hackAIR

COLLECTIVE AWARENESS
FOR AIR QUALITY

D8.8: Sustainability & exploitation strategy

WP8 - Communication, Dissemination and Exploitation

Document Information

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Document History

Version	Issue Date	Stage	Description	Contributor
0.1	30/06/2018	Research	First version of licensing and documentation information received	NILU, CERTH, DRAXIS
0.2	22/08/2018	Consultation	Consultation on hackAIR sustainability plan	DRAXIS
0.3	19/09/2018	Consultation	Consultation on hackAIR exploitation plan	DRAXIS
0.4	20/09/2018	Consultation	Input from hackAIR advisory board	DRAXIS
0.5	12/10/2018	Consultation	Presentation on sustainability + exploitation plan at hackAIR partner meeting	ONSUB
1.0	01/11/2018	Draft	Written input received from partners on all aspects of sustainability + exploitation plan	DRAXIS, NILU, CERTH, BUND, VUB
1.1.	16/11/2018	Draft	Draft for final review	ONSUB
1.2	30/11/2018	Final	Document submitted	ONSUB, DRAXIS, CERTH

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Copyright message

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Executive summary

hackAIR is an open technology platform to access, collect and improve air quality information in Europe. The project combines measurements from own DIY sensors with data from official sources and other citizen science initiatives to create a comprehensive map of the air that we breathe. hackAIR contributes to the wider movement around participatory sensing and citizen science and has received funding from the Horizon 2020 programme for the period 2016-2018.

This document contains hackAIR's final sustainability and exploitation strategy, building on the earlier deliverable D8.2 Sustainability & exploitation strategy (1st version), submitted in September 2016.

Results of the hackAIR project are described in chapter 2, including technical results such as software and hardware specifications and knowledge-based results such as scientific publications and other papers.

As an open technology platform, hackAIR has published its results under open source or Creative Commons licenses where possible. In addition, they have been made available in public repositories such as GitHub, Zenodo and OpenAIRE. A full overview of licenses and dissemination channels for hackAIR's results is included in chapter 3.

hackAIR and its partners are committing to maintain the availability and sustainability of the existing platform and infrastructure. Chapter 4 outlines the necessary arrangements including organisational structures and costs.

The projects results are being exploited in a number of activities outside the scope of the original project. These efforts include future research, products and services and a number of collaborations and partnerships. In addition, individual organisations in the consortium have outlined their exploitation plans beyond these joint efforts. All are described in chapter 5.

1 Introduction

hackAIR is an open technology platform that you can use to access, collect and improve air quality information in Europe. hackAIR combines official air quality data with a number of community-driven data sources, including:

- An easy-to-build open hardware sensor module that transmits regular air quality measurements via Ethernet, Bluetooth or Wi-Fi;
- Air quality information derived from mobile phone pictures of the sky and webcams; and
- A low-tech measurement setup involving cardboard and petroleum jelly.

In addition, hackAIR calculates air pollution estimates for locations without measurements to create a continuous air quality map for Germany and Norway. APIs are freely available for fetching information from the database.

About this document

This document contains the final version of hackAIR's sustainability and exploitation strategy. It describes how results produced in the project will be used in the future (e.g. in other research activities; in developing, creating and marketing a product, process or service; in standardisation activities). It also covers how the results will be made public (dissemination) and what efforts the project partners are making to ensure resources for the future maintenance and availability of the results (sustainability).

hackAIR's sustainability and exploitation strategy aims to:

- Describe the project results and the ways in which they will be diffused after the end of the project (including details on what actions will be carried out, when, by whom and using what source of finance) (see chapter 2: Results and chapter 3: Dissemination)
- Ensure resources for the future maintenance and availability of the hackAIR toolkit, platform and website (see chapter 4: Sustainability)
- Describe user needs for further development and related problems that the project's tools could be adapted to and explore opportunities for commercial (and non-commercial) exploitation (see chapter 5: Exploitation).

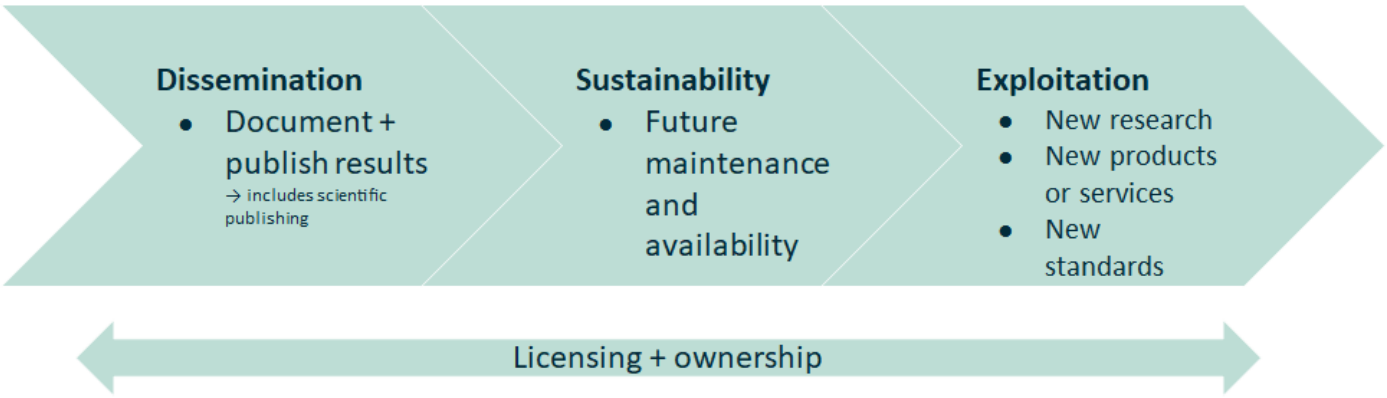
The first version of the sustainability and exploitation strategy (D8.2, submitted in month 8 of the project) explored potential options for the further exploitation of hackAIR's results, using the following structure: (1) Commercial offer, (2) Target users and customers, (3) Value proposition, (4) Competitive environment, (5) Preliminary business model, (6) Commercialisation of Intellectual Property, (7) IPR strategy and management, (8) Individual exploitation plans, (9) Sustainability activities, and (10) Scientific Exploitation. Two distinct directions were explored:

- Accessible air quality sensors. In particular, this included the option to
    - Procure, sell, and distribute the parts required to build a hackAIR-compatible sensor;
    - Produce, sell, and distribute pre-assembled hackAIR-compatible sensors; and
    - Design, produce, sell, and distribute compatible accessories for such sensors, such as cases, tools, stickers and attachments.
- Customised air quality intelligence. This includes the provision of support services to organisations interested to adopt and operate the hackAIR platform and the development of added value services.

In addition, each project partner contributed an initial direction for their individual exploitation plans.

This present strategy builds upon this potential and the experiences from nearly three years of project implementation and stakeholder engagement and translates them into specific commitments and actions for hackAIR and accessible air quality sensing into the future.

Requirements and clarification of terms



In this document, we are covering three distinct use cases for hackAIR's results:

- Dissemination
- Sustainability
- Exploitation

An underlying requirement for all of them is clarity on licensing and ownership of the results (including intellectual property rights). Following the Horizon 2020 Glossary, we are using these terms as follows:

- Dissemination: Means to make the results of a project public (by any appropriate means other than protecting or exploiting them, *e.g. scientific publications*).
- Sustainability: Means to enable the project to continue to deliver benefits to the project beneficiaries and/or other constituencies for an extended period after the Commission's financial assistance has been terminated[1].
- Exploitation: Means to make use of the results produced in an EU project in further activities (other than those covered by the project, e.g. in other research activities; in developing, creating and marketing a product, process or service; in standardisation activities).
- Results: Any tangible or intangible output of the action (such as data, knowledge and information, whatever their form or nature, whether or not they can be protected), which are generated in the action, as well as any attached rights, including intellectual property rights.
- IPR (intellectual property rights): Legal rights granted to people to protect their ideas. These rights include industrial property rights *(*e.g. *patents, industrial designs* and *trademarks)*, copyright (rights of the author or creator) and related rights (rights of performers, producers and broadcasting organisations).

[1] Definition following the European Commission Directorate General Education and Culture (2006) "Sustainability of international cooperation projects in the field of higher education and vocational training - Handbook on Sustainability".

