 73245 (CE24 to CE26), information that was also consistently confirmed by multiple documents (DC4, DC5, DC9, DC15 and DC24).

A hybrid scaling method for NO was also verified, resulting in examples of conformity evidence CE30 and CE31, which provide details about gold pod slopes applied with network based intercept for pod 20245 and average slope from network calibration for pod 21245, respectively.

4.1.3. Stage 2 – Manual quality assurance procedures

This stage of the QA/QC document concerns manual credibility checks conducted by qualified project members to identify abnormal results or other operational issues requiring further investigation (2.1). It also confirms the validity period of the empirical verifications previously applied (2.2). Examples of conformity evidence CE32 to CE37 concern the first sub-stage (2.1) and present results for NO_2 and $PM_{2.5}$, acquired by two different pods (36245 and 21245, respectively), which were initially flagged as delivering abnormally high concentrations and were subsequently redacted from the data sets published on the Breathe London website.

Findings related to sub-stage 2.2 verified compliant retrospective application of scaling factors for NO_2 measurements from pods 3245, 13245 and 31245, as well as to $PM_{2.5}$ results from pod 9245 (CE38 to CE41). Records of hardware maintenance and sensor replacements were also verified, concerning the same sub-stage 2.2, and evidence was collected from NO sensor replacement for pod 48245, which generated an also verified results redaction episode between 14th of February and 8th of March 2019 (CE42 and CE43).

4.1.4. Stage 3 – Automated quality assurance procedures

Stage 3 of the QA/QC describes a set of pre-defined limits to which results from all pods must be automatically compared and flagged accordingly. Representing these conditions, the collected evidence confirms that data for $PM_{2.5}$ from pod 5245 were partially flagged as ‘PM25 Greater Than PM10’ (CE45), whilst NO_2 results from the

same pod were flagged as ‘Less Than Lower Limit’ (CE46) and particle count results from pod 17245 were flagged as 'Less Than Concentration Limit' (CE44).

4.1.5. Stage 4 – Special issues

Power supply Issues with EMF and RF interference, changes in provisional LAQN data, fog effects on PM data, PM-specific humidity adjustment, anomalous behaviour in NO_2 concentrations and baseline evaluation anomalies are amongst the activities described in the special issues stage of QA/QC (stage 4). Most of these post-processing activities were considered as non-routine and are not envisaged to be completed by the end of the project. Therefore, consistent records of stage 4 activities were only verified for power supply issues. Pieces of evidence CE47 to CE48 present details of data and time periods when new filtered power supply units (PSU) were fitted and its implications to publishing data retrospectively. For instance, pod 20245 had its PSU replaced on 26/03/2019 (CE47), and consequently only gaseous pollutants results acquired from April 2019 onwards were published on the Breathe London website (CE48). In contrast, pod 22245 did not require PSU replacement as it was powered by a solar panel, which did not cause the same harmful interference (CE49).

4.2. Nonconformity evidence

Information collected as nonconformity evidence represented a minority of data, accounting for only nine items described in Appendix D. The first pieces of nonconformity evidence present conflicting information about the QA/QC sub-stage 1.1. The pod 132245, listed as a hospital pod in document DC18, had scaling factors assigned to as ‘-999’ and the scaling method identified as ‘None (don’t publish)’ (NCE1). However, the C40 Master Doc (DC18) defines the status of the same pod as ‘Online’ and the data status as ‘All good’ (NCE2). Additionally, the same pod appears to be online and data is available for download on the restricted access AM platform (NCE3). Based solely on the documentation collected and complementary communication, it remains unclear as to the true cause for this conflicting information episode and, moreover, for hospital pods constituting a distinct group of pods which were not subjected to any scaling methods (sub-stage 1.1).

