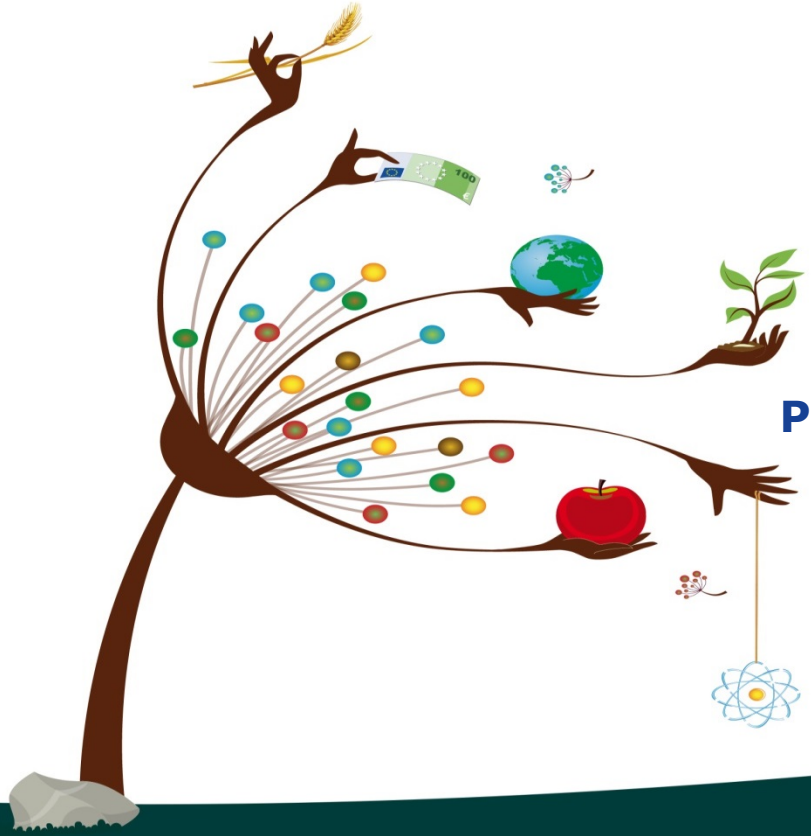
European Union Perspective on Sensor Standards –What factors were used to develop EN standards?



Michel Gerboles

European Commission - Joint Research Centre,

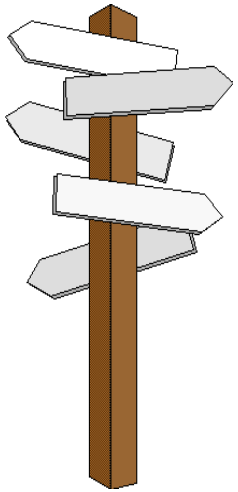
Air Sensors 2019:
EPA's Second Workshop of Deliberating Performance Targets for Air Quality Sensors
July 16 2019

Sheraton Imperial Hotel,
Durham, NC, USA

European Commission

RoadMap

- Objective of the sensor evaluation
- Metrics of the performance of sensors
- EU protocol – flowchart of tests
- Parameters to be tested
- Representativeness and comparability of field tests
- Conclusions: which aspects were taken into consideration



Technical Specification for Sensors

-**Rationale**: Can a network of fixed low-cost sensors monitor air quality for legislative purpose ≠ estimate population exposure using low-cost sensors in mobility

-**Main question**: can low-cost sensors meet prescribed data quality objectives set in the European Air Quality Directive

-**Expected result**: a protocol describing specific performance requirements and test methods under prescribed laboratory and field conditions

