After-LIFE plan

1 Introduction

1.1 Project scope & objectives

In recent years the awareness on the influence of air quality on human health increased exponentially. This led to the start of many citizen science initiatives which measure air pollution on a local scale. This evolution also lead to the development of vast amounts of low cost devices to measure the air quality.

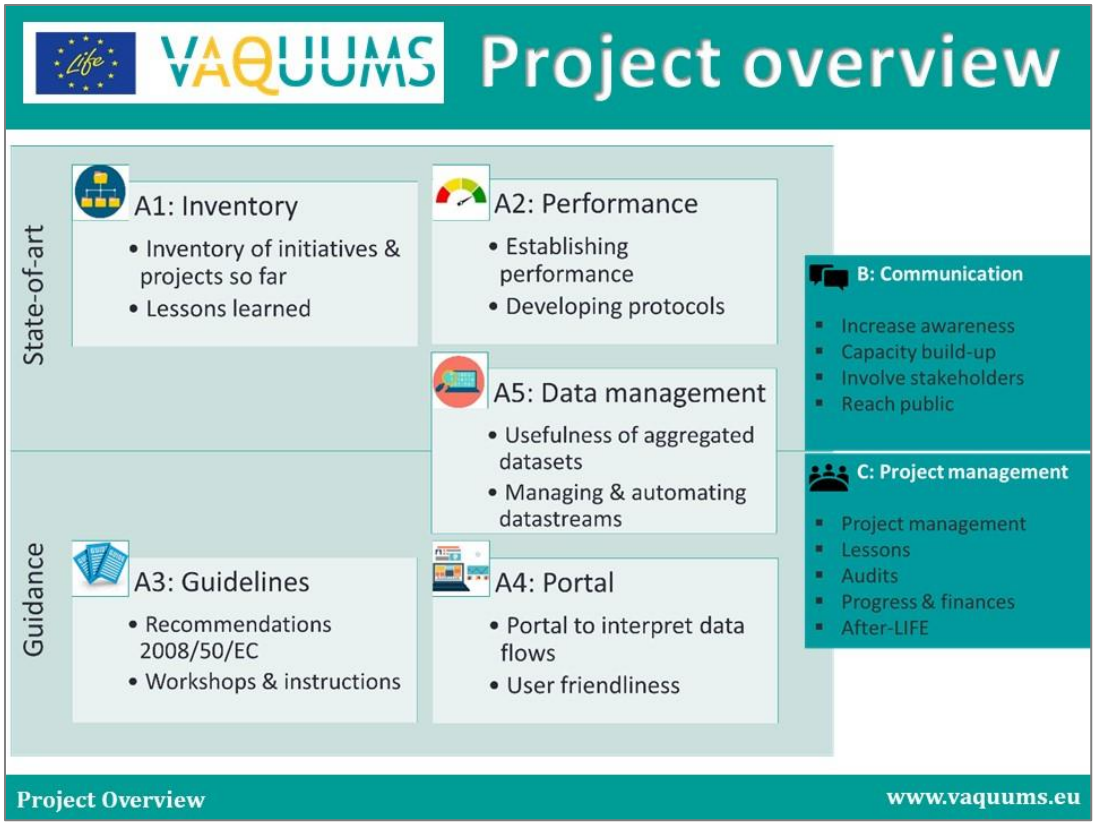
These devices are often mobile and potable which enables everyone to start measuring air quality in their neighborhoud. This leads to a high spatiotemporal resolution of te measurements, but the quality of these measurements is often unknown. Our literature review learns us that previous projects and studies each follow their own methodology which makes it very hard to compare sensor performance between studies.

The LIFE VAQUUMS-project was started in order to support citizen scientists and local governments that want to start measuring air quality. To be able to give advice on the use of air quality sensors we needed to better understand their performance. Therefore the LIFE VAQUUMS-project did their own large scales tests on 18 different low cost sensors for particulate matter (PM), nitrogen dioxide (NO_2) and ozon (O_3). As it is important to know sensor performance on a fixed location, before mobile measurements are started, the project focused on the tesing of low cost air quality sensors at a fixed location. The results of the tests enabled us to formulate guidelines on the use of low cost air quality sensors and a roadmap on air quality sensor networks.