Two other pieces of nonconformity evidence were collected for the co-location with reference instruments section of QA/QC (sub-stage 1.2). The co-location record for pod 37245 was not found in the spreadsheet ‘Colocation History’ from C40 Master Doc (DC18 and NCE4). Similar observations were made for other pods, which suggested that those records may have not been kept up to date by the time of audit. The same C40 Master Doc recorded (in a different section) that the co-location for pod 37245 occurred between 6th and 10th of October 2019, whilst the DC1 cited in CE12 provided a different period, 6th to 8th of October 2019 (NCE5).

Nonconformity evidence was also collected for the sub-stage 1.3, regarding the gold pod co-location scaling method. The document DC16 provided $PM_{2.5}$ scaling factors assigned as ‘-999’ for pod 87245 due to low covariance (NCE6), what conflicts with

slope and offset values provided by document DC25 and cited as conformity evidence CE16. Similarly, conflicting NO_2 scaling factors for pod 64245 were provided by DC2 (NCE6) when compared to information collected from document DC24 and cited in CE15.

The last pieces of nonconformity evidence (NCE8 and NCE9) refer to the sub-stage 1.4, network calibration method. In the first piece, the NO_2 network calibration slope and offset values for pod 14245 were both assigned a code of '-999' and flagged as 'covariance too low' (similarly as NCE6). However, this criterion (covariance) was not contemplated by any the QA/QC requirements. Finally, NCE9 confirms that the average slope applied to NO scaling factors was 0.805, whilst the QA/QA requirement states 0.81.

5. Conclusions

The activities conducted for the audit purpose and the associated findings revealed a strong adherence of data processing and management to the Breathe London QA/QC requirements. Each requirement from all the defined stages of this document was verified and presented in the conformity evidence. More importantly, the audit also concluded that the presented examples of conformity evidence are believed to be representative of the vast majority of data and information generated by the project.

Although nonconformity evidence was also collected, it only represented occasional episodes, and these are not believed to be representative of the overall data processing and management. Most of the nonconformity evidence relates to conflicting information, which is linked to the 'living' status of some of the documents collected, as previously highlighted by some project partners during interviews. In such cases, the completion of the project and its associated final document updates would most likely be sufficient as corrective actions. Nonconformity NCE8 identifies a quality criteria (covariance) that was not considered in the original QA/QC requirement, whereas NCE9 indicates a significant figure discrepancy between QA/QC and consulted documents. In such cases, it is expected that either the QA/QC or the actual data processing procedures are updated to achieve full adherence to each other.

Lastly, part of the special issues described in stage 4 could not be verified. This is because of their non-routine and provisional nature. In such cases, final versions of QA/QC and, more importantly, of the complete Breathe London report, should contemplate the latest methodologies and present the relevant findings on all special issues identified in stage 4.

Appendix A – QA/QC requirements table

QA/QC requirements			
Stage	**Stage description**	**Sub-stage**	**Requirement description**
0	Factory settings	N.A.	Pods provide data sets of raw measurement results (pre-scaled) after applying factory settings and proprietary algorithm
		N.A.	Each data point generated receives a timestamp and a status flag based on fault codes
		N.A.	Pre-scaled data sets become available to the consortium on the Air monitors platform
1	Empirical verification	1.1	Linear regression results from co-locations should provide **slope and offset statistically equivalent to 1.0 and 0.0**, respectively, at a 95% confidence interval
			Pre-scaled data from candidate pods is confirmed after co-location and **scaling factors are not applied**
		1.2	Linear regression results after three to seven days long **co-location with reference monitors provide slope and offset statistically different to 1.0 and 0.0**, respectively, at a 95% confidence interval
			Assessing compliance of co-locations results with acceptance criteria of **R^2 > 0.7 and normalized RMSE < 0.5**
			Scaling factors (slope and offset) from reference monitors co-locations are applied to measurement results from candidate pods
		1.3	Initial gold pods' performances characterization by co-locations with reference monitors for a minimum period of two weeks
			Intermediate gold pods' performance characterization by co-locations with reference monitors for a minimum period of seven days
			Linear regression results after seven to fourteen days long **co-locations with gold pods provide slope and offset statistically different to 1.0 and 0.0**, respectively, at a 95% confidence interval
			A minimum of 130 hourly results must be acquired during the co-location with gold pods
			Assessing compliance of co-locations results with acceptance criteria of **R^2 > 0.7 and normalized RMSE < 0.5**
			Scaling factors (slope and offset) from gold pods co-locations are applied to measurement results from candidate pods
		1.4	Novel **network calibration** procedure developed by University of Cambridge **is applied when co-locations results are not available**
			Network calibration scaling factors are applied to measurement results from candidate pods
			Hybrid scaling method for NO with network offset and slope from co-location
			Hybrid scaling method for NO with network offset and generic average slope of 0.81