As part of the hackAIR grant agreement, hackAIR partners have committed to the following minimum requirements for dissemination, sustainability and exploitation:

Obligation	hackAIR approach
25.2 The beneficiaries must give each other access — under fair and reasonable conditions — to background needed for exploiting their own results [...].	hackAIR's results (and relevant background) mostly use open source licenses - giving not just project partners, but everyone interested fair and reasonable access. For details see chapter 2 of this document: Results.
26.1 Results are owned by the beneficiary that generates them.	The copyright holder for each of hackAIR's results is clearly defined as the lead organisation responsible for the results. In cases where multiple beneficiaries collaborated on a result, DRAXIS - as the project coordinator - holds the copyright. For details see chapter 2: Results.
28.1 Each beneficiary must — up to four years after the period set out in Article 3 — take measures aiming to ensure 'exploitation' of its results (either directly or indirectly, in particular through transfer or licensing [...]) by: *1. Using them in further research activities (outside the action);* *2. Developing, creating or marketing a product or process;* *3. Creating and providing a service, or* *4. Using them in standardisation activities.*	Each beneficiary has defined an individual exploitation plan that describes how they ensure exploitation of the project. For details see chapter 5: Exploitation (Individual exploitation plans).
29.1 Unless it goes against their legitimate interests, each beneficiary must — as soon as possible — 'disseminate' its results by disclosing them to the public by appropriate means (other than those resulting from protecting or exploiting the results), including in scientific publications (in any medium). *29.2 Each beneficiary must ensure open access (free of charge online access for any user) to all peer reviewed scientific publications relating to its results.*	hackAIR's project partners have collaborated to provide direct access to project results available through the project website (and related repositories for code and data). In addition, results have been published in multiple scientific publications, ensuring open access where possible. For details see chapter 2: Results.

2 Results of the hackAIR project

As a first step towards a sustainability and exploitation strategy, we need to identify the results of the hackAIR project and explain how these will be disclosed to the public.

Technical results

Based on hackAIR's description of work, the initial tech cards created as part of Work Package 2 (Analysis and requirements) and the main technical results emerging from the project, we suggest the following list of results:

Number	Title	Description
R3.1[2]	Data retrieval	The hackAIR data retrieval module collects air quality measurements from official web sites or web services and public images from media sharing platforms (i.e. Flickr) and public webcams. An image analysis process is applied on the collected images that involves detection of sky and localization of the sky part.
R3.2.1	hackAIR home	The hackAIR home sensor is an open hardware air quality sensor, based on Arduino (or Wemos for version 2). Connected through Ethernet or Wi-Fi, it measures particulate matter concentrations and sends the results to the hackAIR platform.
R3.2.2	hackAIR mobile	The hackAIR mobile sensor is an open hardware air quality sensor, based on PSOC. It is powered with a mobile power bank and uploads its measurements through Bluetooth on your phone.
R3.2.3	hackAIR cardboard	The hackAIR cardboard sensor is low-cost and easy to use. You expose the cardboard for 24 hours, and then analyse a macro-photograph of the jelly to calculate pollution levels in the hackAIR app.
R4.1	Data fusion	The hackAIR data fusion module combines hackAIR observations with model output from the Copernicus Atmosphere Monitoring Service (CAMS) to provide estimates of the current air quality at any location within the study domains.
R4.2	Knowledge base and reasoning framework	The hackAIR knowledge base and reasoning framework handles both the semantic integration and reasoning of environmental and user-specific data, in order to provide recommendations to the hackAIR users, with respect to: (i) personal health and user preferences (activities, daily routine, etc.), and (ii) current air quality conditions of the location of interest.
R5.1	Web platform	The hackAIR web platform integrates air quality data and provides user access to the hackAIR data via a web browser.
R5.2	Mobile app	The hackAIR mobile app provides access to hackAIR data and results via a mobile device, enables users to upload sky and cardboard photos and to add their perception. The app is available for both Android and iOS.
R5.3	hackAIR API	The hackAIR API provides free access to the hackAIR data for the mobile and web applications through a middleware, which applies all the business logic.
R6.1	Social media monitoring	The hackAIR social media monitoring module monitors a number of keywords and accounts of interest and calculates a set of indicators that represent the "engagement" of social media users with the topic described by the keywords.
R8.1	hackAIR website	The hackAIR website provides information about air quality, the hackAIR project and technical documentation through a customised WordPress platform.

[2] The numbers are based on hackAIR's original description of work and align with tasks and work packages.

In addition to the technical results above, hackAIR also generated a number of datasets (covered by the hackAIR Data Management Plan: D1.5) and knowledge-based results (such as additional scientific publications on engagement and behaviour change).

Knowledge-based results

During the course of the project, hackAIR published a number of scientific and peer-reviewed papers. Following Horizon 2020 guidelines, open access to all peer-reviewed scientific publications relating to hackAIR's results is ensured. The knowledge-based results also include conference papers that will continue to be available after the end of the project.

Scientific articles and conference papers for hackAIR

Title	Authors	Date	Journal/ book	Repository link	Digital object identifier
Towards Air Quality Estimation Using Collected Multimodal Environmental Data	A. Moumtzidou, S. Papadopoulos, S. Vrochidis, I. Kompatsiaris, K. Kourtidis, G. Hloupis, I. Stavrakas, K. Papachristopoulou, and C. Keratidis,	Sept 2016	Collective Online Platforms for Financial and Environmental Awareness. Lecture Notes in Computer Science, Vol. 10078	arXiv.org	DOI:10.1007/978-3-319-50237-3_7
Mapping urban air quality in near real-time using observations from low-cost sensors and model information.	Schneider, P., Castell, N., Vogt, M., Dauge, F. R., Lahoz, W. A., & Bartonova, A.	June 2017	Environment International 106	ScienceDirect	DOI:10.1016/j.envint.2017.05.005
Citizen Science Is in the Air – Engagement Mechanisms from Technology-Mediated Citizen Science Projects Addressing Air Pollution	McCrory, G., Veeckman, C., Claeys, L.	Nov 2017	International Conference on Internet Science (pp. 28-38)	ResearchGate	DOI:10.1007/978-3-319-70284-1_3
Open-Source Monitoring, Search and Analytics Over Social Media	Schinas, M., Papadopoulos, S., Apostolidis, L., Kompatsiaris, Y., & Mitkas, P. A.	Nov 2017	International Conference on Internet Science (pp. 361-369)	Zenodo	DOI:10.1007/978-3-319-70284-1_28
hackAIR: Towards raising Awareness about Air Quality in Europe by developing a Collective Online Platform	E. Kosmidis, P. Syropoulou, S. Tekes, P. Schneider, E. Spyromitros-Xioufis, M. Riga, P. Charitidis, A. Moumtzidou, S. Papadopoulos, S. Vrochidis, I. Kompatsiaris, I. Stavrakas, G. Hloupis, A. Loukidis, K. Kourtidis, A.Georgoulias, and G. Alexandri	May 2018	ISPRS International Journal of Geo-Information 7 (5)	ResearchGate	DOI:10.3390/ijgi7050187
An Ontology-based Decision Support Framework for Personalized Quality of Life Recommendations	M. Riga, E. Kontopoulos, K. Karatzas, S. Vrochidis, and I. Kompatsiaris	May 2018	Decision Support Systems VIII: Sustainable Data-Driven and Evidence-Based Decision Support	Zenodo	DOI:10.5281/zenodo.1196022
Towards improved air quality monitoring using publicly available sky images	E. Spyromitros-Xioufs, A. Moumtzidou, S. Papadopoulos, S. Vrochidis, Y. Kompatsiaris, A. K.	June 2018	Multimedia Technologies for Environmental & Biodiversity Informatics	Zenodo	DOI: 10.1007/978-3-319-76445-0_5

	Georgoulias, G. Alexandri, K. Kourtidis				
Twitter-based Sensing of City-level Air Quality	Charitidis, P., Spyromitros-Xioufis, E., Papadopoulos, S., Kompatsiaris, I.	June 2018	Image, Video, and Multidimensional Signal Processing Workshop (IVMSP), 2018 IEEE 13th. IEEE	Zenodo Slideshare	DOI:10.1109/IVMSPW.2018.8448704

CERTH has been targeting conferences and journals that are related to the collection, processing and mining of multimodal data for air quality estimation. CERTH has already presented parts of hackAIR framework in the following conferences:

- Presentation entitled "Collection of Multimodal Environmental Data for Air Quality Estimation" in SWEEM conference (1st International Workshop on the Social Web for Environmental and Ecological Monitoring) that was held in Cologne, Germany on 17 May 2016
- Paper entitled "Towards Air Quality Estimation Using Collected Multimodal Environmental Data" was presented at ISEM 2016 workshop (1st International Workshop on Internet and Social media)
- Demo paper entitled "Open-Source Monitoring, Search and Analytics Over Social Media" was presented at the INSCI 2017 conference (International Conference on Internet Science)
- Paper entitled "Twitter-based Sensing of City-level Air Quality" was presented at IVMSP 2018 workshop (13th IEEE workshop on Image, Video, and Multidimensional Signal Processing)

Finally, it is significant to mention that the conducted activities during the hackAIR project enables TEI-A EDML to activate undergraduate and postgraduate students to conduct their dissertations on the topic of IoT as well as to call for relevant PhD positions.

3 Dissemination and licensing of results

An open technology project like hackAIR needs to be explicit about licensing and copyright because any creative work (which includes code) is under exclusive copyright by default. This copyright is always with a legal entity (i.e. you as a natural person or your employer as a legal entity). The project hackAIR is not a legal entity and can thus not hold any copyright to its results; however, individual partner organisations can.

