VAQUUMS

Sensor selection procedure

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For the LIFE VAQUUMS project we aimed to select an array of low to medium budget air quality sensors to measure particle matter, nitrogen dioxide and ozone. These sensors will be tested in lab conditions and in a field experiment where they will be compared with reference instruments. In this way we can test the reliability of the sensors and give advice to governments and citizen science groups.

We took the following steps to select a workable number of relevant sensors.

Step 1. Inventory build-up: desktop research

In a first step we gathered relevant information about the existing know-how of air quality sensors. This knowledge can be available in several forms: scientific literature, other literature, project results of monitoring networks, results of European and worldwide projects, etc.

We started our desktop research in google scholar by combining different search entries (and/or): 'Sensor, PM, Particulate matter, fine dust, O3, ozone, NO2, nitrogen dioxide, comparison, low cost'. In this search, literature up to September 2017 was taken into account. In addition, the work of AQ SPEC was included. When all literature was gathered, we checked our literature database against the AirMonTech database, to avoid missing references. Moreover, all partners checked if there were sensors missing which would possibly indicate missing literature about these specific sensors.

Step 2. Inventory build-up: Literature review

The available literature was then reviewed by the project partners. Besides the results (R^2) of the studies we also gathered information like initiating body, design of project (lab or field tests), type of sensors, scale and duration, comparative testing at official stations, conclusions and lessons learned.

Step 3. Longlist sensors

Based on the literature review we selected those sensors that fulfilled certain quality requirements. Preferably, we based our selection on field tests. If a sensor was tested in the field it was selected for the longlist when the R^2 value was above 0.8 for PM sensors and above 0.6 for gas sensors. If a sensor was only tested in lab conditions, it was considered good enough when R^2 values were above 0.8 for both PM and gas sensors. These values were based on the partnership's expert opinion and reflect the overall poorer performance of gas sensors compared to particle sensor that was observed in literature. Additionally we did not use too stringent requirements as to not exclude too many sensors. As we see it, we will identify several use cases with varying quality requirements and thus also sensors with mediocre performance can ultimately have their place in some of these cases. Furthermore we recognize that sensors can display a wide range of R^2-values in different experiments. Again to not exclude sensors that would prove worth testing later on, we considered the highest reported R^2 for each sensor.

Step 4. Internal expert consultation

As a fourth step the longlist based on the literature was only circulated to the experts within the partner institutions. They were asked if the sensors in our longlist were either 'not worth testing', 'worth testing due to (expected) high quality', 'worth testing since they are widely used' or 'obsolete'. Secondly, the experts were also asked to indicate which sensors were missing in our longlist and why they would be interesting to include them in the tests. It was also possible to give additional remarks regarding the sensor selection.

Based on the input of the internal experts, additional sensors were added to the longlist. A new desktop search and literature review were performed, specifically aiming to check available knowledge about these additional sensors. This way of working allowed us to further capture all relevant experience regarding the sensor selection within the partnership.

Step 5. External expert consultation

The new version of the longlist was then further distributed amongst other experts in this field, including experts of JRC, WG15 and WG42. They were asked the same two questions as the internal experts: 1. Do you think this sensor is worth testing? Why? (Annex 1); 2. Are there sensors missing in our longlist? (Annex 2)

The experts' opinions were summarized in an extended version of the longlist.

Step 6. Scoring the sensors

Next, we scored the different sensors based on the experts' opinions, both internal and external. Every time a sensor was recommended ('worth testing due to high quality', 'worth testing since they are widely used') by an expert one point was added to the score. While the score was reduced by one point for every expert that discommended a sensor. This resulted in a new version of the longlist were every senor had a certain expert score.

Step 7. Sensor selection

Finally, a shortlist of sensors to test during the LIFE VAQUUMS project was selected based on all the information gathered (Annex 3).

The LIFE-program demanded knowledge build-up on mobile and portable devices. Since several system solutions for measuring air quality are fixed, they were excluded from this project. Furthermore, after consulting JRC it also became clear that many of these more expensive system sensors would be tested during the AQUILA project, wherefore it is not necessary to also test them in our project. In general, testing loose sensors was preferred over testing the same sensors included in boxes. Note that these boxes and system solutions are typically more expensive, making them less suitable for citizen science.

We followed several steps to select the sensors we will test during the VAQUUMS project.

1. A sensor from the longlist was selected based on the expert consultation if it scored 2 or more points. If two sensor types of the same manufacturer scored 2 points or higher, we selected only one to include in the tests. This was for example the case for the 'Plantower PMS sensors type 7003 and A003'. Since the 'Plantower PMS 7003' had a higher score and the models are identical in all ways but their physical size, we selected this one.
2. Next, the sensors on the longlist which were not selected by their expert score were re-evaluated by the project partners. In this way we ensured that no sensors which were worth testing were excluded from the shortlist due to a low or absent expert score.
3. The missing sensors that were advised by the experts could not be evaluated by our scoring system, since they were not scored by all experts. Therefore, these missing sensors were evaluated by the project partners. This resulted in the addition of two extra sensors to the shortlist. The 'Shinyei PPD42' was selected since it is widely used and the 'Membrapor NO2/C-20' was recommended and considered interesting to include in the tests.