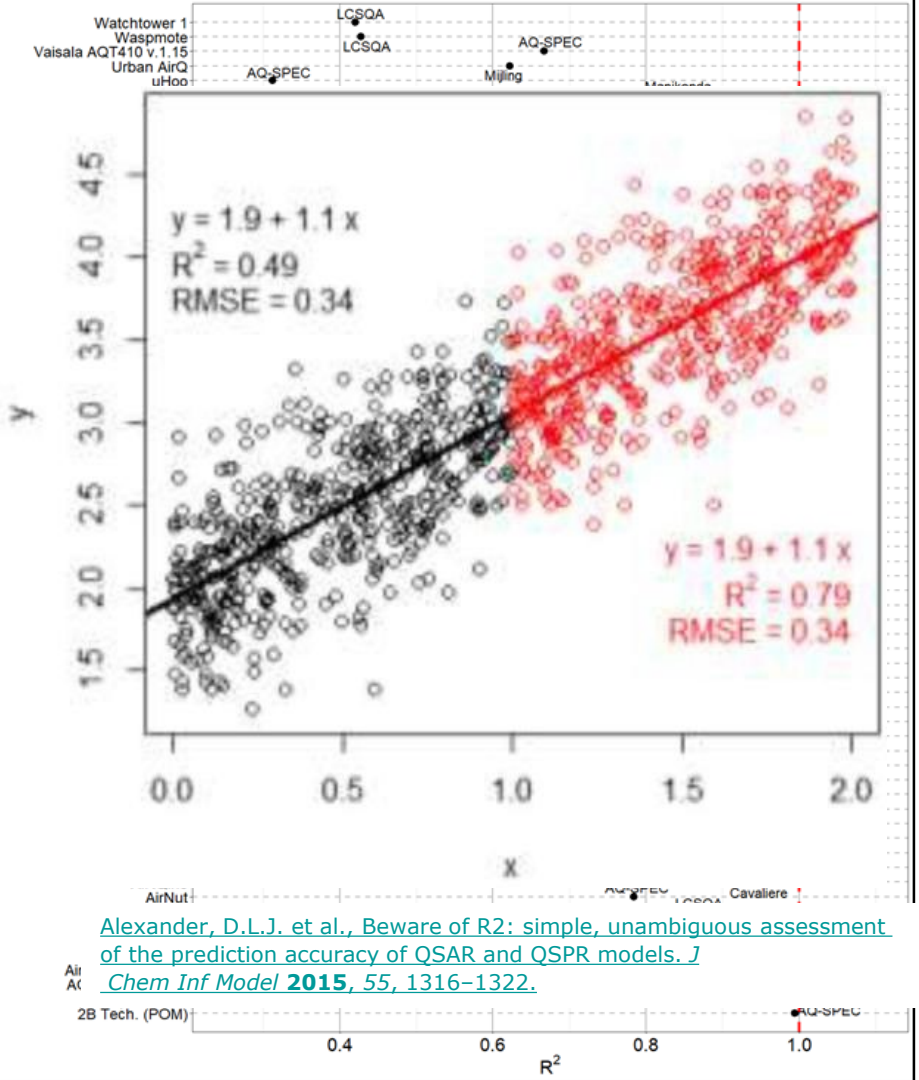
→ classification of sensors: class 1 and 2 for legislative purposes and class 3 (measurement uncertainty < 200 %)

Metrics in literature (articles, report of NRLs…)

Metrics	n. Field Tests	n. Laboratory Tests
Total tests	1290	133
R^2, calibrations	218	60
R^2, comparisons	1160	72
slope of reg. line	1063	55
Intercept of reg. line	1027	54
Root Mean Square Error (RMSE)	285	5
Measurement uncertainty (U)	153	29

Comparing using R^2

- R^2 gives the strength of association between x,y ; not the agreement (slope and intercept needed)
- R^2 increases with the range reference measurements (RMSE would be better)
- R^2 changes with seasonality (cross-sensitivities + meteorological conditions)
- R^2 generally decreases with the length of tests (time drift and ageing) and time average



Alexander, D.L.J. et al., Beware of R2: simple, unambiguous assessment of the prediction accuracy of QSAR and QSPR models. *J Chem Inf Model* **2015**, *55*, 1316–1322.

