Blueprint For The Deployment Of Municipal Air Quality Sensor Networks

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SYNOPSIS

This blueprint was developed together with municipalities and the Flanders Environment Agency (VMM), based on insights from the project "*Municipal sensor network for air quality measurements*", a cooperation of municipalities Kampenhout, Sint-Niklaas, Schoten, Dilbeek and Oudenaarde, funded through the CoT call (2018) of the Flemish Agency for Innovation & Entrepreneurship (VLAIO).

It serves as a **practical tool for local authorities** that want to deploy air quality sensor networks in their municipality/city. This blueprint includes **different phases** (preparatory stage, sensor selection, roll-out, follow-up, analysis & interpretation and communication) to achieve a successful roll-out of sensors and tries to differentiate from previous roadmaps[1, 2] by means of **practical examples**, **dedicated tools** (e.g. sensor selection tool) and **experiences and learnings** from stakeholder workshops and 2 pilots with air quality sensors in Sint-Niklaas and Kampenhout (BE).

The research trajectory towards this blueprint covers a **literature study** on air quality sensors, **market analysis**, **workshops and surveys with local authorities**, a **co-design workshop on communication**, a report on **IoT network solutions** and **2 pilot studies** with sensor networks in Sint-Niklaas and Kampenhout, and a **business case** in which all the associated costs of a sensor network (purchase, maintenance, visualization, processing) are listed. This trajectory is described in detail in the full report (dutch).

1. *Hofman, J.; Panzica La Manna, V.; Muylaert, J. Measuring and Modeling Air Quality in Smart Cities; IMEC: 2021. https://www.imeccityofthings.be/drupal/sites/default/files/inline-files/AQ_Report_CoT_062029_1.pdf*
2. *VMM, VAQUUMS Air Quality Sensor Roadmap. In VMM: 2021. https://vaquums.eu/deliverables/life-vaquums_roadmap_v1-0.pdf/view*

BLUEPRINT FOR MUNICIPAL AIR QUALITY SENSOR NETWORKS

This blueprint is based on a research trajectory described in detail in the full report (Dutch).

Based on relevant experiences from the preliminary surveys, workshops, co-design session, literature study, ... and developed tools, we tried to refine design processes of existing roadmaps for air quality sensors with relevant **scoping suggestions (scoping)** and **best practices (practical tools)**. Doing so, the blueprint provides a practical implementation of existing conceptual roadmaps ready to use for local authorities.

For each step in the design process, the scoping suggestions and best practices are listed below:

RESEARCH QUESTION

- Define **users and target groups** (environmental officer, citizens, schools, …) and emphatize with the exhibited problems and perspectives of each target group. LIFE VAQUUMS roadmap en brainstorm templates will get you going!
- Define your research question:
    - Compare prevailing concentrations to air quality limits
    - Impact from traffic, industry,… on local air quality
    - Air quality mapping of your municipality or city
    - Measuring impact from a local policy measure
    - …
- Experiences from City of Things project:
    - Major interest in traffic contribution, local hotspots and personal exposure.
    - Potential of sensor networks for evaluation of traffic measures and awareness raising among citizens
    - Air quality is closely related to mobility, climate, health, noise,… Try to frame the research question in a broader context by involving target groups and interdisciplinary environmental officers.
- Consider **what information is yet available**:
    - School streets
    - Low Emission Zones (LEZ)
    - Dynamics Air Quality in Flanders
    - Citizen Measurements

EXPERIMENTAL SETUP

- Consider general VAQUUMS sensor guidelines.
- Connect with **existing netwoks or initiatives** (eg https://samenvoorzuiverelucht.eu/), which might already have taken several hurdles on experimental setup, calibration, visualization and interpretation.
- Consider **beneficiaries** in your ecosystem, potentially enriching your experimental setup (both literally and figuratively).
- Experimental setup: Make sure that the experimental setup is tailored to the research question needs

- Environment (indoor vs outdoor)?
- Mobile vs fixed?
- Availability resultats (5 min <> week)?
- Visualisation results (real-time, map, time series,…)?
- Required monitoring resolution (1 second - 24 hours)?
- Acceptable uncertainty (<10% - >50%)?
- Which pollutants ($PM_{2.5}$, PM_{10}, black carbon, CO, CO_2, O_3, NO, NO_2, SO_2, CH_4, VOCs, pollen)?
- Number of monitoring locations (1 <> 50)?