Without clear licensing, nobody can use, copy, distribute, or modify hackAIR's work without being at risk of takedowns, shake-downs, or litigation. For results that have more than one contributor (each a copyright holder), "nobody" starts including individual authors and consortium partners.

hackAIR thus needs to be clear about two things:

1. Which legal entity holds the copyright to a result? This can be a group of people or a group of organisations. As the project coordinator, DRAXIS serves as the default copyright holder to keep things simple.
2. Under which license can others use, copy, distribute or modify our results? As a project "focusing on the development of open source tools that can be used (and further developed) by anyone at no charge"[3], most of hackAIR's results will be using open source licenses. A limited number of results use a more restrictive, but still explicit license so that they can be described in scientific publications or exploited directly or indirectly for further scientific or commercial activities.

Licenses used by hackAIR

Most of hackAIR's results use one of the following open source licenses:

For software: GNU Lesser General Public License	**For other results:** Creative Commons Attribution Share Alike
GNU LGPLv3: Permissions are conditioned on making available complete source code of licensed works and modifications under the same license or the GNU GPLv3. Copyright and license notices must be preserved. Contributors provide an express grant of patent rights. However, a larger work using the licensed work through interfaces provided by the licensed work may be distributed under different terms and without source code for the larger work. Apache License 2.0: A permissive license whose main conditions require preservation of copyright and license notices. Contributors provide an express grant of patent rights. Licensed works, modifications, and larger works may be distributed under different terms and without source code.	CC-BY-SA-4.0: Permits almost any use subject to providing credit and license notice and requires derivatives be distributed under the same or a similar, compatible license. Frequently used for media assets and educational materials. Alternative CC-BY-4.0: Permits almost any use subject to providing credit and license notice. The most common license for Open Access scientific publications.

[3] From hackAIR's Description of Work.

Background technologies

The first version of the sustainability strategy detailed background technologies and their proposed protection strategy. In consultation with partners, this list is now revised as follows:

Name	Used in	Copyright / Licensing
MultiForecast tool	R4.2 Knowledge base and reasoning framework	Copyrighted and available at http://mklab-services.iti.gr/multiforecast
VERGE system	Not used	Copyright CERTH
Social indexer	R6.1 Social media monitoring	This is available as an open-source project under the Apache License v2.
Social media dashboard	R6.1 Social media monitoring	This is available as an open-source project under the Apache License v2.

Licensing and dissemination information for all results

For each of the results listed above, we captured information about where and how we are making it publicly available. Lead developers provided information on the results using a structured questionnaire (see annex). Information was provided in June 2018, and updated in November 2018 (towards the end of the project).

Number	Title	License / Copyright holder
R3.1[4]	Data retrieval	Apache License v2 / CERTH
R3.2.1	hackAIR home	LGPL v3 / DRAXIS
R3.2.2	hackAIR mobile	LGPL v3 / DRAXIS
R3.2.3	hackAIR cardboard	LGPL v3 / DRAXIS
R4.1	Data fusion	LGPL v3 / NILU
R4.2	Knowledge base and reasoning framework	Apache License v2 / CERTH
R5.1	Web platform	AGPL v3 / DRAXIS
R5.2	Mobile app	AGPL v3 / DRAXIS
R5.3	hackAIR API	AGPL v3 / DRAXIS
R6.1	Social media monitoring	Apache License v2 / CERTH
R8.1	hackAIR website	CC-BY-SA / DRAXIS

Approaches to dissemination of results

During the course of the project, hackAIR set up intensive activities to communicate with users and disseminate its results and progress, including:

- A central web presence at www.hackAIR.eu;
- A regular email newsletter to users and stakeholders;
- An active social media presence on Twitter, Facebook and Instagram, and
- A comprehensive set of communications materials, including posters, brochures and stickers.

Together, the hackAIR partners represented the project and discussed its achievements at more than 60 events between 2016 and 2018.

[4] The numbers are based on hackAIR's original Description of Work and align with tasks and work packages.

Going forward, hackAIR is making the results of the project available in line with the FAIR Guiding Principles ("findable, accessible, interoperable, reusable"), originally developed in the context of scientific data management and stewardship[5].

The hackAIR website prominently features the page hackair.eu/results, with the following information:

- A list of all technical results (as defined above), with links to original code and documentation;
- A list of all data sets (as defined in D1.5 Data Management Plan), with links to data sets and documentation;
- A list of all academic papers (as listed above), with links to original publications and/or abstracts as available;
- A list of all public deliverables of the hackAIR project, with links to the original files.

In addition, hackAIR is making use of popular repositories for most of its results, in particular:

- Github as a repository for open source software and documentation: https://github.com/hackair-project;
- Zenodo as a repository for publications and research data: https://zenodo.org/search?q=keywords:"hackAir".

The full list of hackAIR results is also available on OpenAIRE[6].

[5] Wilkinson, M. D. *et al.* The FAIR Guiding Principles for scientific data management and stewardship. *Sci. Data* 3:160018 doi: 10.1038/sdata.2016.18 (2016).

[6] https://explore.openaire.eu/search/project?projectId=corda__h2020::60d46da9a9bc9dd6394ab3c967f16644

4 Sustainability

In order to continue delivering benefits to the project beneficiaries and other constituencies for an extended period after the financial assistance has been terminated, hackAIR needs to ensure - at the minimum - that its existing platform and services continue to be available for a reasonable period. The sustainability strategy identifies the requirements for providing hackAIR's services beyond the project duration, until 2020 or longer.

hackAIR is currently serving the following primary beneficiaries and constituencies:

Key audience	Customer needs	Current numbers (Nov 2018)
Users of the hackAIR app and platform	Access air quality information for their neighbourhoods (or other relevant geographical areas of interest)	> 2.700
Operators of air quality sensors in line with the hackAIR specifications	Continue to contribute and access air quality measurements	> 750
Users of hackAIR open data	Access and analyse air quality data through the hackAIR API	< 100

To continue serving these audiences, hackAIR needs to maintain - at a minimum - the following key modules and services:

- hackAIR platform, mobile apps and API;
- hackAIR website with access to tutorials, technical documentation and contact details.

Further activities beyond the current status of development are covered in Chapter 5: Exploitation.

Required effort and cost structure

The fixed costs for the continued operation of the hackAIR platform are estimated as follows:

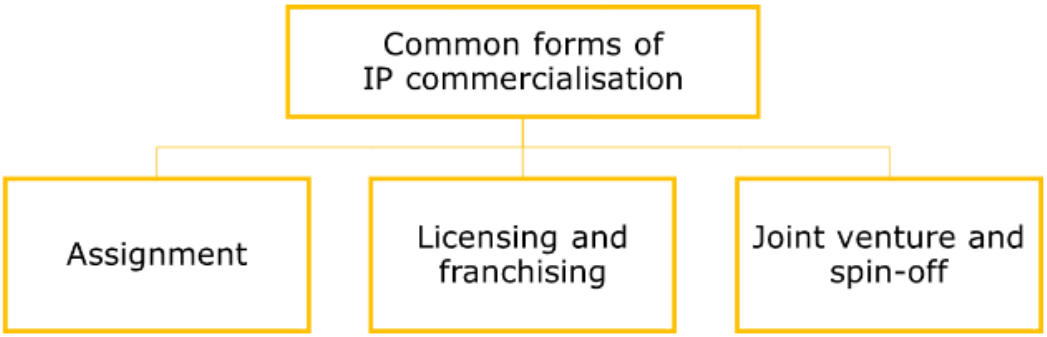
	Annual costs
Website hosting and domains	€110
Rental of server for the hackAIR platform and API	€3,500
Backup service	€600
Sum	**€4,210**

In addition, we will need to ensure sufficient staff capacity for necessary maintenance and security updates (estimated at 1.5 person-months per year) and time for additional development in line with user needs (estimated at up to 2 person-months per year). This would also include adjusting to potential changes to prerequisites for the hackAIR platform (e.g. changes in open air quality databases). Depending on the amount of additional development, this brings the operating costs for the current hackAIR platform to €10,000-20,000 per year.

Organizational structure and delivery

The first version of the hackAIR Sustainability & Exploitation Strategy (D8.2) suggested the creation of a joint venture company in which all partners would be given the option to participate. After the academic partners (CERTH, VUB and NILU) indicated that they would not be able to join due to administrative barriers posed by their organisations,

partners explored simpler models to create an on-going organizational structure for hackAIR, including IP assignment and licensing and franchising.



[7]

As described in chapter 3: Dissemination and licensing of results, close to all results of the hackAIR project are already available under an open source license and can be freely reused by any interested party without financial compensation.

The one exception to this is the internal module to estimate air quality information from images of the sky. Developed by associated partner DUTH on contract for DRAXIS, the intellectual property rights to the approach already belong to DRAXIS. All other partners signed a non-disclosure agreement with regards to that module in November 2018.

With servers and other hackAIR infrastructure already operated by DRAXIS, the organisation is thus well suited to continue the operation of the hackAIR services in line with its mission to develop real life environmental ICT solutions and provide specialised environmental consultation services. With the support of all partners, DRAXIS will lead on the management, limited continued operation and transition of the hackAIR platform beyond the project duration.