Data Quality Objectives (DQO) of the European Directive

	O_3	CO, NO_2, SO_2	PM_{10}, $PM_{2.5}$
DQO reference measurements	U = 15 %	U = 15 %	U = 25 %
DQO indicative measurements	U = **30 %**	U = **25 %**	U = **50 %** ← Class 1
DQO Objective estimation	U = **75 %**	U = **75 %**	U = **100 %** ← Class 2
Additional class	U=**200 %**	U=**200 %**	U=**200 %** ← Class 3

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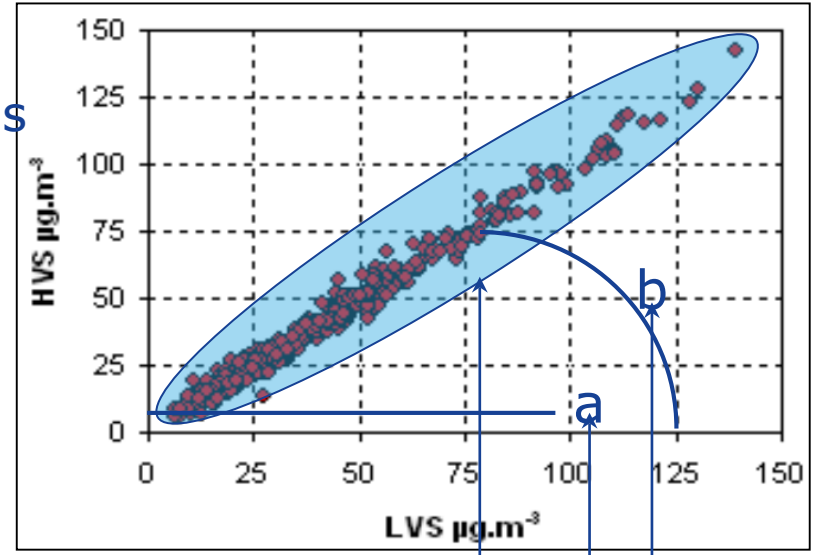
Analogy with reference measurements: Guide for the Demonstration of Equivalence

- A EU Member State may use any method which it can demonstrate gives results equivalent to reference methods.
- The guide requires that new methods satisfies prescribed requirements in laboratory and field tests
- The tests needs to demonstrate that the measurements uncertainty is lower than the Data Quality Objectives set in the European Directive



repeatability

$$U = 2\sqrt{u_{bs,s}^2 - u_{bs,RM}^2 + \frac{RSS}{(n-2)} + [a + (b-1)X_i]^2}$$

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Technical Specification for sensors - method