The LIFE VAQUUMS-project had the following objectives:

- Providing an overview of the state-of-art applicability and use of low cost air quality sensors
- Developing a supporting framework for local and regional air quality monitoring networks to facilitate the uptake of flexible monitoring systems
- Creating building blocks for online platforms for knowledge and experience exchange, data collection and analysis
- Providing input for reviews of the air quality directive
- Informing all stakeholders according to their role in the air quality networks of the future

1.2 Project overview



During the LIFE VAQUUMS-project five implemantation actions were realized in order to reach the project goals. These actions primary focused on the state-of-art of low cost air quality sensor measurements (PM, NO_2, O_3) and secundary on giving guidance on how to use these low cost air quality sensors.

The first action focused on the inventory build-up. In this action we gathered information on the available devices and their performance; past and current projects and their lessons learned; legislation on the usage of low cost air quality sensors. All this gathered information allowed us to make a longlist of interesting low cost air quality sensors. In order to select devices for the large scale tests of the LIFE VAQUUMS-project we developed a sensor selection procedure which involved two rounds of expert consultation. In this way we were able to select 18 promising sensors to start our experiments.

The second action involved the testing of the 18 selected low cost sensors for particulate matter, nitrogen dioxide and ozon. To standardize the test we first developed a test protocol that describes the set-up and evaluated parameters. Before the tests could start the sensors needed to be programmed and assembled. All steps taken were well documented. First we conducted laboratory tests whereafter the sensors were co-located at a reference station in Antwerp for just over one year. After the analyses were finshised all results were presented in reports and factsheets.

The third action involved giving recommendations and making guidelines on how to use low cost air quality sensors. As a first deliverable we wrote a *Technical manual*. This manual provides information on how to build a working low-cost sensor, both on the hardware and the software side. Besides, it also contains information on how to acquire data form low cost sensors and how to keep them

operational (QA/QC). We also provide an interactive PDF with *the roadmap for the use of low cost air quality sensors*. This roadmap is intended as a step-by-step guide for local authorities in planning an air quality sensor network. Next we also formulated *guidelines on applying (low cost) air quality sensors*. We distinguish two elements in our guidelines: a draft air quality sensor charter and a set of key recommendations in support of this charter.

In addition, we developed a dataportal (www.vaquums.eu) in the fourth action. On this website we gather general information on the project, all project results and deliverables and supplmentary video's which explain the most important facets of the LIFE VAQUUMS-project. Besides, the website also contains a data platform. Based on an elaborate stakeholder inquiry and user tests a platform was build according tot heir needs and wishes. In the current version a map for PM2.5 with all official monitoring sites in Flanders together with the citizen measurements is shown. The citizen measurements are only from the sensor connected to the senor.community network (former Luftdaten) but can be elaborated in the future. When selecting sensors and reference stations, one can compare the measurements in a graph below the map. Both the map and the graph are accompanied by information about the measurements and how to interpret the data. More functionalities can be added to the platform in the future.

As sensors can produce a lot of data, the fifth action is about data management. Tob e able to conduct our tests we had to make a working real time data flow feeding the sensor data tot he database. Also the desired level of aggregation for sensors measurements was studies in this action. Guidance on data management were incorporated in the guidelines developed in action 3.

Besides the implementation actions the LIFE VAQUUMS-project also payed attention tot he communication actions. During the project a number of general communication channels were used: website, newsletters, flyers, posters,… The project team attended several conferences, workshops, webinars and others where the project and its results were presented and we had the chance to network with related projects. At the onset of the project we conducted an extensive online consultation where different stakeholder groups (local governments, citizens, citizen science projects, research institutes, environmental agencies, sensor developers and other industries) where questioned. We also contacted several related projects about their activities and lessons learned. During the project, we organized three workshops: two with local governments and one with sensor experts. During the two workshops with local governments (in cooperation with the VLAIO CoT project on local sensor networks) in June 2019 we discussed the different use cases for sensors. In November 2019 we organized a workshop with air quality (sensor) experts to improve the concept of the Data Quality Index by determining the required sensor data quality as function of the use case. At the end of the project we organized a closing webinar. As a webinar can only contain a limited amount of presentations, we also recorded a whole series of supporting videos which explain all important results and guidelines of the LIFE VAQUUMS-project.