Transition arrangement

Until exploitation activities (as described in chapter 5) take off to deliver sustainable revenue, hackAIR partners jointly agreed to the following transition arrangement:

- The hackAIR platform and the apps will continue to be maintained at least for the first semester of 2019 by DRAXIS. If no additional funding is found, these will then be kept online without further maintenance until early 2020.
- Users currently operating sensors will be offered the opportunity to install new software on their sensors which would send measurements to the Luftdaten platform instead of hackAIR.
- As long as the hackAIR platform is available, all hackAIR measurement data can be imported by other air quality platforms (e.g. Luftdaten, RIVM or NILU) through the API.
- The hackAIR website will remain online and provide documentation and links to the results of the project until 2022 or longer.

An overview of the practical steps needed for the transition:

When?	What?	Who?
December 2018	Make new hackAIR sensor software available for users	DRAXIS
December 2018	Update hackAIR website and social media channels for the post-project period	ON:SUBJECT
January 2019	Update hackAIR platform to inform users that the project has ended	DRAXIS

[7] Source: https://www.iprhelpdesk.eu/sites/default/files/newsdocuments/Fact-Sheet-Commercialising-IP-Assignment-Agreements.pdf

5 Exploitation

In addition to the maintenance of the existing hackAIR services, we also explored how we can "make use of the results produced in further activities (other than those covered by the project, e.g. in other research activities; in developing, creating and marketing a product, process or service; in standardisation activities)". The directions outlined below can be seen as potential directions for the movement to provide better air quality information for citizens and provide options for how hackAIR as a platform and a service can be scaled.

As part of this chapter, we will review

- Future research directions that make use of the hackAIR results,
- Potential products, processes and services,
- Standardisation and partnerships; and
- Individual exploitation plans.

We also describe activities conducted during the project to validate the exploitation plans.

Future research directions and scientific exploitation

The hackAIR partners have developed concrete ideas on how to continue the scientific and societal impact of hackAIR through scientific publications and future research.

DRAXIS will incorporate the results of hackAIR in future research proposals.

DUTH may secure the methodology AQ estimation from images with an IPR agreement (e.g. trade secret), prepare papers, and further explore research opportunities within the university.

For the near future, NILU has planned the following scientific activities:

Tentative title or topic	Date (expected)	Journal/ book/conference/location
Performance assessment of a very low-cost $PM_{2.5}$ sensor over a three-month period in Oslo, Norway	End of 2018, submitted	Atmosphere
Mapping $PM_{2.5}$ in near real-time using observations from multiple tools and model information.	2019	To be decided
Potential accuracy improvement by taking into account the external meteorological data and applying machine learning techniques	2019	To be decided
Public perception in contributing to improve air quality information in Norway	2019	To be decided

CERTH is interested in pursuing a journal submission on the topic of air quality sensing based on images. The approach implemented within hackAIR is based on the combination of sky detection, localization and a set of predefined look-up tables that translate the computed sky image statistics into Aerosol Optical Depth (AOD) values and ultimately into air quality levels. CERTH is interested in evaluating end-to-end image analysis approaches based on deep learning frameworks that will attempt to directly predict the air quality level based on the image content, without resorting to the intermediate step of computing image statistics and performing table look-ups. Preliminary end-to-end approaches have been recently proposed in the literature, however, we feel that further improvements and breakthroughs are needed in order to reach a satisfactory working solution.

Moreover, CERTH is interested in further extending the conducted research on Twitter-based air quality sensing by a) refining the proposed approach aiming at more accurate predictions, b) carrying out more extensive and systematic experiments, and c) exploring the feasibility of the approach in non-English speaking areas.

CERTH is also interested in investigating further the recommendation system and by doing research on the deployment of non-monotonic reasoning (e.g. Defeasible Logics (Gabbay & Smets, 2013[8]) on top of the ontology. This reasoning approach will assist in handling incomplete and/or potentially conflicting information, and offers advanced mechanisms for prioritizing rule execution and for resolving rule conflicts.

VUB will continue expanding its research agenda and expertise on engagement and behavioural change, co-creation methodology, and evaluation and impact assessment. Research methodology and findings will be discussed and published in scientific publications (peer-reviewed journals and academic conferences).

Potential products, processes and services

The first version of the hackAIR sustainability and exploitation strategy outlined two core potential commercial offers that could result from the project: accessible air quality sensors and customised air quality intelligence. The third potential commercial offer mentioned in the deliverable (expertise on citizen science and sensor data) will be covered in partners' individual exploitation plans.

In this strategy the commercial offers are fine-tuned and specified, based on hackAIR learnings, market analysis and validation activities. The focus is on the following two commercial offers:

- Air quality sensors: Easy-to-use and affordable pre-assembled and pre-programmed PM2.5/10 sensors, connected and compatible to air quality platforms, in two versions: hackAIR home and hackAIR mobile.
- Customised air quality intelligence in the form of partnership agreements, including advanced API access, data visualisation tools, customised adaptation of the hackAIR platform and other added value services.

Market analysis and competitive environment

hackAIR is part of a broader community of organisations, research institutions and companies focusing on environmental data measurements and intelligence, mainly operating in Europe, North-America and Asia. Within this competitive environment hackAIR has to find its own added value for exploitation. For this it is necessary to describe the current market trends and potential users.

There are many (indoor and outdoor) air quality sensors on the market, differing in capabilities, usability and prices. Indoor sensors are mainly targeted at concerned individual consumers and businesses (offices) with prices ranging between €170 - €300. Most indoor sensors measure at least VOC, PM2.5, temperature and humidity. Outdoor sensors' main targets also seem to be concerned individuals, added with educators, researchers and local communities. These sensors show a variety of capabilities, most (but not all) sensors measure NO2 and PM2.5/10, added with O3, VOC, light, SO2, CO2, etc.

Pricing varies based on convenience. The Luftdaten project offers no more than a tutorial and platform for a do-it-yourself-sensor – users have to buy parts themselves for around €26 online. A full toolkit from projects like SenseBox and PublicLab can be purchased between €40 and €200, depending on its capabilities. For users looking for ready to use sensors there are several options on the market, both for home or mobile usage. Plume offers FLOW, a personal mobile air quality tracker for €139, while other (home) sensors like PurpleAir, SmartCitizenKit and AirQuality Egg cost between €200 and €250.

[8] Gabbay, D. M., & Smets, P. (Eds.). (2013). Handbook of Defeasible Reasoning and Uncertainty Management Systems: Algorithms for Uncertainty and Defeasible Reasoning (Vol. 5). Springer Science & Business Media.

Sensors alone are meaningless without good platforms to visualise, download and analyse sensor measurements and – ideally – complement them with additional information from other sensors or on specific health risks. Most of the researched sensors offer at least a free air quality map, displaying sensor data from own and other sensing devices and providing information and health suggestions on the air quality levels.

Concerning air quality sensors, it seems the market opportunity lies in offering devices that are easy for people in terms of soldering, design and programming. hackAIR won't beat do-it-yourself-sensors like Luftdaten with the lowest prices, nor professional sensors with the highest status and accuracy. However hackAIR could offer accessible and easy-to-use sensors that are connected with an up-to-date platform for a decent price below most commercial prices.

The market for customised air quality intelligence is – by definition - less transparent with specialised features and bespoke pricing. Publicly available are air quality API data plans , e.g. an API plan of €475 /month for non-commercial use offering 1000 daily data calls, air quality access for 1 country and dominant pollution name (Breezometer) or the Plume API-powered platform with 50.000-15.000 calls of real-time pollution from > 400 cities for €430-€700/month. Companies as ekoNet and Ambience Data offer end-to-end IoT solutions, including sensors, monitoring and data storage, analysis and visualisation. Here also machine learning is presented as commercial offer. Some offer free services for academic research, NGOs and local communities (Plume); all provide customised plans (and prices) for enterprises.

A commercial air quality intelligence offer should include an integrated solution with, besides advanced API-access, additional features on data analysis and visualisation and customised platform integration. There also seems to be a market for commercial sharing of machine learning, alerts for air quality patterns and/or forecasting.

Customer insights

Since the beginning of 2018 hackAIR has operated fully with pilot projects in Germany and Norway. More and more enthusiasts are using the hackAIR platform and sensors to contribute and retrieve air quality measurements and reported back on technical and usage issues. Information from users gathered at the workshops organised in Germany, Norway and Belgium and survey outcomes on user performance and satisfaction also contributed to the hackAIR learnings. What has been learned from operating hackAIR in terms of technical issues and user requirements?

The first user survey outcomes show a high acceptance of the hackAIR solution and an interest to continue using the mobile application and web platform[9]. User performance scores on the sensors are very good. A clear need for more detailed data provision and display of own sensor and other measurements is expressed by users. An easier process for assembling the sensors ("plug-and-play") is also often requested, as well as graphical data visualization and more information about how to interpret the measurement results.