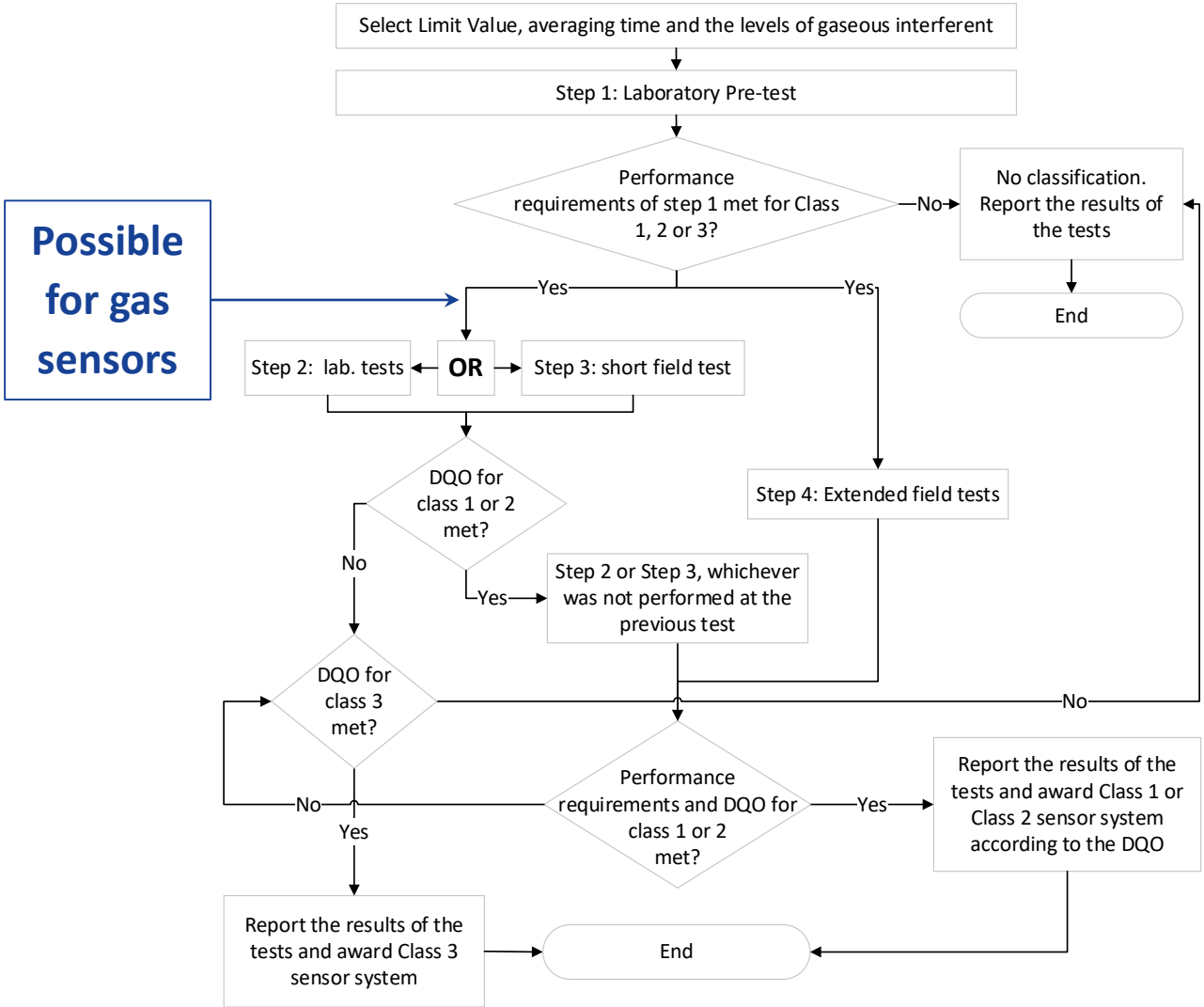
Gas sensors:

- A lab. pre-test is required to check linearity, response time and limit of detection
- Two routes are feasible for the classification of sensors:
  - perform a list of laboratory tests in exposure chamber using synthetic gas mixture plus a short field test programme
  - or only perform an extended field test programme

PM sensors:

- Check flow rate, effect of temperature and power supply in lab.
- Perform an extended field test programme.

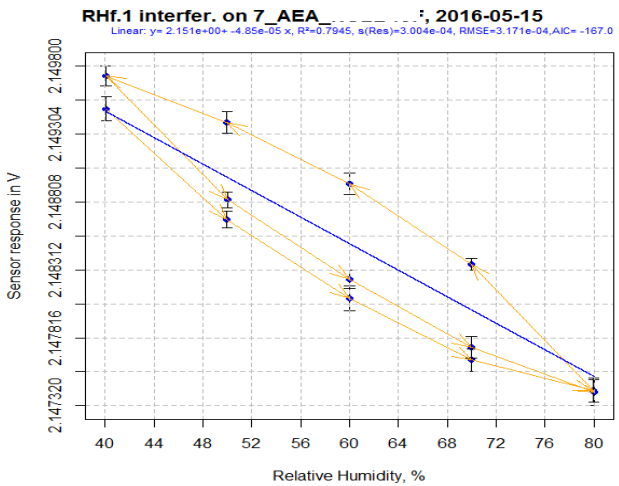
The field tests of gas and PM sensors are evaluated with the method of the “Guide for the Demonstration of Equivalence”.