1.3 Assessment of situation at the end of the project

The project developed the following key deliverables and outputs:

- **Test protocol**: a test protocol was developed based on previous projects, CEN-drafts and partners' experience. The protocol facilitated uniform testing of all sensors. It describes the experimental set-up and procedures both in the laboratory and in the field. In addition, it also defines the sensor evaluation criteria and how to calculate these criteria.
- **Technical manual**: in the technical manual we describe how we built working low cost air quality sensors, how we attained data from these sensors and how to keep multiple sensors operational for over one year. The document provides hands-on recommendations for operating low-cost air quality sensors.
- **Lab tests:** the laboratory tests of the gas sensors were conducted from September to November 2018 at RIVM. The laboratory tests of PM-sensors were conducted at TNO from October 2018 to January 2019. During these tests the accuracy, correlation with a reference instrument, stability, co-pollutant interference, influence of temperature and relative humidity and the intra-sensor variability were determined.
- **Field tests:** in February 2019, the sensors were transferred from lab to field. The sensors remained in the field just over one year – an unprecedented benchmark. To place the sensors as close as possible to the reference monitors at the measurement station Antwerp (Belgium) three tailor –made shelters were used. The shelters protect the sensors from rain and sun, air circulation is guaranteed by two fans per shelter.
- **Guidelines:** we distinguish two elements in our guidelines: a draft air quality sensor charter and a set of key recommendations in support of this charter. The draft charter should be elaborated at the regional, national or European level, providing a base for commitment to harmonious sensor deployments by local communities, cities etc. The set of recommendations stimulates further development of the state-of-art.
- **Air Quality Sensor Roadmap:** the roadmap is a step-by-step guide for local authorities in planning an air quality sensor network. It can obviously also be used by any organisation supporting them in this development. It will take into account any strategic considerations such as participation, scale, exposure … The roadmap provides a hands-on and trialed approach to get started with an air quality sensor network. As a user you'll be guided through 3 distinct journeys derived from the basic design thinking process: assessing needs, envisaging solutions & managing implementation
- **Data portal:** on the LIFE VAQUUMS data portal citzens (in Flanders) can compare their $PM_{2.5}$ measurements with the official reference stations of the Flanders Environmental Agency. The portal has been incorporated in the SamenVoorZuivereLucht (ToghetherForCleanAir) website[1], where information on how to measure air quality and a toolbox with measures to imporve air quality are available. The portal is build according to the same principles as the Dutch portal samenmeten.rivm.nl.

LIFE VAQUUMS managed to deliver a return to the community of citizen scientists and motivated local authorities throughout its lifetime by:

- Actually distinguishing "the best from the rest", particularly in PM-sensors
- Providing hands-on advice on handling sensor devices
- Making their work easier by providing blueprints on assembling and coding devices

[1] www.samenvoorzuivereLucht.eu/dataportaal

Furthermore we have laid some groundwork for a dispersed, multi-actor future in the field of air quality, because we now have:

- Open building blocks for data portals bringing together official, urban and citizen data on air quality
- A set of guidelines and recommendations on applying air quality sensors
- A solid approach for designing local air quality monitoring networks

However, additional efforts are still needed:

- One major issue is the establishment of a single coherent view on air quality across available datasets. Even if the issues below are overcome (in which we are rather confident), our stakeholder research has shown that the end-users (e.g. citizens, local authorities, NGO's) lack the knowledge and expertise to sift through the available datasets. As one would not "see the forest for the trees", it has already become difficult for these user to "see reality for the data". Bringing together official, urban, private and citizen monitoring data with modelled data at various aggregation levels, both historical and predictive, into a "single" comprehensible representation as a basis for urban action and local policy development is the primary upcoming challenge we put forth.
- Low-cost air quality sensors clearly have their limitations. In depth investigation of commercial boxes, algorithms and technological improvements are required to unlock more of the desired use cases for air quality sensors, in particular for NO_2.
- Test results remain difficult to compare across research projects. LIFE VAQUUMS has established a fresh and unprecedented benchmark, but efforts are needed to push a generalised testing protocol. Our standard testing protocol has been presented to the relevant CEN working groups and we have been able to weigh in on that ongoing discussion

The applicability of air quality sensors in a given situation will also retain a level of 'trial & error'. We acknowledge this in our roadmap for designing sensor networks and guide our peers through this process.

2 After-LIFE communication plan

2.1 After-LIFE objectives & methodology

Project website

The project website will be maintained for at least five years after the end of the project. In addition, the whole website will get an update such that the project results and outcomes are better findable for the visitors.

Data platform

The data platform that was built during the LIFE VAQUUMS-project will remain available on the website. In addition, it is incorporated in the 'SamenVoorZuivereLucht'-portal (TogetherForCleanAir) that was developed in the Interreg project Zuivere Lucht (Clean Air). In this way, the portal will receive more visitors.