Feedback from users and workshop participants indicated that users are mainly interested in the air quality sensors, data visualisation and the usage, export and access of data. The main issues that have been reported by users are:

- Soldering of sensors: expressed need for a plug-and-play sensor;
- Programming the sensors: hackAIR received feedback from several users who got stuck while installing the software on their sensor;
- Immediate feedback: many users expressed their need for immediate feedback on their measurement activities, including:
    - Receiving a quick estimate of the air quality at the location after making a picture of the sky using the hackAIR app
    - Integration of sensor data into the platform

[9] Source: Liu & Grossberndt (2018). Intermediate pilot implementation and evaluation report. hackAIR

  - Access to own sensor measurement data and opportunities for data analysis
  - Visibility of own sensor measurements on the platform / map;
- Data visualisation and interpretation: users shared requests and doubts about the visualisation and meaning of data on the platform. E.g. what does it mean that the platform indicates the air as "good"?

The hackAIR consortium actively used the feedback from users to advance the platform and its functionalities, for example by improving the display of measurements of sensors, a more accurate and up-to-date location search modality, new pop-up tags for platform icons and integration of other projects' measurements.

From these learnings it becomes clear that as a commercial offer, hackAIR sensors should be soldered, programmed and connected to a well-functioning platform offering immediate feedback. A customised air quality offer should include data visualisation tools and customised data integration modalities.

Product: Accessible air quality sensors

Offer and value proposition

hackAIR has developed designs and tutorials for an open hardware toolkit. As a commercial offer, hackAIR could produce, sell and distribute two versions of pre-assembled and pre-programmed hackAIR-compatible sensors: hackAIR home and hackAIR mobile.

The hackAIR home sensor measures PM2.5 and PM10 (and optional temperature and humidity). The node is based on the wemos microcontroller[10], it connects to a home or office Wi-Fi, needs to be plugged into a power socket and automatically uploads a measurement every five minutes.

The hackAIR mobile sensor is powered with a mobile power bank and uploads its measurements through Bluetooth on a phone. It also measures PM2.5 and PM10, is based on PSoC (Programmable System-on-Chip) and can be moved around and measure air quality in multiple locations.

PM measurements from both sensors are uploaded and visualized at the hackAIR platform and are made compatible with other air quality platforms as well. The sensors can be provided pre-assembled and pre-programmed: users only have to register the sensor on the hackAIR platform and connect it to their Wi-Fi or phone.

Target users and markets

The hackAIR sensors are targeted to concerned individuals who are curious to try out a sensor and eager to contribute to better air quality (information) in their neighbourhood or wider community. They have some technological interest but are not active members of an open hardware or maker community and feel more confident using a sensor that is pre-assembled and pre-programmed. Potential users are triggered by a clear environmental and/or health motivation, especially parents with young children. Immediate feedback on sensor measurements gives them a clear sense of engagement with the wider air quality community and provides tangible information for their individual, family or group activities. The first focus is on enthusiastic citizens in European cities.

For educational users, e.g. school classes and college courses, the hackAIR sensor can be used to teach electronics, programming and environmental awareness, particularly for adolescents (12-18 years). For this purpose, an educational toolkit can be made available, consisting of material for five hackAIR home sensors and three hackAIR mobile sensors, background information and teaching ideas.

[10] https://wiki.wemos.cc/products:d1:d1_mini

Pricing and cost structure

Based on the market analysis, target market and the validation activity (described below), we propose to market hackAIR sensors at an average commercial price of €100, positioning it at an accessible level.

The educational toolkit with five hackAIR home sensors and three hackAIR mobile sensors can be marketed at €500.

This offer covers:

- The cost of materials and the direct cost of shipping and processing;
- Basic customer support via email and updates for tutorials and educational materials;
- Contribution to the maintenance of the hackAIR platform.

In this way we offer two accessible sensing devices that are affordable, easy to use and compatible with platforms, serving the market of concerned individuals interested in contributing to a better air quality in their neighbourhood.

Service: Customized air quality intelligence

Offer and value proposition

As part of the project, hackAIR integrates existing air quality information with data sourced from mobile images and DIY sensors. Through the combination of multiple sources and sophisticated data fusion approaches, hackAIR can provide more detailed air quality information than any individual source. These air quality intelligence activities can evolve into a commercial offer in the form of partnerships, including advanced API access, data visualisation tools, customised adaptation of the hackAIR platform and other added value services.

hackAIR plans to offer two different levels of access: Priority and Premium. In addition, we can undertake the installation of the hackAIR platform to a client's server, ensuring an efficient and reliable platform performance, at a price of €4,800. hackAIR partners can benefit from a 20% discount.

Priority access

With this agreement, partners receive an advanced version of API access, allowing to download more data and access to data for the entire European continent. It can also include new services, especially data visualisation tools. Organisations could for example have access to time series or patterns of air quality data.

Premium access

The content of this agreement will be negotiated and adapted to the customer. Some examples of such a partnership agreement could be:

- Integration of hackAIR's particulate matter infrastructure into projects that focus on other pollutants
- Sharing of data for advanced analysis / machine learning with a big research project.
- Advanced social media monitoring tools such as real-time news related to AQ, influential accounts on Twitter, trending topics, etc.
- Provision of data infrastructure and engagement strategies to support cities in reducing air pollution.
- An air quality forecast service combined with continuous maps for a weather forecast website

Within such a partnership agreement, white labelling of the hackAIR platform and the use of an own logo might also be included.

Target users and markets

These partnership agreements are targeted at research and educational institutions, networks of non-profit organisations like the European Environmental Bureau (EEB), businesses and (local) governmental organisations in Europe.

hackAIR's air quality services are particularly suitable for entities that want convenient up-to-date air quality information to inform policy or research actions. They need comprehensive access to air quality data and easy trend analysis through advanced automated access to data and data visualisation tools. By providing a one-stop-shop for air quality information, hackAIR can save costs and help integrate multiple sources of information and make sense of them through fusion maps and other machine learning tools.

Cities and local governments can use a service like hackAIR to demonstrate their environmental and health focus and provide a convenient service for their citizens, allowing them to manage their exposure to harmful air pollution.

Pricing and cost structure

Based on the market analysis, target market and the validation activity (described below), we propose to provide market priority access to the hackAIR API and visualisation tools for an annual price of €1.000, with monthly trials available for €100.

This offer covers:

- Dedicated development capacity;
- Priority support within 24 hours;
- Contribution to the maintenance of the hackAIR platform.

Premium partnerships as described above need to be negotiated and customised to the specific needs of the interested party. Prices are expected to start at €10.000 per project.

Business model

Assuming annual sales of 300 sensors, 5 educational kits, 10 annual priority access contracts and 2 premium partnerships, we arrive at the following income projection:

	Unit	Per item	Items	Total
Material expenses				**€17,600**
Sensor material + shipping	Sensor	€40	340	€13,600
Servers + IT	Year	€4,000	1	€4,000
Staff time				**€76,575**
Sensor sales	Sensor	€15	305	€4,575
Maintenance + security updates	Person-month	€4,000	3	€12,000
Additional development in line with user needs	Person-month	€6,000	3	€18,000
Support	Person-month	€4,000	3	€12,000
Custom development	Person-month	€6,000	3	€18,000
Marketing	Person-month	€6,000	2	€12,000
Total costs				**€94,175**
Income				**€96,900**
Individual sensor sales		€100	300	€30,000
Educational toolkit		€500	5	€2,500
Priority access		€1,000	10	€10,000
Premium access		€20,000	2	€40,000
Installation on external servers		€4,800	3	€14,400
Balance				**€2,725**

While these products and services are meant to be offered through standard commercial distribution channels, a crowdfunding campaign to pre-finance a larger order of sensors would also be a possibility.

Free services

As hackAIR remains an open technology project, a number of services will remain available for free as part of the hackAIR exploitation plan:

- Download instructions to build hackAIR sensors;
- Access technical support through email and social media;
- Use the hackAIR platform to view measurements on a map and download your own measurements;
- Use the hackAIR API to download basic hackAIR air quality data; and
- Download the source code for app and website to set up separate installations and customise them.

Validation activities

To validate some of the assumptions made in the commercial offers above, hackAIR engaged in a set of in-depth validation activities:

1. Test: sensor sales (August-October 2018)
2. Test: demand for air quality data (August-September 2018)

Test: sensor sales

In August 2018, ON:SUBJECT purchased materials for 100 hackAIR home sensors and 18 hackAIR mobile sensors. These were soldered and programmed, and offered for sale publicly in early September 2018.

The test meant to provide answers to the following questions:

- What are the actual costs involved in selling and distributing hackAIR sensors?
- What is the demand for sensors of the hackAIR type?

For the hackAIR home sensor, we estimated the cost of materials and distribution at about €33 per sensor (excl. VAT), and ended up paying less than €27, mostly due to lower costs for customs and for shipping, as we managed to keep the weight of each package at 100g. The costs for a hackAIR mobile sensor were marginally higher than for the hackAIR home sensor (final expenses around €30).

hackAIR home	Estimate	Actual
Material	€20.95	€20.29
Shipping + Distribution	€12.28	€6.45
Sum (excl. VAT)	€33.23	€26.74
Item price (excl. VAT)	€39.87	€40.50
Item price (incl. 21% VAT)	€48.24	€49.00[11]

To cover for eventual faulty sensors, reclamations and/or promotional give-aways, we added 20% margin to the actual cost. Including VAT, this resulted in a sales price of €49 including international shipping.

