HAQT – Helsinki metropolitan Air Quality Testbed

Deliverable D7-2: Final Report

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Introduction

Poor air quality is the most severe environmental hazard to people globally. In particular, urban areas are commonly adversely affected by poor air quality. Obviously, to address this problem, steps should be taken to improve the air quality and air quality monitoring. To improve the accuracy and availability of air quality measurements, measurements with higher spatial and temporal resolution are needed. Lately, low-cost sensors have been suggested and tested as a novel way to measure air quality. Especially combined with the high-resolution air quality modeling, the low-cost sensors may provide the much needed higher spatial resolution to augment the traditional AQ measurement networks. On a related note, simply being aware of the poor air quality situation is already useful, in particular if the citizens can then plan their activities to reduce their exposure to the various types of airborne pollution. To this end, air quality maps and forecasts are needed. The HAQT project set out to study and address these issues.

Project objectives and main activities

The key objectives of the HAQT project were:

1. To calibrate and test performance of affordable air quality sensors in laboratory
2. To characterize the performance of commercial, affordable air quality sensors both as stand-alone instruments and as members of an air quality network;
3. To establish how to best build an air quality measurement network cost-effectively by mixing instruments of varying performance levels and costs;
4. To enable air quality services by providing high-resolution, open and free air quality data for the Helsinki metropolitan area; and
5. To improve the brand of the Helsinki metropolitan area as a forerunner in the fields of clean air, healthy living, digital services and smart cities.

To reach these objectives, the following activities were carried out:

1. Validation of the performance of commercial, affordable air quality sensors in laboratory.
2. Expansion of the existing, reference-level air quality measurement network of the Helsinki metropolitan area with the commercial sensors.
3. Model study of the impact of each air quality instrument and sensor in the network on air quality forecasts in the Helsinki metropolitan area.
4. Development and utilization of an analysis tool under FMI-ENFUSER model, to assess optimal locations for air quality instruments and sensors in the Helsinki metropolitan area.
5. Integration of the commercial air quality sensors to the Cityzer platform and moving the air quality model to operationally monitored computational environment to enable operational air quality service at the Helsinki metropolitan area.
6. Design and implementation of the air quality service “Ilmanlaatukartta” and the underlying operational FMI-ENFUSER modelling system required.
7. Dissemination of the project results in various national and international conferences, in social media and through media releases.

Additional activities not directly related to the aforementioned objectives included, e.g., mapping user needs and sketching potential service ideas based on the HAQT air quality data, evaluating potential for new types of air quality measurements, and preparing a road map for building future air quality measurement networks.

As commercial air quality sensors, Vaisala AQT420 and Pegasor AQ Urban sensors were employed in the project. These are mid-range sensors in terms of price. The sensor performance was validated both by laboratory measurements and by side-to-side measurements in the field against reference-level air quality instruments. The latter allowed addressing the performance under varying weather conditions. The Cityzer platform was adapted as an IoT platform for building the HAQT pilot implementation, modified accordingly to accommodate the new types of sensors not supported by the platform. This involved implementation of new interfaces, data structures and control routines in the platform.

The FMI-ENFUSER air quality model was employed for all air quality modeling activities, i.e. both off-line studies (optimization of the sensor locations and quantification of the benefit of each measurement location and instrument type) and on-line computations for the air quality service. During the project FMI-ENFUSER was deployed as an operational air quality service for the first time.

Project organization and main partners

The project consortium was composed of the following organizations: The Finnish Meteorological Institute (FMI; the prime), the University of Helsinki (UHEL), Helsinki Region Environmental Services Authority (HSY), and two commercial companies: Vaisala and Pegasor.

The work plan was organized into 7 work packages:

1. WP1: Complementary AQ instruments (the role of commercial instruments in the network)
2. WP2: Cityzer platform and HAQT pilot (integration of HAQT components with the platform)
3. WP3: New AQ sensors: Performance (laboratory and side-to-side testing of sensor performance)
4. WP4: New air quality observations (evaluation of potential new types of air quality measurements and quantities)
5. WP5: Services and products for decision making (mapping user needs, ideas for new services)
6. WP6: Roadmap for future air quality networks (preparation of the roadmap document)
7. WP7: Project coordination (all project management work)

Work packages WP1, WP2, WP3, WP5 and WP7 were led by the Finnish Meteorological Institute. The University of Helsinki led work packages WP4 and WP6. Overall, the project work was coordinated such that the project coordinator was responsible for the high-level concepts and looking over the project as a whole. Under the coordinator worked the project manager, who took care of day-to-day management of the project and planned the work together with work package leaders.