o Experiences CoT project:
  - **Nitrogen oxide (NO)** is (apart from NO_2) a very useful traffic indicator
  - A **background location** is vital to in order to derive local source contributions

o Consider all available measurement methods (not only sensors):
  - **Regulatory networks** (open available, hourly, very accurate, no calibration needed): eg. https://www.irceline.be/nl/luchtkwaliteit/metingen/meetstations
  - **DIY sensor** (real-time, inexpensive, need for calibration/technical know-how): vb. https://sensor.community/nl/sensors/
  - **Sensorbox** (real-time, expensive, nood for calibration/technical know-how): vb. http://www.aqmd.gov/aq-spec/sensors
  - **Passive sampling tubes** (2-weekly/monthly measurement, inexpensive, robust, no need for calibration): vb. https://curieuzenair.brussels/nl/hoe-werken-de-buisjes/
  - **Wearable monitors** (real-time, expensive, no need for calibration/know-how): vb. https://www.airqmap.be/

o Consider relevant pollutants for your application:
  - General air quality (regulated pollutants): $PM_{2.5}$, PM_{10}, NO_2, O_3
  - Road traffic: NO, NO_2, $PM_{1/2.5}$, black carbon (BC), UFP
  - Wood burning: PM_1, $PM_{2.5}$, PM_{10}, black carbon (BC), polyaromatic hydrocarbons (PAHs)
  - Shipping: SO_2, PM
  - Indoor air quality: CO_2, PM, VOCs

o Involve (local) experts and/or environmental agencies (VMM, …)

o Sensor selection:
  - Check EMIS sensor selection tool developed during this project
  - Consider **functional properties**, tailored to your research question, when selecting a sensor: measured pollutants, availability results, plug & play, required technical know-how, recurring costs (maintenance, software license), lifetime integrated sensors, temporal monitoring resolution, data quality sensor system, price. Don't forget **visualisation needs** and **quality assurance and control** (QA/QC)
  - Consult existing evaluation platforms to get an idea about data quality:
    - http://www.airlab.solutions/en/projects/microsensor-challenge
    - http://www.aqmd.gov/aq-spec/evaluations
    - https://vaquums.eu/test-results

DEPLOYMENT

o Experience project: make sure to include comparative measurements (co-location sensors), ideally at an air quality monitoring stations (AQMS) to evaluate **between-sensor uncertainty** and **uncertainty against reference**! In Flanders, you can contact VMM as they can aim to open up an AQMS for comparative measurements.

o Monitor the proper operation of your sensor network (online or on-site) and foresee hours/effort to go on-site for maintenance and sensor failure purposes

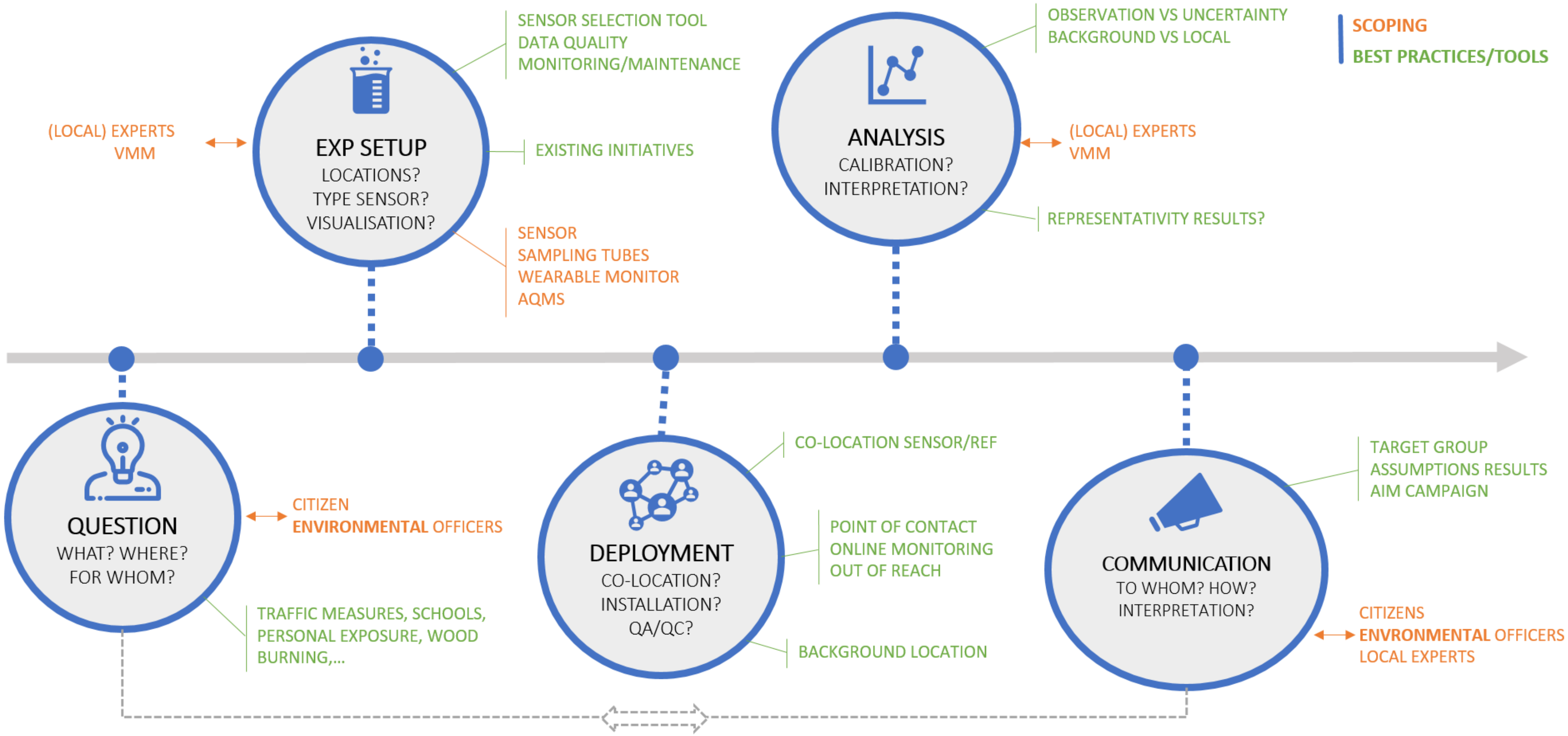
- Make sure to have a point of contact (sensor supplier/manufacturer) for questions/assistance
- Experiences CoT project:
  - Sensors should be deployed out of reach for vandalism (>~2.5m)
  - Include a background location (not affected by nearby sources) to evaluate impacts from local sources/measures om lokale effecten (vb van een beleidsmaatregel) te evalueren. Using this background location, you can distinguish between background pollution dynamics and local source effects.