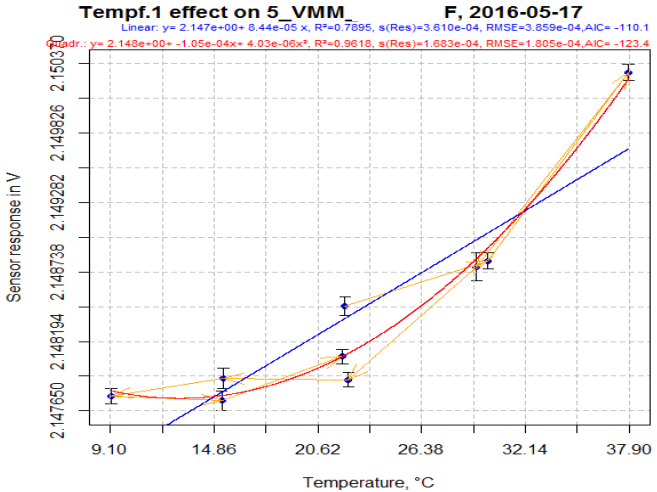

Select Limit Value, averaging time and the levels of gaseous interferent
Step 1: Laboratory Pre-test
Performance requirements of step 1 met for Class 1, 2 or 3?
No
No classification. Report the results of the tests
End
Possible for gas sensors
Yes
Yes
Step 2: lab. tests
OR
Step 3: short field test
DQO for class 1 or 2 met?
No
Yes
Step 2 or Step 3, whichever was not performed at the previous test
Step 4: Extended field tests
DQO for class 3 met?
No
No
Performance requirements and DQO for class 1 or 2 met?
Yes
Report the results of the tests and award Class 1 or Class 2 sensor system according to the DQO
Yes
Report the results of the tests and award Class 3 sensor system
End

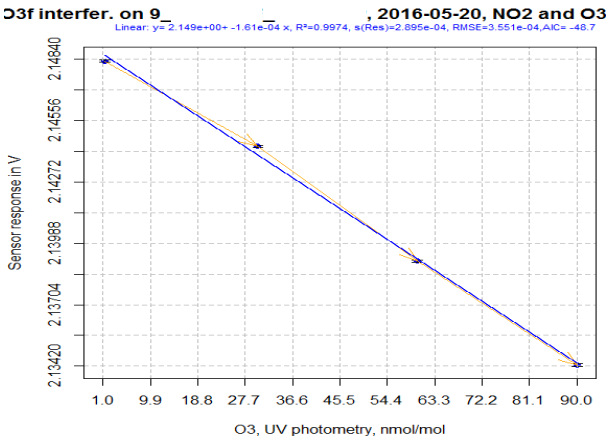
Parameters to be tested

- **Pre-test**: for gas: check of basic metrologic parameters: lack of fit of calibration, repeatability and response time in lab. For PM: check flow rate, effect of temperature and power supply in lab.
- **Gaseous laboratory tests**: parameters are selected based on the results of tests performed in previous studies: temperature, humidity, cross sensitivities and long term drift…
- **Field tests**: The AQMS shall also cover the range of meteorological conditions (concentration levels and temperature /humidity) that are expected to be be encountered during future use of the sensors.