2	Manual quality assurance procedures	2.1	Manual revision of results carried out by trained AM staff to identify any abnormalities
			Suspect results and/or pods are flagged in communication between AM and CERC
		2.2	Manual revision of historical data to determine the retrospective validity of the empirical adjustments from Stage 1
			Scaling factors are applied retrospectively provided there have not been any intervening maintenance or disruption
			Hardware maintenance is carried out by AM consistently and sensors are replaced when appropriate
3	Automated quality assurance procedure	N.A.	Automated revision and flagging of pods' results considering pre-set concentration limits
4	Special issues	N.A.	Non routine procedures, yet to be finalized, related to power supplies, LAQN ratification, fog and humidity effects on PM results, ozone interference with NO_2 measurements and baseline anomalies.

Appendix B – Documentation list table

Documentation list

Document number	File name	Content / comments	Project partner / origin	Person of contact
DC1	Colocation Analysis 2020-08-12 Reference.csv	Metadata and various statistics results of linear regressions from co-locations between pods and reference instruments	EDF	Daniel Peters
DC2	Colocation Analysis 2020-08-13 Gold.csv	Metadata and various statistics results of linear regressions from co-locations between candidate pods and gold pods	EDF	Daniel Peters
DC3	20191010_CambridgeOnly_SlopesOffsets_PM2.5.xlsx	Network calibration scaling results for $PM_{2.5}$ for all pods, including flag labels for those who should and should not be published	EDF	Daniel Peters
DC4	RLJ_ucam_no2 pod cals v2_250919.csv	Network calibration scaling results for NO_2 for all pods	EDF	Daniel Peters
DC5	20180901_20200112_NO2_site_info.csv	Detailed information about site locations, NO_2 scaling factors and method applied	EDF	Daniel Peters
DC6	20180901_20200112_PM2.5_site_info.csv	Detailed information about site locations, $PM_{2.5}$ scaling factors and method applied	EDF	Daniel Peters
DC7	Sullivan 97 NO2 comparisons Aug 16.xlsx	Co-location studies' results for NO_2 with reference instruments and gold pods carried out in 2019	EDF	Daniel Peters
DC8	Sullivan autumn_stats.xlsx	Co-location studies' results for NO_2 with reference instruments only carried out in 2018	EDF	Daniel Peters
DC9	20180901_20200810_NO2_site_metadata.csv	Detailed information about site locations, NO_2 scaling method only	BL Methodology page	Direct download (public)