In the back-end of the data portal there are already multiple additional visualizations and statistical analyses build. In the after-LIFE VMM will engage to interact with the stakeholders of the data platform (citizen scientists, local governments) to gather information on which functionalities are of high additional value for the portal. These functionalities will then be incorporated into the data platform.

New sensors that are entering the sensor.community network will automatically be incorporated in the data platform. VMM will investigate the possibilities to also incorporate other sensor data as well as data from for example passive samplers.

Protocols & guidelines

All our protocols and guidelines are available on the project website. But they will also be shared actively when there are opportunities.

At VMM we are starting a trajectory to work more closely with Flemish cities and municipalities. Although that the trajectory just started in April 2021, we already shared the VAQUUMS protocols and guidelines tens of times, and we only expect to share them more regularly in the future.

The colleagues that are part of the working groups (WG12, WG15, WG42) also shared the protocols and guidelines with the other working group members. Also JRC was informed about the protocols and guidelines of the LIFE VAQUUMS-project.

Conferences/webinars

When there are interesting opportunities, the project partners will share the results and findings of the project at conferences and webinars.

For example, the project was asked to give a presentation in November 2021 at the closing conference of the LIFE HungAIRy project.

Also when there is no opportunity to give a presentation, the partners will spread the word about the project during the networking events.

Newsletter

In the first year of the after-LIFE the final news letter about the LIFE VAQUUMS-project will be sent. This newsletter will describe the available project outputs and announce the dataplatform.

Test additional sensor

During the project we heard several times that the Sensirion PM sensor is an interesting sensor to test. This sensor was not yet on the radar at the onset of the project. Therefore, VMM decided to start testing the sensor at the end of the LIFE-VAQUUMS-project. The results will be available on the website during the After-LIFE.

2.2 Funding needs & sources of funds

Data quality appraisal and enhancement

Within the LIFE VAQUUMS project we have established a benchmark for low-cost air quality sensors. Performance for particulate matter sensors was quite good and it is now really a matter of creating examples and getting the use cases out there. Performance for gas sensors (NO_2 and O_3) is lacking without proper calibration applied and there is an additional need for thorough development of these calibration algorithms. Therefore screening of commercial sensor platforms or boxes that incorporate these algorithms can possible "unlock" additional use cases. Furthermore, investigation into generalized calibration algorithms (e.g. SensEURCity project) can help improve overall performance of air quality sensor networks. Furthermore many low-cost, citizen owned devices are already out there. Automatically assessing the quality of their output and perhaps validating individual data points through machine learning algorithms and other data science strategies, will enrich the existing datasets and facilitate their uptake "down the line" (e.g. in air quality models, calamity monitoring, hot spot screening …). So a first funding need we now see arising covers "data quality appraisal and enhancement" for air quality sensors. The following list breaks it down into actions/projects and potential funding sources:

- Quality appraisal of enhanced air quality sensors
  - VAQUUMS-like benchmark of sensor solutions including calibration algorithms
  - Requires private sector cooperation as VAQUUMS' "purchase & test" strategy will not be cost-effective
  - Major challenges are dealing with proprietary platforms, algorithms updates during experimentation etc.
  - "Applied" funding sources like LIFE, INTERREG etc. where the benchmark is followed by one (or more) implementations of the sensors to create good examples and usable use cases (cf. VAQUUMS principle #4)
- Research of (generic) calibration algorithms
  - Improve sensor performance independently of the type of sensor device
  - As a co-benefit these strategies often feature automated quality appraisal of realtime measurements which is a very useful tool in itself (cf. next bullet)
  - Major challenges are using only real-world physical parameters (otherwise it is modelling rather than monitoring), quality of other input data (e.g. temperature and relative humidity sensors) and applicability at greater distance or very different environment from reference sites used for calibration
  - Research oriented funding sources such as H2020 are best suited for a project where this is the main outcome. Potentially it can be part of an application/implementation oriented project, but such a project will likely result in less generic algorithms
- Developing data science strategies for realtime quality handling
  - Automated realtime quality appraisal and validation through the use of machine learning and other data science techniques
  - Results in a "reliability estimate" as meta data for each individual data point, supporting use and interpretation of sensor data by third parties who are not involved in the specifics of the deployment
  - Results in automated validation process for air quality senors – which because of their likely high number in a typical deployment is not feasible manually – can provide higher quality data sets at the cost of more data gaps. This increases usability in other automated processes such as data fusion for modelling
  - Major challenges are generating sufficiently large training datasets with a form of calibration (e.g. LIFE VAQUUMS dataset), developing a sensor-independent method