Not included in our pricing was the staff time required for the experiment, with most effort going to soldering, programming and packing of the sensors. Additional effort went to planning, purchasing, setting up the sales process and order processing. In total, we spent 7.5 days on implementing sensor sales.

By 15 November 2018, we sold 61 sensors to hackAIR users in 18 countries. Given the positive feedback, including from institutions like RIVM and the European Commission, we decided to maintain stocks and continue with the current offer into 2019.

Test: demand for air quality data

In August 2018, DRAXIS contacted 23 data driven companies around the world to explore their willingness to use the hackAIR air quality data from sensors and sky photos for their research purposes. The contacted stakeholders were mainly developers of air quality and weather applications, companies working on the provision of environmental management services, and sensor manufacturers. Only 1 out of the 23 contacted companies sent us their feedback and expressed their enthusiasm to use the hackAIR air quality data.

[11] This resulting price for the test was lower than the prices budgeted in the full exploitation offer as it did not have to cover personnel costs.

We received a stronger response from entities involved in the use of air quality data for research and educational purpose. In particular, we participated in a number of hackathons and summer schools:

- In September 2018 hackAIR collaborated with the Crowd4Roads project and organized a joint hackathon during their summer school on citizen science data[12].
- hackAIR data was also part of the INSPIRE hackathon 2018[13] organised by the Plan4all project.
- In October 2018, DRAXIS participated in the NASA Space App Challenge[14] in Thessaloniki, where they provided mentoring and made the hackAIR air quality data available for the hackathon.
- In April 2019, VUB will be contributing hackAIR air pollution data in the hackathon organised during the Air Quality & Citizen Science Conference.

Standardisation and partnerships

As discussed in the market analysis above, hackAIR is not alone in increasing the availability and use of air quality data in Europe. While governmental institutions have long collaborated in integrating their data (e.g. through the European Environmental Agency), citizen science initiatives and low-cost sensors so far have had to create their own infrastructure and lack overall integration, leading to a fragmented landscape and underused data.

hackAIR thus engages in a number of initiatives aiming to a) better integrate air quality information from citizen science initiatives and other data sources, b) scale the impact of low-cost sensing in air quality beyond single initiatives and c) increase the use of air quality data that is available across initiatives. This included an active participation in the European Citizen Science Association (ECSA), culminating in a co-chair position for the new ECSA air quality working group.

Individual partnerships: data use and platform sharing

hackAIR was set up to combine a variety of data sources for air quality information. The main external data sources for air quality measurements come from the Luftdaten initiative, a large grassroots citizen science project, and from OpenAQ, an aggregator of air quality data from public data sources provided by government. In addition, hackAIR explored data integration with OpenSenseMap and RIVM's "Samen Meten Aan Luchtkwaliteit" initiative.

Several research institutions, educators and individuals offered some kind of collaboration. DRAXIS is also in close contact with the Kantas private school in Athens, which participated in the project pilot activities. The director of the school expressed their interest to use the hackAIR platform and sensing devices after the end of the project for educational purposes each years in their high school.

DRAXIS has also been invited to the ERA-PLANET project SMURBS to provide some of the experiences gained through hackAIR. Specifically, DRAXIS is discussing to provide a visualization tool for air quality measurement from high-cost stations in Athens, including graphs and decision support for public authorities.

Given that the hackAIR project has already built the infrastructure to receive, store and display sensor data from multiple sources, we also received requests to make our platform available for new air quality projects, including the ECSA initiative to establish a European Clean Air Day and the Flemish Environment Agency VMM. The Community Observation Networks for Air (CONA) in New Zealand is interested to use the hackAIR open platform code and customize the platform for their area, while they will also use the hackAIR air quality data for research purposes.

[12] http://www.c4rs.eu/summer-school-hackaton/
[13] https://www.plan4all.eu/inspire-hackathon-2018/
[14] https://2018.spaceappschallenge.org/locations/thessaloniki

Already in 2017, the Bulgarian electronics distributor Innovafabs agreed to distribute assembly kits and pre-assembled materials for hackAIR sensors, resulting in more than 80 sales by July 2018. This collaboration is on-going.

Towards citizen science interoperability

In 2018, a number of citizen science initiatives, including the Horizon 2020 projects WeObserve and NextGEOSS together with the Open Geospatial Consortium started a citizen science interoperability experiment to demonstrate the interoperability of citizen science projects and the way existing standards can be applied to citizen science. hackAIR is participating in the process to explore the potential for a) ensuring future use of hackAIR data, b) building relationships with key actors in the field and c) encouraging the adoption of open data standards.

The first step was to provide a description of the hackAIR project following the draft project metadata model. In addition, hackAIR provided a formal description of the hackAIR datasets available through the API.

We then explored adding existing SOS-compliant data sources to the hackAIR platform. However, existing clients were still at the demo stage and would not have added sufficient value to the hackAIR platform. Instead, we are currently working on setting up a Sensor Observation Service-Server to provide standard-compliant access to hackAIR data in cooperation with 52°North[15].

Round table: New opportunities for air quality sensing

Following a number of conversations within the hackAIR Network of Interest and at events hackAIR presented at, the project took the initiative to propose a round table conversation for governmental authorities, network operators, citizen science initiatives and academic researchers interested in lower cost sensors for air quality. JRC's Digital Earth and Reference Data Unit immediately offered to co-host and co-finance the event.

[15] https://52north.org/software/software-projects/sos/

On 24 October 2018, 46 participants representing 41 organisations from 14 countries met in Frankfurt, Germany. The resulting joint statement covers recommendations to increase the uptake of air quality information in policy and society and integrating air quality data from multiple sources, including

- Data quality: coping with varying levels of data quality
- Interoperability: comparing and integrating measurements from multiple sources
- Modelling: analysing and learning from the multitude of air quality measurements available
- Calibration: improving the quality of air quality information
- Data management: sharing data and honour sources, confidentiality and ownership

This joint statement can be found in the annex of this document.

Inspiring air quality initiatives across Europe

In addition to formal partnerships, hackAIR has also been in touch with a number of individuals and organisations building citizen science initiatives around air quality based on the hackAIR approach and technology. At this stage, the different hackAIR open source repositories have been forked 14 times, including with substantive improvements to the usability, interoperability and error handling of the sensors.

After collaboration with hackAIR on a number of events, the initiative beweging.net started a crowdfunding initiative[16] to scale up sensor use and public education in Belgium. Perks include assembly kits for sensors and workshops based on the hackAIR workshop toolkit.

[16] https://growfunding.be/en/bxl/luchtpijp

Individual exploitation plans

DRAXIS

DRAXIS is an environmental software SME with strong experience in successfully bringing software solutions to the market. DRAXIS has an interest in both hackAIR exploitation channels (support services, development of new air quality information services). With hackAIR DRAXIS can broaden its portfolio of services.

Future exploitation plans

- Air quality forecasting. New service providing air quality forecasting of high accuracy. The air quality data from hackAIR will be used to improve a forecasting algorithm developed by DRAXIS, while the hackAIR air quality estimation models will be used to simulate the air quality levels for areas where no air quality measurements are available. DRAXIS will capitalise on the knowledge gained and networks built during the project around air quality.
- Development of an advanced air quality sensor (indoor & outdoor). Advanced air quality sensors may be developed based on the hackAIR open sensors' design guidelines. The new sensors may be sold accompanied by appropriate software which could offer additional services (e.g. personalised health tips, recommendations to reduce indoor air pollution and minimise exposure, etc.).
- Air quality platform customization. Although the codes of the platform are publicly available, there is the option for customers to ask for customization of the platform or installation to their server from DRAXIS. Potential customers may be (but not limited) environmental organizations, citizen initiatives, schools, and public authorities. There is a specific list of prices mentioned above.
- Advanced API access rights. hackAIR offers an open API with which users can access the hackAIR air quality data. DRAXIS may exploit advanced access rights to an enriched API service (e.g. with weather or air pollution forecasts).

CREVIS, as a spin-out of DRAXIS, has a Memorandum of understanding (MoU) with DRAXIS which shares with CREVIS all the rights to exploit the scientific outcomes resulted from DRAXIS' projects, including hackAIR.

DUTH

The mission of the Department of Environmental Engineering of the Democritus University of Thrace (DUTH) is to educate prospective graduates in the design, construction, operation and management of modern infrastructures for the conservation of the critical natural capital of the planet, required to cover the needs of present and future generations. The main areas of specialization focus on waste management, the control and management of air pollutants, the renewable energy production, resources management, energy management and the environmental management for sustainable development.

Future exploitation plans

- Air quality estimation from digital camera images. New method providing air quality estimates from digital camera images containing parts of sky. DUTH would work on them in publications and research, and develop a generalised methodology for air quality estimation from digital images as a product or service.

TEI-A - EDML

The Electronic Devices and Materials Laboratory (EDML) currently with University of West Attica (Former TEI of Athens) as a Higher Education Institute active in top level education and focusing on research, is working on IoT platform development (both in hardware and software) for a wide range of applications like smart cities, environmental, measurement technologies and sensing devices.