DC10	20180901_20200810_NO2_AQMesh_Scaled_Dataset_UGM3.csv	NO_2 hourly averaged results and location of all pods	BL Methodology page	Direct download (public)
DC11	20180901_20200810_PM2.5_site_metadata.csv	Detailed information about site locations, $PM_{2.5}$ scaling method only	BL Methodology page	Direct download (public)
DC12	20200626_All_AQMesh_Locations.csv	Auxiliary information for each site	CERC	Amy Stidworthy and Ella Forsyth
DC13	0200313_Start_Dates.csv	Valid start dates for each pod, as provided by Air Monitors.	CERC	Amy Stidworthy and Ella Forsyth
DC14	20200612_Sensor Changes within Breathe London Network	Contains records of maintenance carried out in pods. This is derived from the Air Monitors spreadsheet	CERC	Amy Stidworthy and Ella Forsyth
DC15	20180901_20200810_NO2_calibration_end_dates.csv	NO_2 scaling factors for each pod and their valid period (accounting for pod rebasing). NA for start date means valid back to pod start date. NA for end date means still valid at end of dataset	CERC	Amy Stidworthy and Ella Forsyth
DC16	20180901_20200810_PM2.5_calibration_end_dates.csv	$PM_{2.5}$ scaling factors for each pod and their valid period. NA for start date means valid back to pod start date. NA for end date means still valid at end of dataset	CERC	Amy Stidworthy and Ella Forsyth
DC17	20200612 Periods to redact.csv	Additional periods of data to redact manually for various reasons	CERC	Amy Stidworthy and Ella Forsyth
DC18	C40 MASTER DOC.xlsx	Master spreadsheet containing various details about pods' colocations and maintenance	AM	Lauren Mills
DC19	telemetry-1245_20200814095121.csv	Raw data set from pod 1245	AM platform	Direct download (restricted access)
DC20	devices_20200908144038.csv	Complete metadata about all pods, e.g. location, serial number, ID etc.	AM platform	Direct download (restricted access)

DC21	17245-channelsetup_20200908143405.csv	Metadata for pod 17245, containing information summary, e.g. sensors, labels, last readings etc.	AM platform	Direct download (restricted access)
DC22	telemetry-5245_20200914110656.csv	Raw data set from pod 5245	AM platform	Direct download (restricted access)
DC23	telemetry-17245_20200914110708.csv	Raw data set from pod 17245	AM platform	Direct download (restricted access)
DC24	20180901-20200914_NO2_scaling_factors.csv	NO_2 scaling factors for each pod and their valid period (accounting for pod rebasing). NA for start date means valid back to pod start date. NA for end date means still valid at end of dataset. Results updated up until September 2020.	CERC	Ella Forsyth
DC25	20180901-20200914_PM2.5_scaling_factors.csv	$PM_{2.5}$ scaling factors for each pod and their valid period (accounting for pod rebasing). NA for start date means valid back to pod start date. NA for end date means still valid at end of dataset. Results updated up until September 2020.	CERC	Ella Forsyth
DC26	AM-1600940874-PM2.5.pdf	Graph presenting $PM_{2.5}$ results for pod 21245 which were considered abnormally high and flagged accordingly to be redacted	AM platform	Direct download (restricted access)
DC27	AM-1600941041-NO2.pdf	Graph presenting NO_2 results for pod 36245 which were considered abnormally high and flagged accordingly to be redacted	AM platform	Direct download (restricted access)
DC28	20180901_20200810_PM2.5_AQMesh_Scaled_Dataset_UGM3.csv	$PM_{2.5}$ hourly averaged results and location of all pods	BL Methodology page	Direct download (public)
DC29	20180901_20200921_NO2_AQMesh_Scaled_Dataset_UGM3_2020.csv	NO_2 hourly averaged results and location of all pods	BL Methodology page	Direct download (public)

DC30	AM-1600949425-NO-sensor-failure.pdf	Graph presenting NO results for pod 48245 which confirmed sensor failure flagged between 14/02/2019 14:30 and 08/03/2020	AM platform	Direct download (restricted access)
DC31	AM-1600956858-132245.pdf	Graph presenting NO_2 and $PM_{2.5}$ apparently normal time series for pod 132245	AM platform	Direct download (restricted access)
DC32	20180901-20200914_NO_scaling_factors.csv	NO scaling factors for each pod and their valid period (accounting for pod rebasing). NA for start date means valid back to pod start date. NA for end date means still valid at end of dataset. Results updated up until September 2020.	CERC	Ella Forsyth