(might not be achievable) and the quality of other data used in assessing quality (e.g. temperature, relative humidity …)
    - Funding sources can range from H2020 to applied funds such as LIFE and INTERREG

A single, coherent view on air quality

During the lifetime of the LIFE VAQUUMS-project we have unfortunately seen some citizen initiatives disappear because they felt their effort was not picked up by policy and their data did not seem to contribute to anything. In the bigger picture any form of additional/supplementary monitoring should serve the goal of air quality (policy) improvements. By working closely with local authorities and through our user research in the VAQUUMS-project we noticed they already struggle with processing the amount of air quality information available to them. For non-experts in the field of air quality – and at times even for experts – it is a daunting task to distill a single assessment and from that assessment a mitigation strategy out of:

- Realtime and time series data from
    - Reference sites
    - Temporary monitoring campaigns
    - Citizen initiatives
    - Industry monitoring networks
    - Mobile measurements
- Realtime models using only a portion of the above data
- Assessment models using only a portion of the above data
- Predictive models
- Cross-domain information becoming available in smart cities
    - Mobility data (reference, temporary and additional)
    - People flows
    - Industrial activities
    - Weather data

Hence we put forth an innovation track of equal importance to the aforementioned “data quality appraisal and enhancement” track, summarised as “Creating a single, coherent view on air quality across available datasets”. It will provide the ability to valorise efforts in sensor development and adoption by greatly reducing the translation of heterogeneous air quality datasets into impactful policy. We see this as an innovation track rather than a research track as it focuses on creating a workable/usable context for policy makers, NGO’s and even citizens for the development of air quality solutions at the local scale. The main innovations we propose are:

- Combining monitoring datasets
    - Provide a single platform accessing all relevant monitoring data and facilitating side-by-side comparison
    - LIFE VAQUUMS already provides some building blocks in our data visualisation library and data portal demonstration, hence this is rather innovation than research
    - Major challenges are intuitive distinctions between datasets and more importantly providing an intuitive representation of the quality appraisal of each dataset (e.g. how to interpret reference, urban and citizen data in close proximity?)
    - This entire innovation track is very well suited for funding linked to a clear demonstration with real-world impact. Typically found in LIFE and INTERREG projects
- Fusing datasets into a coherent, geographical view through modeling

    - All monitoring initiatives in the foreseeable future still cannot provide a view with full spatial coverage. All relevant modelling data should be used to improve models both assessment and in real time
    - Within the context of FAIRMODE first efforts are being undertaken to link sensors to air quality models, but there are many approaches to explore. For example you could use sensors as the starting point, you could use them only to improve temporal resolution (e.g. adjust levels every 5 minutes within each calculated hourly average map) and integrating mobile sensors would require even another approach
    - The main challenge is a good characterisation of the uncertainty in the monitoring data and organizing the dispersed dataflows. Recent developments in IoT and Digital Twins (e.g. H2020 DUeT) could provide the basis for the latter
    - This entire innovation track is very well suited for funding linked to a clear demonstration with real-world impact. Typically found in LIFE and INTERREG projects
- Providing in depth tools for analysis and solution development
    - A usable context for the various parties that are able to contribute to solution development will have to provide the data with some form of layering instead of just providing everything at once. Therefore intuitive tools will have to be developed linking the available datasets (also cross-domain) to use cases and questions posed by these parties.
    - Furthermore these tools will need to provide a call-to-action or even guide the user to potential solutions to actually have an impact on local air quality. Ideally these analysis tools would link to specific policy and/or scenario tools predicting outcomes of policy changes
    - Some basic tools exist but most challenges lie in providing an intuitive, usable user experience, linking multiple datasets and providing the level of detail required for policy development at the very local level.
    - This entire innovation track is very well suited for funding linked to a clear demonstration with real-world impact. Typically found in LIFE and INTERREG projects

Policy makers, NGO's and citizens are currently "seeing reality (but) for the data"[2], realising this single, comprehensible representation will trigger urban action and local policy development ultimately resulting in the required local improvements in air quality.

[2] As an analogy to "seeing the forest (but) for the trees"