DATA ANALYSIS

- Involve **(local) experts and/or environmental agencies (VMM)** and reflect on the original research question
- Compare observed **concentration differences between sensor locations** with **between-sensor uncertainty** to determine whether the measured impacts are due to local sources/measures or simply instrument noise.
- When quantifying local effects:
  - Use the background location to normalize/correct for background pollution dynamics.
- Evaluate the representativity of the observed effects (at considered locations and during certain hours, days, seasons,…) taking into account the spatial and temporal variability in air quality.

COMMUNICATION

- Test the **assumptions of the results in advance** before organising a wide-scale communication campaign to guarantee its effectiveness.
- Focus on the **target group**, **assumptions of the results** and **aim of the communication campaign** (eg behavioural change).
- Depending on the reserach question, raw data will need data analysis/processing (eg normalisation for background dynamics) and might lead to misinformation
- Consider multiple communication concepts:
  - Visualisation app
  - Visualisation sign
  - Game on transportation choice
  - Route dashboard
  - …


SENSOR SELECTION TOOL
DATA QUALITY
MONITORING/MAINTENANCE
OBSERVATION VS UNCERTAINTY
BACKGROUND VS LOCAL
SCOPING
BEST PRACTICES/TOOLS
(LOCAL) EXPERTS
VMM
EXP SETUP
LOCATIONS?
TYPE SENSOR?
VISUALISATION?
EXISTING INITIATIVES
ANALYSIS
CALIBRATION?
INTERPRETATION?
(LOCAL) EXPERTS
VMM
REPRESENTATIVITY RESULTS?
SENSOR
SAMPLING TUBES
WEARABLE MONITOR
AQMS
CO-LOCATION SENSOR/REF
TARGET GROUP
ASSUMPTIONS RESULTS
AIM CAMPAIGN
QUESTION
WHAT? WHERE?
FOR WHOM?
CITIZEN
ENVIRONMENTAL OFFICERS
DEPLOYMENT
CO-LOCATION?
INSTALLATION?
QA/QC?
POINT OF CONTACT
ONLINE MONITORING
OUT OF REACH
COMMUNICATION
TO WHOM? HOW?
INTERPRETATION?
CITIZENS
ENVRONMENTAL OFFICERS
LOCAL EXPERTS
TRAFFIC MEASURES, SCHOOLS,
PERSONAL EXPOSURE, WOOD
BURNING,...
BACKGROUND LOCATION

Existing tools and knowledge platforms for each step in the design process (Figure 1) are listed below:

	VAQUUMS SCOPING ROADMAP	Scoping/brainstorm Roadmap developed in the VAQUUMS project
	SAMEN VOOR ZUIVERE LUCHT	Inspiring examples, actions and tools
	SENSOR SELECTION TOOL	Inventory/selection tool sensors (EMIS)
	OVERVIEW MONITORING TOOLS	Measurement techniques
	DATA QUALITY - AIRLAB - AQ-SPEC - VAQUUMS	Independent evaluation platforms of sensor data quality
	VMM/LOCAL EXPERTS	Point of contact VMM for local authorities that need information on air quality monitoring or qualitative policies
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