Appendix C – Conformity evidence table

Conformity evidence

Piece of evidence	QA/QC stage	Requirement description	Document number	Evidence location	Evidence description / comments
CE01	0	Raw measurement data provided by pod after applying factory settings and proprietary algorithm	DC19	Columns Z and AB, rows 2 to 2881	Raw (pre-scaled) NO_2 results in µg/m^3
CE02	0	Raw measurement data provided by pod after applying factory settings and proprietary algorithm	DC19	Columns BD and BF, rows 2 to 2881	Raw (pre-scaled) $PM_{2.5}$ results in µg/m^3
CE03	0	Each data point generated receives a timestamp	DC19	Column A, rows 2 to 2881	Timestamps for all one minute readings acquired by the sensors
CE04	0	Each data point generated receives a status flag based on fault codes	DC19	Column AE, rows 2 to 2881	Every NO_2 result flagged as 'Valid'
CE05	0	Each data point generated receives a status flag based on fault codes	DC19	Column BI, rows 2 to 2881	Every $PM_{2.5}$ result flagged as 'Valid'
CE06	0	Each data point generated receives a status flag based on fault codes	DC23	Column M, rows 2 to 720	CO_2 results flagged as 'Rebasing'
CE07	1.1	Slope and offset statistically equivalent to 1.0 and 0.0 + scaling factors were not applied	DC15	Columns A to D, row 102	NO_2 Slope and offset values for pod 128245 were considered 1 and 0, respectively. Additionally, the co-location information provided was 'Hospital Pod'
CE08	1.1	Slope and offset statistically equivalent to 1.0 and 0.0 + scaling factors were not applied	DC16	Columns A to D, row 103	$PM_{2.5}$ Slope and offset scaling factors for pod 129245 were considered 1 and 0, respectively. Additionally, the co-location information provided was 'Hospital Pod'
CE09	1.1	Slope and offset statistically equivalent to 1.0 and 0.0 + scaling factors were not applied	DC24	Columns A to H, row 140	NO_2 Slope and offset scaling factors for pod 372245 were considered 1 and 0, respectively. Additionally, the co-location information provided was 'Hospital Pod'

CE10	1.1	Slope and offset statistically equivalent to 1.0 and 0.0 + scaling factors were not applied	DC18	Hospital Pods' spreadsheet, columns AH to AN, rows 3 to 11	Master spreadsheet confirms that 'Hospital Pods' provided pre-scaled data for their operation period
CE11	1.2	Application of scaling factors (slope and offset) statistically different to 1.0 and 0.0, obtained by co-locations with reference instruments	DC15	Columns A to D, row 38	NO_2 Slope and offset values for pod 37245 were considered 1.593 and 2.128, respectively, which were derived from co-location with reference instruments
CE12	1.2	Co-location with reference instruments should last from three to seven days	DC1	Column E, row 16	NO_2 co-location of pod 37245 with reference site occurred from 06-08/10/2018
CE13	1.2	Compliance with acceptance criteria of R^2 > 0.7 and normalized RMSE < 0.5	DC8	PODS_P75_P90' spreadsheet; columns D, F and Q; row 72	Acceptance criteria were met, as R^2 and normalized RMSE results were 0.8698 and 0.17, respectively, for NO_2 co-location of pod 37245 with reference instruments
CE14	1.3	Application of scaling factors (slope and offset) statistically different to 1.0 and 0.0, obtained by co-location with gold pods	DC15	Columns A to D, row 65	NO_2 Slope and offset values for pod 64245 were considered 1.252 and 0.917 respectively
CE15	1.3	Application of scaling factors (slope and offset) statistically different to 1.0 and 0.0, obtained by co-location with gold pods	DC24	20180901_20200914_NO2_scaling_f' spreadsheet, columns A to H, row 78	NO_2 Slope and offset values for pod 64245 were confirmed as 1.252 and 0.917 respectively
CE16	1.3	Application od scaling factors (slope and offset) statistically different to 1.0 and 0.0, obtained by co-location with gold pods	DC25	20180901_20200914_PM2.5_scaling', columns A to H, row 94	$PM_{2.5}$ Slope and offset scaling factors for pod 87245 were both considered 1.57
CE17	1.3	A minimum of 130 hourly results must be acquired during the co-location with gold pods	DC2	Colocation Analysis 2020-08-13' spreadsheet; columns B, C and K, row 76 and 184	Co-location of pod 64245 with gold pod 2046150 for NO_2 and NO generated 303 valid hourly results
CE18	1.3	A minimum of 130 hourly results must be acquired during the co-location with gold pods	DC2	Colocation Analysis 2020-08-13' spreadsheet; columns C, W and AC; row 76	Co-location of pod 64245 with gold pod 2046150 for $PM_{2.5}$ and PM_{10} generated 197 valid hourly results
CE19	1.3	Compliance with acceptance criteria of R^2 > 0.7 and normalized RMSE < 0.5	DC2	Colocation Analysis 2020-08-13' spreadsheet; columns C, W and AC; row 76	Acceptance criteria were met, as R^2 and normalized RMSE results were 0.913 and 0.08, respectively, for NO_2 co-location of pod 64245 with gold pod