Project meetings were held roughly once a month. These meetings served multiple roles. First, they served as a steering committee. Consortium-level decisions were made in these meetings. Second, they served as a main communication arena between work packages, project partners and individual members of the project team. Typically 10 to 20 members of the project team participated in the meetings. Third, they acted as the main communication channel between the project team, the representatives of the funding agency (Uusimaa regional council) and the sponsoring organization (Smart & Clean foundation).

Budget

As specified in the financing plan presented in the proposal, the total estimated budget for the project was ca. 1.23 M€. For financial support, 590 k€ (48% of the total) was applied from Uudenmaan liitto. The total budget granted for the project was slightly smaller, ca. 1.22 M€, however with the same 590 k€ funding share from Uudenmaan liitto.

The budget breakdown for the granted budget and the actual usage can be found in Table 1. As can be seen, the distribution of costs was somewhat off the plan, but the total costs were within the budget frame. There were slightly more personnel and external services costs than expected; whereas, expert services and materials costs were smaller than anticipated. Overall, the total cost of the project was 1.19 M€, with 580 k€ (48.6%) to be covered by Uudenmaan liitto.

Table 1: HAQT project budget, granted vs. actual.

Budget, whole concortium:		**RP 1** 05-12/2017	**RP 2** 01-12/2018	**RP 3** 01-04/2019	**Budget used (total)**	Budget remaining
Personnel costs	920663	148 937	382512	393856	925305	-4642
Expert services	30000	9 695			9695	20305
Travel			76		76	-76
External services			15 088	13 842	28930	-28930
Materials	43000	5 159	47 224	-25 615	26768	16232
Other costs: 24%:	225959	35 745	87964	79972	203681	22278
	1219622	199536	532864	462055	1194455	25167
Uudenmaan liitto	**590000**	**99768**	**266432**	**213967**	**580167**	**9833**
Private funding	91890					
Other public funding	537732					

Results and impacts

A wide variety of results were obtained during the project. For the sake of brevity, here we will focus on the result highlights:

- The Helsinki region air quality measurement network, owned and operated by HSY, was expanded by 15 Vaisala AQT420 (2017 release) and 5 Pegasor AQ Urban sensors. This approximately tripled the number of measurement points in the network. Some additional sensors were co-located also with existing reference-level instruments. For details regarding the fully deployed HAQT air quality measurement network, see Deliverable D1-3: Final optimized sensor network in operational use in different environments.
- The benefits of hierarchical station network consisting of air quality supersites, regional air quality network, and supplementary air quality sensors were explored by analyzing the added value of the data originating from different sources by ENFUSER AQ model. Based on the study the complementary sensors were found to be able to deliver useful additional information on the air

quality. The added benefits for the sensor data in HAQT were seen to be the largest for PM10 and the smallest for $PM_{2.5}$. The successful use for sensor data in this study can be considered as a strong, positive result. In the future, with improving sensor quality and further modelling developments the combination of measurement stations and complementary sensor networks should provide the most cost-effective means for extending the existing measurement networks. For details, see Deliverable D3-2: Impact and benefit of HAQT network on ENFUSER AQ modeling and forecasting accuracy. The aforementioned framework was also adapted for exploring benefits of new types of air quality measurements (e.g., black carbon, aerosol number size distribution dynamics, emission of nanoparticles and clusters from traffic, connecting the traffic emissions to co-emitted CO_2 with observations, and analysis of sources and chemical composition fine particles in the urban environment). For details, see Deliverable 4-1: Evaluation of current Kumpula AQ observations and benefits from two close-by supersites in Kumpula and in Mäkelänkatu.