Future exploitation plans

- Low Cost IoT platform for PM measurements. The platform can be used to integrate Arduino Wi-Fi shield and accept any serial sensor for IoT applications. Wide range of application platforms constitutes a state of the art in IoT technologies and trends. This tool may be used also in smart cities and other similar applications. The designed hardware also includes all the necessary electrical power enhancements enabling users to use modular power systems such as solar panels or/and wireless charging devices.
- Open software libraries for PM measurements. The designed and implemented software may be used for any rapid prototyping and microprocessor hardware that is currently available. It is significant to notice that the designed software includes humidity correction function capability as well as power management and sleep mode for the selected sensing devices.
- Commercial of the shelf sensing system. The designed sensing system incorporates widely available hardware in accordance with smart software based on computer vision technologies to estimate PM concentration on a cardboard. The designed system may be used to qualitatively estimate the PM concentration for users with limited technological skills. It may be further improved and developed as new blob detection and denoise filters will become available in the scientific literature.

NILU

The Norwegian Institute for Air Research (NILU) as a research and development foundation is focusing on air pollution and its effects. NILU will exploit the provision of support services related to sensor testing, data fusion, and machine learning for improving sensor data quality. The know-how acquired in the hackAIR project will enable the Institute to expand its existing research agenda while complementing NILU's mission to transform science into technologies with a profound positive impact on society.

Future exploitation plans

- Data fusion algorithm. New method to add value to air quality information using combination of crowdsourcing and other sources of information, increases relevance of air quality data to individuals and provides new options for visualisation
- Engagement and behaviour change approach. Social impact through behaviour changes, tools for other stakeholders who are interested in air quality related issues and research publications
- Evaluation and impact assessment approach. Societal impact/research relevance in the perspective of citizens' awareness raising and behaviour changes
- Machine learning techniques. New method to improve the data accuracy from low-cost air quality sensors by using machine learning techniques, for example, applying a Random Forest algorithm with features such as meteorological observations recorded around the sensors including Ozone, hourly precipitation, temperature, long-wave radiation from above (irradiance), wind intensity and wind direction, relative humidity, etc.
- Sensor testing. There are great opportunities that hackAIR sensors and sensor platform (in the premise of hackAIR platform continually up and running after the project finished) can be further tested in other on-going projects (e.g., EU H2020 ACTION project) and potential upcoming projects (EEA FAIR project in Romania, EU H2020 MOSAIC project in China), in the aspects of sensor performance in various environments, data flow chain via hackAIR platform, data fusion algorithm and machine learning application, citizen participation and awareness raising activities.

CERTH

The Centre for Research and Technology Hellas (CERTH) as an ICT research centre active in industry- oriented research is seeking to exploit the support services such as the indexing of environmental nodes, the reasoning techniques, and the development of social media monitoring tools. Furthermore, hackAIR will expand the research agenda of CERTH. The spin-out company called Infalia that was founded on 2014 by the CERTH team will work towards commercializing technologically mature solutions developed by the project.

Future exploitation plans

- Personalized alerts for air quality. The tool can be used for providing alerts based on the air pollution levels and thus raise the awareness to the citizens regarding Air Quality by providing suggestions (e.g. avoid a certain area, use another means of transport, etc.). The tool can be incorporated by another system.
- Environmental data collection from the web. This tool has considerable commercial interest since it can be used for collecting environmental related data from open web sources.
- Social media monitoring. Social media monitoring has considerable commercial potential due to the importance of social media for measuring brand awareness, campaign success, user engagement, etc.

VUB

Vrije Universiteit Brussel (VUB) with research group SMI, and linked to Imec, is specialized in socio-economical research regarding digital innovations in IT and media. With the hackAIR project, VUB expands its existing research agenda and expertise in the domain of smart cities, with validated methodologies and tools for impact assessment, engagement strategies and behavioural analysis studies for citizen science projects.

Future exploitation plans

- Engagement and behavioural change approach. The existing experience with regards to engagement and behavioural change research will be further refined. Knowledge gathered within hackAIR with regards to engagement and behavioural change research and methodology will enable VUB to further enhance its (national and international) reputation in this field (e.g. with the knowledge centre on citizen science in Flanders, coordinated by RVO society). VUB wishes to leverage upon this knowledge in the acquisition of national and European research projects. Research methodology and research findings will be discussed and published in scientific publications (peer-reviewed journals, academic conferences) and used for exploitation in new projects.
- Co-creation methodology. The existing experience with co-creation methodologies will be further refined. hackAIR enables VUB to further enhance its co-creation expertise and expand this to the citizen science context. VUB wishes to leverage upon this knowledge in the acquisition of national and European citizen science research projects and with multi-stakeholder co-creation analysis. Research methodology and research findings will be discussed and published in scientific publications (peer-reviewed journals, academic conferences) and exploited in new projects.
- Evaluation and impact assessment approach. The existing experience with setting up an evaluation framework to assess the usability and effectiveness of a platform will be further refined, as well as assessing the impact of a platform on a social and environmental level. VUB wishes to leverage upon this knowledge in the acquisition of national and European citizen science research projects. Research methodology and research findings will be discussed and published in scientific publications (peer-reviewed journals, academic conferences).

BUND

Friends of the Earth Germany (BUND) as a European grassroots NGO has no direct commercial exploitation plan, but will continue to feature the platform for activities of current members as well as to attract new.

Future exploitation plans

- Citizen and NGO Air Quality Data hub. BUND has a huge network of active environmentally active citizens and is a NGO functioning in alliance with other NGOs. As such BUND can facilitate uptake of solutions and feedback by several institutions. BUND will contribute to discussions about the further uptake of the platform in further activities and will remain open to cooperation with other databases or platforms to do so.

ONSUB

ON:SUBJECT (ONSUB) in the Netherlands is a consulting SME focused on the development and implementation of communications strategies on sustainability issues, that activate communities, using insights from behavioural psychology and social network theory. With hackAIR ONSUB will improve its existing services and will broaden the portfolio of existing services.

Future exploitation plans

- Training programme: Strategic communications for your project. Based on the approach used in hackAIR, ON:SUBJECT is in the process of developing a training programme (online / in-person). This product will be offered to other projects and initiatives in need of a strategic communications.

Annex

Market research

Examples of outdoor air quality sensors

Name	Capabilities	Price
senseBox:home	• DIY-kit with connected openSenseMap, -temperature, humidity, barometric pressure, UV, ambient light , PM2.5, PM10	€110-€200
Luftdaten	• tutorial and platform for DIY-sensor PM2.5, PM10	€26
PublicLab Spectrometry Kit 3.0	• open hardware kit • sky, laser, led, sodium, etc.	€40
FLOW (Plume Labs)	• mobile air quality tracker, connected with Plume Air Report platform • PM2.5/10 NO2 VOC	€139
PurpleAir	• dual laser sensor connected to air quality map • PM1.0, PM2.5, PM10, temperature, humidity	€200
Air Quality Egg	• sensor, phone app, web dashboard • CO2, NO2&CO, O3&SO2, PM, VOC	€240
Smart Citizen Kit	• sensor kit, platform, mobile app, API • CO, NO2, temperature, light intensity, sound, humidity	€215

Examples of indoor air quality sensors

Name	Capabilities	Price
Laser Egg 2+ - Kaiterra	• sensor with instant feedback, mobile app • VOC, PM2.5, temperature, humidity, weather forecasts	€190
uHoo	• sensor with mobile app • PM2.5, VOC, temperature, humidity, air pressure, NO2, CO, CO2, ozone	€260
Ambience Data IoT indoor monitoring	• sensor, end-to-end IoT platform • PM, temperature, humidity, air pressure	€300
cair	• sensor, mobile app • VOC, PM2.5/10, temperature, humidity	€159

Examples of air quality intelligence offers

Name	Offer	Price
Breezometer API	1000 daily data calls, air quality access for 1 country and dominant pollution name	€475/month non-commercial use
Plume API - Plume Labs	AI-powered platform with latest level of >12000 monitoring stations and 80 public agencies, focus on PM2.5, PM10, NO2 and O3	€430- €700 / month (free for academic research, NGOs and local communities)
ekoNet	End-to-end solution for environment monitoring: sensors, data storage, data visualisation	Customised prices for enterprises and cities

Ambience Data	Environmental sensor agnostic end-to-end IoT platform, including smart sensors, monitoring, data analytics & BigData	Customised prices for enterprises and cities

Joint Statement: Round Table on Air Quality Sensing

1 Introduction

Low-cost air quality sensors continue to spread. While their measurement quality can usually not compete with high-end instrumentation deployed in official air quality monitoring stations, they have a great potential to complement air quality assessments. Low-cost sensors may help us to create a much denser sensing network and ultimately to improve our knowledge about air pollution.

Already today we witness:

- Sensors operated by citizens directly from their homes or other locations of interest;
- Different kinds of and new initiatives promoting the use of low-cost sensors;
- Variations in data quality, quality control and calibration;
- Rapid innovations in sensing technologies;
- First success stories of collaborations between official authorities and different kinds of low-cost sensing initiatives

On the one hand, we already see progress on data sharing from both governmental air quality sensor networks and low-cost sensing initiatives. What should be the next step in terms of interoperability and collaboration on data assimilation and calibration?