CE20	1.3	Compliance with acceptance criteria of R^2 > 0.7 and normalized RMSE < 0.5	DC2	Colocation Analysis 2020-08-13' spreadsheet; columns C, W and AC; row 290	Acceptance criteria were met, as R^2 and normalized RMSE results were 0.948 and 0.06, respectively, for $PM_{2.5}$ co-location of pod 64245 with gold pod
CE21	1.3	Co-location with gold pods should last from seven to fourteen days	DC2	Colocation Analysis 2020-08-12' spreadsheet; column D rows 76, 184, 290 and 395	NO, NO_2, $PM_{2.5}$ and PM_{10} scaling factors derived from the same co-location of pod 64245 with gold pod 2046150 from 06-18/06/2019
CE22	1.3	Initial co-locations of gold pods with reference instruments for a minimum period of two weeks	DC1	Colocation Analysis 2020-08-12' spreadsheet; column D rows 83, 168, 196 and 278	Gold pod 2046150 initial co-location with reference instruments for NO, NO_2, $PM_{2.5}$ and PM_{10} performance evaluations occurred from 04-22/04/2019
CE23	1.3	Intermediate co-locations of gold pods with reference instruments for a minimum period of seven days	DC1	Colocation Analysis 2020-08-12' spreadsheet; column D rows 84, 169 and 279	Gold pod 2046150 intermediate co-location with reference instruments for NO, NO_2 and PM_{10} performance evaluations occurred from 17-28/07/2019
CE24	1.4	Network calibration scaling factors were applied	DC15	Columns A to D, row 74	NO_2 network calibration slope and offset values for pod 73245 were respectively considered 1.084 and -1.605
CE25	1.4	Network calibration scaling factors were applied	DC9	Column E, row 69	Network calibration was confirmed as scaling method applied to pod 73245 NO_2 results
CE26	1.4	Network calibration scaling factors were applied	DC4	'All scaling factors' spreadsheet, columns B and C, row 73	NO_2 network calibration slope and offset values for pod 73245 were confirmed as 1.084 and -1.605
CE27	1.4	Network calibration scaling factors were applied	DC16	Columns A to D, row 46	$PM_{2.5}$ network calibration slope and offset values for pod 45245 were respectively considered 1.266 and 0.685
CE28	1.4	Network calibration scaling factors were applied	DC11	Column E, row 69	Network calibration was confirmed as scaling method applied to pod 45245 $PM_{2.5}$ results
CE29	1.4	Network calibration scaling factors were applied	DC3	'All scaling factors' spreadsheet, columns B and C, row 46	$PM_{2.5}$ Network calibration slope and offset values for pod 73245 were confirmed as 1.266 and 0.685