Example of influence of humidity, temperature on NO_2 sensor







Example of influence of ozone concentration on NO_2 sensor

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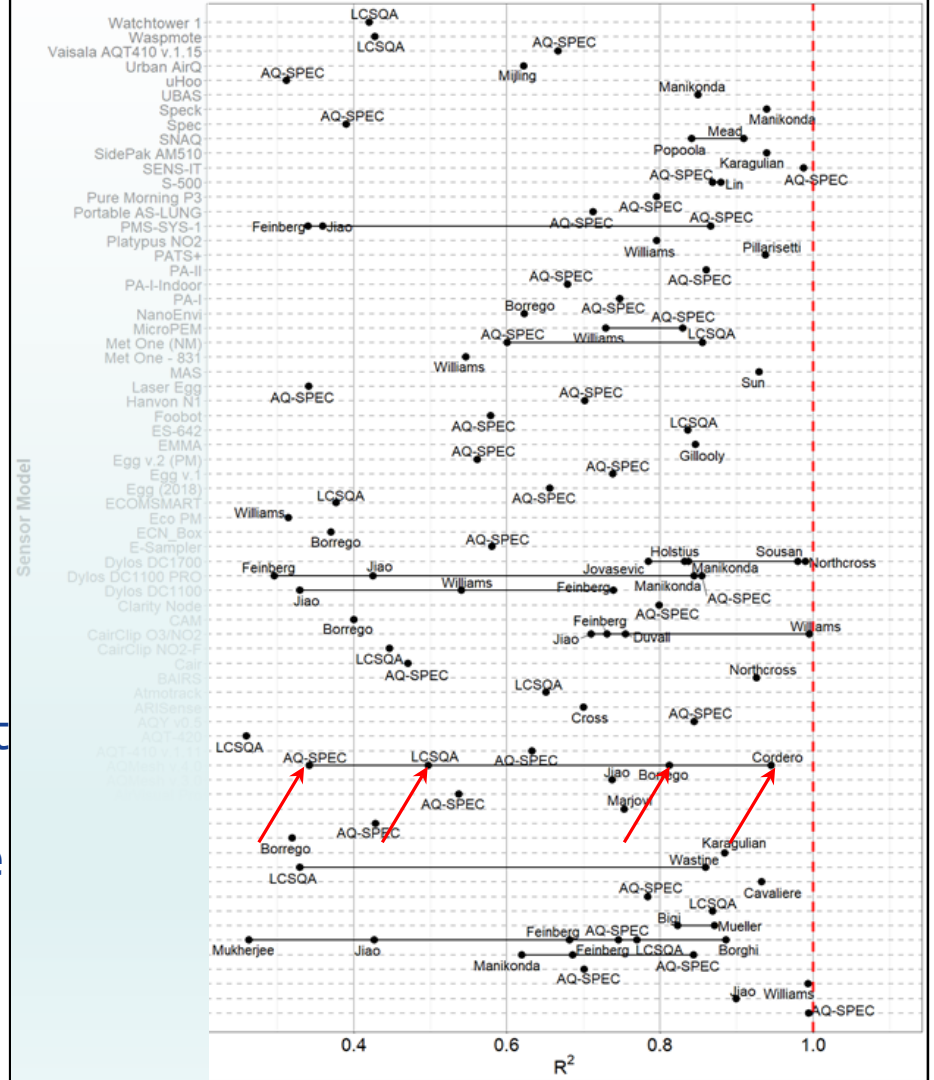
Scattering of R² according to studies of the same sensor system

- Nearly no sensor system with identical R² in different studies

It is likely that the difference R² are caused by:

- Different air compositions and meteorological conditions at different locations
- Different durations and time average
- Difference in skills of the operators



Number of field sites and duration

Compound	Areas			Site		Short field test	Extended field test
	Urban	Suburban	Rural	Traffic	Background	Total number of sites	Total number of sites
NO2	+	+		+	+	4	8
NO	+	+		+	+	4	8
O3	+		+		+	2	4
CO	+			+	+	2	4
SO2	+				+	1	2
Benzene	+			+		1	2
CO2			+		+	1	2

A test of at least 2 periods of 40 days for Class 1 and 2 shall be carried out, e. g. 40 days from May to September, 40 days from December to February

Conclusions

- Fixed low-cost sensors for monitor air quality for legislative purpose
- Evaluation of sensors against the data quality objective of the European Directive for air pollution
- The factors to be tested were selected based on known behavior of sensors when parameters are changed in laboratory tests (cross-sensitivities, temp. humidity, long-term drift …)
- We define the duration of fields tests and a minimum number of test sites showing differences of air composition and meteo conditions in order to capture the variability of sensor performances.

Conclusions

- Averaging time = the reference measurements set in the European Directive
- QA/QC: Operator shall works in conformity with the requirements of internationally accepted standards for test laboratories. **Not mandatory**: A formal accreditation by a member body of the European Accreditation Organisation to EN ISO/IEC 17025 is a demonstration of conformity.
- In literature the methods and metrics used for reporting the sensor performances are different to compare each other→ need for an ISO standard?