Annexes

1. Longlist: Expert scoring

$PM_{2.5}$ sensors

Particulate Matter sensors			Worth testing?					
Model	**Lit.**	**Price (€)**						
2 PMS 5003 sensors in Purple Air PA II monitor	Y	200						
Air nut sensor	Y	200						
Air Quality Egg v2	Y	240						
Alphasense OPC-N2 Particle monitor	N	~$500						
DYLOS 1700	Y	425						
Dylos DC 1100 PRO	Y	300						
Honeywell HPM	N	22						
Met One ES-642	Y	Exp.						
Nova fitness SDS011	N	20						
Nova fitness SDS018	N	20						
Nova fitness SDS019	N	1000						
Nova fitness SDS021	N	20						
PLANTOWER PMS 1003	N	14						
PLANTOWER PMS 3003	N	14						
PLANTOWER PMS 5003	N	14						
PLANTOWER PMS 6003	N	<50						
PLANTOWER PMS 7003	N	23						
PLANTOWER PMS A003	N	25						
RTI MicroPEM	Y	2000						
Samyoung DSM501A	N	~8						
SEEED dust sensor								
Sharp DN7C3CA007	N	20						
Sharp DN7C3CD015	N	20						
Sharp GP2Y1010AU0F	N	~8						
Sharp GP2Y1023AU0F	N	20						
Shinyei in PUWP monitor (PPD42NS)	Y	<$500						
Shinyei PM Sensor Evaluation kit	Y	1000						
Shinyei PPD-20V	Y	?						
Shinyei PPD42								
Shinyei PPD60	N	14						
SM-PWM01c								
Vaisala AQT420	N	NA						
Winsen ZH03A	N	72						
Xiaomi PM 2.5 Detector								

NO_2 sensors

Nitrogen Dioxide sensors			Worth testing?					
Model	**Tes**	**Price (€)**						
Alphasense in AQMesh (NO2-B43F)	Y	£4000						
Alphasense in NASUS (NO2A1-A3)	Y	NA						
Alphasense NO2A1-A3	Y	155						
Alphasense NO2-B4 in AirSensEUR								
Alphasense NO2-B43F	Y	274						
Alphasense NO2-B43F in SNAQ box van Cambi	Y							
Cairpol, cairclip	Y	NA						
Citytech 3E50 in Airbox	Y	NA						
SENS-IT	Y	2200						
Vaisala AQT420	N	NA						
Winsen ZE03-NO2	N	90						

O_3 sensors

Ozone sensors			Worth testing?					
Model	**Tes**	**Price (€)**						
2B technologies personal ozone monitor	Y	4500						
Aeroqual (SM50)	Y	325						
aeroQUAL S500 OZU	Y	500						
Air Quality Egg v1	Y	200						
Alphasense sensor in AQMesh	Y	£4000						
Cairpol CairclipO3/NO2	Y	NA						
Citytech O3_3E1F	Y	NA						
Membrapor O3/M-5								
Membrapor O3/M-5 in AirSensEUR								
MICS OMC2	Y	1000						
MiCS-OZ-47 in NanoEnvi-platform	Y	NA						
Nano Envi O3 Mote	Y	4460						
Perkin Elmer Elm	Y	NA						
UNITEC SENS3000= ETL3000?	Y	2000						
Unitec SENS-IT	Y	2200						
Winsen ZE03-O3	N	90						

2. Missing sensors

MODEL	POLLUTANT
SM-PWM01C	PM
SEEED DUST SENSOR	PM
SHINYEI PPD42	PM
XIAOMI PM 2.5 DETECTOR	PM
SHARP GP2Y1010AU0F	PM
SAMYOUNG DSM501A	PM
SHARP DN7C3CA007	PM
SHARP GP2Y1023AU0F	PM
SHARP DN7C3CD015	PM
SHINYEI PPD-20V	PM
KUNAK AIR	PM
TERRA KOMT MET NIEUWE SENSOR	PM
MINIDISC VAN MPA	PM
ALPHASENSE NO2-B4 IN AIRSENSEUR	NO2
MEMBRAPOR NO2/C20	NO2
MEMBRAPOR O3/M-5	O3
MEMBRAPOR O3/M-5 IN AIRSENSEUR	O3

3. Shortlist selected sensors

PM

- Alphasense OPC-N2
- Dylos DC1700
- Honeywell HPMA115S0
- Nova fitness SDS011
- Plantower PMS 7003
- Shinyei PPD42NJ
- Shinyei PPD60PV-T2
- Winsen ZH03B

NO_2

- Alphasense NO2-B43F
- Citytech NO2 3E50
- Envea Cairclip NO2
- Membrapor NO2/C-1
- Membrapor NO2/C-20

O_3

- Alphasense OX-B431
- Citytech O3 3E1F
- Envea Cairclip O3/NO2
- Aeroqual SM50
- Membrapor 03/C-5