CE30	1.4	Hybrid scaling method for NO with network offset and slope from co-location	DC32	Column A to E, row 21	NO gold pod co-location slope and network calibration offset values for pod 20245 were confirmed as 0.67 and 0.302, respectively
CE31	1.4	Hybrid scaling method for NO with network offset and generic average slope of 0.81	DC32	Column A to E, row 22	NO average slope and network calibration offset values for pod 21245 were confirmed as 0.805 and -0.032, respectively
CE32	2.1	Suspect results and/or pods are flagged after manual revision of results	DC17	Column A to E, row 10	$PM_{2.5}$ results from pod 21245 acquired between 29/07/2019 06:00:00 and 31/07/2019 12:00:00 were considered abnormally high and flagged accordingly to be redacted
CE33	2.1	Suspect results and/or pods are flagged after manual revision of results	DC17	Column A to E, row 11	NO_2 results from pod 36245 acquired between 08/01/2020 02:10:00 and 13/01/2020 00:00:00 were considered abnormally high and flagged accordingly to be redacted
CE34	2.1	Suspect results and/or pods are flagged after manual revision of results	DC26	$PM_{2.5}$ time series results in the main graph	Pre-scaled data confirmed the high $PM_{2.5}$ results from pod 21245 flagged as abnormally high for the considered period (CE30)
CE35	2.1	Suspect results and/or pods are flagged after manual revision of results	DC27	NO_2 time series results in the main graph	Pre-scaled data confirmed the high NO_2 results from pod 36245 flagged as abnormally high for the considered period (CE31)
CE36	2.1	Suspect results and/or pods are flagged after manual revision of results	DC28	Columns A to E, rows 224636 to 224689	$PM_{2.5}$ results from pod 21245 acquired between 29/07/2019 06:00:00 and 31/07/2019 12:00:00 were redacted and published as -999 on the Breathe London website
CE37	2.1	Suspect results and/or pods are flagged after manual revision of results	DC29	Columns A to E, rows 172327 to 174404	NO_2 results from pod 36245 flagged as abnormally high (CE33) were redacted were not published on the Breathe London website - only data from 23/06/2020 is available
CE38	2.2	Scaling factors applied retrospectively after manual verification of maintenance related disruptions	DC15	Columns A to G, row 4	NO_2 scaling factors from gold pod co-location were applied to the whole operation period of pod 3245, as there was not any identified maintenance related disruption

CE39	2.2	Scaling factors applied retrospectively after manual verification of maintenance related disruptions	DC15	Columns A to G, row 14	NO_2 scaling factors from network calibration were applied to the whole operation period of pod 13245, as there was not any identified maintenance related disruption
CE40	2.2	Scaling factors applied retrospectively after manual verification of maintenance related disruptions	DC15	Columns A to G, row 31	NO_2 scaling factors from gold pod co-location were applied to the whole operation period of pod 31245, as there was not any identified maintenance related disruption
CE41	2.2	Scaling factors applied retrospectively after manual verification of maintenance related disruptions	DC16	Columns A to G, row 10	$PM_{2.5}$ scaling factors from network calibration were applied to the whole operation period of pod 9245, as there was not any identified maintenance related disruption
CE42	2.2	Hardware maintenance and sensor replacements when appropriate	DC14	Columns A to N, row 16	NO sensor failure was recorded for pod 48245 between 14/02/2019 and 08/03/2019
CE43	2.2	Hardware maintenance and sensor replacements when appropriate	DC30	NO time series results in the main graph	NO time series results from pod 48245 confirm sensor failure episodes occurring from 14/02/2019 and 08/03/2020 (CE42)
CE44	3	Automated revision and flagging of pods' results considering pre-set concentration limits	DC23	Column AK, rows 14 to 19	Particle count results from pod 17245 were flagged as 'Less Than Concentration Limit'
CE45	3	Automated revision and flagging of pods' results considering pre-set concentration limits	DC22	Column G, rows 86369 to 86380	$PM_{2.5}$ results from pod 5245 were flagged as 'PM25 Greater Than PM10'
CE46	3	Automated revision and flagging of pods' results considering pre-set concentration limits	DC23	Column AE, rows 3566, 12406 and 32789	NO_2 results from pod 17245 were flagged as 'Less Than Lower Limit'
CE47	4	Power supply units (PSU) were replaced to correct for EMF interference with sensors' performance	DC18	Master' spreadsheet, columns AH to AN, row 20	Power supply unit (PSU) for pod 20245 was fitted on 26/3/2019 at 11:35 and results of gaseous pollutants are publishable from April 2019 onwards