On the other hand, some agencies running official monitoring networks still seem to struggle to communicate their work and to reach public awareness. How could both citizen initiatives and public authorities benefit from each other's interests and mandates? How do we make sense of the air quality data we have available and communicate with citizens?

On the 24th of October 2018, we gathered as a group of governmental authorities, network operators, citizen science initiatives, environmental NGOs and academic researchers to explore how we can collaborate and better leverage each other's work. This statement captures our joint findings.

2 Increasing uptake of air quality information in policy and society

Sources of air quality information keep increasing while policy still seems to build on authoritative measurements only. We clearly see the need to support citizens, academics and policy makers interested in accessing (and contributing to) better air quality information from multiple sources.

Given the available expertise, we investigated different perspectives in order to help stakeholders make better use of the available air quality information. As a result we want to recommend the following:

To involve citizens and bottom up-initiatives,

- work with existing enthusiasm, leaders and multipliers and provide them with tools
- bring communities physically together and allow them to learn from one another
- make it easy to share technical knowledge and access existing solutions
- emphasise the context of the data: what do limit values mean? What are the health implications?

To involve scientists and researchers,

- engage scientists from the beginning and take time to clarify the research questions and methodology (keeping in mind potential constraints)
- be clear about what you can and cannot offer (expectation management)
- help translate scientific data into clear and simple communication (visuals, not just µg/ppm)
- consider the price gap between citizen science and authoritative research: the cost for calibration/scientific accuracy is much higher than just sensors

To involve public authorities and governmental agencies,

- provide clear information about the quality of the measurements and their source (metadata);
- encourage exchange between stakeholders and different types of data.

3 Making use of air quality data from multiple sources

Making use of air quality data from multiple sources poses many scientific and technical challenges. What would be sound practical solutions that fit the needs of all stakeholders involved?
From our joint discussions we conclude the following.

3.1 Data quality: coping with varying levels of data quality

- We see a need (and an opportunity) to provide guidance and standard operating procedures for the operation and calibration of low-cost Sensors in order to increase the data quality delivered by participants of Citizen Science projects.
- Stakeholders shall be informed that sensor systems may under or overestimate the true air pollutant levels. Because of the increasing size of sensor big data, new automatic procedures shall be designed to detect data anomalies without human intervention.
- One way to increase confidence and usability of low-cost sensor data for science and policy is to complement sensor datasets with metadata describing data quality, e.g. (measurement accuracy, calibration, methodology used, etc.) following an agreed framework.
- For practical deployment by users it is important to estimate the lifetime of sensor systems and their periodicity of re-calibration.
- One does not necessarily need data of the highest accuracy, but data of an accuracy that is sufficient to address a given research question.
- For example, we think that relative comparability of the sensor data need be evaluated to ensure that sensors are able to capture the true spatial and temporal variability of air pollutants.
- In order to make more sense of the data, sensor measurements should be compared and combined with data from other sources, including reference stations, meteorological conditions, models, emission data.
- At this point in time we prefer to consider fixed-stationary sensors in a network instead of mobile sensor data, especially stationary data should not be aggregated with data from mobile sensors.

3.2 Interoperability: comparing and integrating measurements from multiple sources

- The need for interoperability should be clearly articulated and promoted, including aspects such as enabling data comparison and integration across borders (e.g. EU wide), easy access to a large data pool to directly work with, creating a unified market for entrepreneurs to build upon, making data relevant and accessible for policy, etc.
- The re-use of data, sensing solutions and data management platforms should be rewarded by funding bodies.

- Interoperability needs an adequate infrastructure that would facilitate the re-use and long-term curation of air sensing results. We welcome the developments of the European Open Science Cloud (EOSC) that might meet the demand of the community.
- A comprehensive pool of supporting tools, made available under an open license shall complement the emerging infrastructure for interoperable observation data.
- Appropriate standards and guidelines need to be provided. At the same time we agree that no single solution can be adopted to meet all expectations. That is why a brokering system that allows different already existing systems to interoperate should be put in place.

3.3 Modelling: analysing and learning from the multitude of air quality measurements available

- It is essential to know which sensors are operating and which need special attention. Operators should keep track of sensor up-time and send warnings to sensor owners in case of data lacks or atypical sensor behavior.
- In order to advance in this field, models are already existing at EU-level. These can directly be used to investigate possible validation and modifications based on data from other sources, incl. lower-cost sensors systems. The output of CAMS (Copernicus Atmosphere Monitoring Service) can be used as a first guess.
- The use of sensors and combination with modelling can increase the trust in models - which is a persistent issue. This work can open a dialogue and help increase the understanding of air quality models and their value.
- Following the point above, model owners benefit. Projects running lower-cost sensor systems benefit because they can not only present measurements at the points where there are systems deployed but also in the entire area in between.

3.4 Calibration: improving the quality of air quality information

- Co-operation between official monitoring networks (reference quality data) and low-cost sensor operators is a key to make air quality data more usable.
- Transparency about data quality is important to build more trust in the data, and to avoid unrealistic expectations.
- A calibration/quality check is recommended, esp. relating to calibration validity and representativity. This has to clarify the measurement range, meteorological condition of the sensor operation, environmental conditions, aerosol composition, etc.
- Promote open access for comparison measurements.
- When dealing with lower-cost sensor networks, projects should prominently include a disclaimer about the data quality and validity. A template of such a disclaimer might be shared to reduce the burden and guide projects.
- Standards and certification mechanisms could be offered to communities that use lower-cost sensor systems.
- The aging of sensors and their need for maintenance should be studied and communicated to users.

3.5 Data management: sharing data and honour sources, confidentiality and ownership

- We identified a need to develop a data sharing framework that holds to legal requirements (esp. GDPR), explains possibilities on how to best preserve privacy of participants, guides us to be (technically) interoperable e.g. to approaches of public administration, and is fit for the future - foresight is needed in order to address issues that might appear when sensors are carried by people including minors.

- We suggest a dedicated meeting and surrounding activity in order to start building such a framework. Here, we see a need to invite researchers dealing with the ethics of technology, lawyers, data scientists, experts on interoperability.
- For the short term we recommend to provide a guidebook (which might evolve incrementally) for new projects that start now. This should basically ask the question: What would we recommend these projects to do?
- Dedicated action is needed to investigate storage possibilities of Citizen Science data, this should also elaborate on the roles that citizens might play in this e.g. considering highly decentralized storage and involving the hacker community.

4 Moving ahead

Given that this statement emerged from a single day meeting, we do see a need to take further action. In a nutshell we consider the following actions most important and urgent to take:

- Agreeing and publishing a stable version of this statement, e.g. in the Research Ideas and Outcomes (RIO) Journal.
- Taking up some of the recommendations of this document in smaller groups.
- Sharing the results with the wider community and re-use practices, e.g. via the ECSA (European Citizen Science Association) Working Group on the topic but also with the AQUILA network (Network of Air Quality Reference Laboratories) and others.
- Organising a follow-up meeting considering also the feedback received in Frankfurt.

This statement is a result of a meeting at which individual representatives of the following organisations took part: *Belgian Interregional Environment Agency (IRCELINE), Belgium; European Commission, DG Environment, Belgium; Flanders Environment Agency (VMM), Belgium; VITO NV, Belgium; AirBG.info, Bulgaria; Airthings, Bulgaria; European Climate Foundation, Bulgaria; New Bulgarian University, Bulgaria; Sofia EU Green Capital, Bulgaria; Sofia Municipality, Bulgaria; European Environment Agency, Denmark; Plume Labs, France; 3S GmbH - Sensors, Signal Processing, Systems, Germany; Breeze Technologies UG, Germany; BUND / Friends of the Earth Germany, Germany; European Citizen Science Association, Germany; Federal Environment Agency (Umweltbundesamt), Germany; Hessisches Landesamt für Naturschutz, Umwelt und Geologie, Germany; Humboldt-Universität zu Berlin, Germany; Institut für Geoinformatik, Uni Münster, Germany; Johannes Gutenberg-University, Mainz, Germany; Landesanstalt für Umwelt Baden-Württemberg, Germany; Leibniz Institute for Tropospheric Research (TROPOS), Germany; Luftdaten.info, Germany; University Saarland, Germany; DRAXIS / hackAIR, Greece; Environmental social science research group, DIY Science LAB, Hungary; EU Joint Research Centre, Italy; Leiden University, Netherlands; ON:SUBJECT, Netherlands; Radboud University, Netherlands; RIVM - National Institute of Public Health and the Environment, Netherlands; Waag Society, Netherlands; City of Oslo, Norway; NILU, Norway; Euro Centrum Science and Technology Park, Poland; Meritum / Doing it together science, Poland; Barcelona Institute for Global Health, Spain; CAPTOR, Spain; IAAC / Fablab Barcelona, Spain; Institute of Environmental Assessment and Water Research (IDAEA), Spain; NanoSen-AQM, Spain; Institute of Occupational Medicine, UK; Lambeth Borough Council, UK*