CE49	4	Power supply units (PSU) were replaced to correct for EMF interference with sensors' performance	DC10	Columns A to D, row 212741	Only NO_2 results from pod 20245 acquired from April 2019 were published on Breathe London website, in accordance with CE47
CE49	4	Power supply units (PSU) were replaced to correct for EMF interference with sensors' performance	DC18	Master' spreadsheet, columns AH to AN, row 22	Power supply unit (PSU) for pod 22245 was not required as power was supplied by solar panel, which did not cause EMF interference

Appendix D – Nonconformity evidence table

Conformity evidence

Piece of evidence	QA/QC stage	Requirement description	Document number	Evidence location	Evidence description / comments
NCE1	1.1	Slope and offset statistically equivalent to 1.0 and 0.0 + scaling factors were not applied	DC15	Columns A to G, row 105	NO_2 scaling factors for pod 132245 were considered -999 and the scaling method was filled in as 'None (don't publish)
NCE2	1.1	Slope and offset statistically equivalent to 1.0 and 0.0 + scaling factors were not applied	DC18	'Hospital Pods' spreadsheet, columns AM to AN, row 7	Pod 132245 status was considered 'Online' its Data status considered 'All good', which disagrees with NCE1
NCE3	1.1	Slope and offset statistically equivalent to 1.0 and 0.0 + scaling factors were not applied	DC31	NO_2 and $PM_{2.5}$ time series results in the main graph	NO_2 and $PM_{2.5}$ time series results suggest that pod 132245 appears to be normal
NCE4	1.2	Co-location with reference instruments should last from three to seven days	DC18	Colocation History' spreadsheet	Pod 37245 was not found in colocation history in C40 Master Doc
NCE5	1.2	Co-location with reference instruments should last from three to seven days	DC18	Master' spreadsheet, columns AC, row 37	Co-location period for the pod 37245 was 06-10/10/2019, whilst DC1 states different period (06-08/10/2018)
NCE6	1.3	Application od scaling factors (slope and offset) statistically different to 1.0 and 0.0, obtained by co-location with gold pods	DC16	Columns A to H, row 94	$PM_{2.5}$ Slope and offset scaling factors for pod 87245 were both assigned -999 value, and the co-location information stated the absence of such scaling factors due to unacceptable covariance for network calibration - what differs from DC25 cited in CE16
NCE7	1.3	Application of scaling factors (slope and offset) statistically different to 1.0 and 0.0, obtained by co-location with gold pods	DC2	Colocation Analysis 2020-08-13' spreadsheet; columns U and V; row 76	NO_2 Slope and offset values for pod 64245 differ from DC24 cited in CE15
NCE8	1.4	Network calibration scaling factors were applied	DC15	All scaling factors' spreadsheet, columns B to D, row 15	NO_2 network calibration slope and offset values for pod 14245 were both considered -999 and flagged as 'covariance too low' - criterion not described in QA/QC

NCE9	1.4	Hybrid scaling method for NO with network offset and generic average slope of 0.81	DC32	Column A to E, row 22	NO average slope applied for pod 21245 was 0.805, instead of 0.81 (CE31)