- For gaseous pollutants, the performance of the Vaisala Air Quality Transmitter AQT420 sensor systems (2017 release) were tested in laboratory conditions against reference methods following the draft document that was being developed and constantly updated by the CEN/TC264/WG42. The AQT420 sensor system passed part of the requirements for test quantities or performance parameters for Class 1, Class 2 or Class 3 sensor systems; however, not all the requirements set in the draft of the Technical Specification being developed for the performance testing of air quality sensors were met. It was concluded that the calibration/testing of performance of sensors is of utmost importance prior to using them.
- A comparison study of AQT-420 sensors (2017 release) against the reference method for the PM2.5 and PM10 size fraction was performed. The data from AQT 420 sensors was within the expanded uncertainty defined by the AQ-directive, (AQD 2008/50/EC, 2008) with PM10 mass concentrations, but not in PM 2.5 mass concentrations. For more details, see Deliverable 3-3: AQ instrument benchmarking report in the laboratory and in the field.
- A new operational version of the air quality model FMI-ENFUSER was designed and implemented using the pre-existing infrastructure of the CITYZER platform. This new service was (and still is) used to generate the AQ data for additional services such as "ilmanlaatukartta". The model was also improved during the project so that a large number of sensor data can be included in the data fusion in the modelling. Also, a real time connection to Vaisala NM10 was created for the model. Finally, an algorithm for software-based automatic sensor re-calibration was implemented and tested during the project (see D3-2).
- Side-by-side observations against the reference instruments at the supersites indicated that relative humidity influenced the measurements due to the hygroscopicity of the particles. The carbon monoxide and ozone sensors' performance had a dependency on temperature. For more details, see Deliverable 3-3: AQ instrument benchmarking report in the laboratory and in the field.
- Additional laboratory tests with the AQT420 sensor (2017 release) showed that the AQT420 was able to detect aerosol particles down to 250 nm in size and with improved blue laser (405nm; prototype) down to 200 nm in size. This indicated potential in improving the optics of the AQT 420 sensor towards detecting smaller particles. For more details, see Deliverable 3-3: AQ instrument benchmarking report in the laboratory and in the field.
- Seven Pegasor AQ Urban instruments were tested against state-of-the-art instruments in determining lung-deposited surface area of the atmospheric aerosols (LDSA). Linear regression indicated that the slopes and intercepts indicated a maximum deviation of approximately ± 3 %

across all instrument units. Overall, the Pegasor AQ Urban was observed to be a stable and accurate instrument for the measurement of particles emitted from local combustion sources. For more details, see Deliverable 3-3: AQ instrument benchmarking report in the laboratory and in the field.

- A new air quality service "Ilmanlaatukartta" was introduced. The service visualizes the air quality situation over the Helsinki metropolitan area up to 12h in the past and into the future, and is available both on-line and in some screens in the Helsinki tram and metro lines.
- The data behind the "Ilmanlaatukartta" service was made open and freely available in a machine-readable form. For more details, see Deliverable 5-2: Delivery of quality-controlled HAQT data with open access.
- Seven example services based on HAQT air quality data were sketched. One of them was implemented as "Ilmanlaatukartta", the rest are available concepts, e.g., for third parties interested in implementing them. For more information, see Deliverable D5-3: Analysis of services to support decision making.
- Based on the experiences and good practices developed in HAQT, an air quality network utilization roadmap was developed. For more information, Deliverable 6-1: AQ network utilization roadmap based on HAQT results.
- We expanded the HAQT concept into global scale with practical examples and presented the scalability of HAQT in Deliverable 6-2: Identification and suggestion of validation AQ networks in China and India.
- The project resulted in 12 publications, including international and national journal articles and conference abstracts. The complete list can be found from Deliverable D7-3: Dissemination activities report.

The estimated impacts of the HAQT project were analyzed in detail. For the analysis, customers were divided into four groups: Different customer groups: citizens, city authorities and government, business and export, and academia. The analysis revealed a variety of impacts, ranging from citizen empowerment and awareness to commerce and potential for positive health and environmental impacts. Further, because HAQT introduces an ecosystem of services in the making, it was obvious that some of the impacts cannot as of yet be assessed – they depend on the kind of services that may or may not become available in the future. The detailed analysis on the impacts can be found in the Deliverable D5-4: Estimated impacts across the customer base.

Finally, 13 AIKO indicators were identified for monitoring the progress of the project. All the indicators were completed during the project. The indicators are listed and their implementation described (in Finnish) in the "HAQT-seurantalomake"-document.

Utilization of project results

The project consortium identified a variety of ways for utilizing the project results. The plans are in varying states of readiness, some being already in process, some being considered for putting in action, and some have been identified but not acted upon as of now. In the following the three main avenues for utilization are discussed.

Utilization in business

Several routes for the business utilization were identified:

1. Instrument and observation system sales
2. Environmental service sales
3. Expertise reference

The HAQT infrastructure employs observational systems, e.g., air quality instruments and sensors, which are fundamental for the operation of the HAQT system. Sales of such instrumentation can be in the form of expanding or replacing existing infrastructure in the target area, or introducing new observational capabilities.

The data provided by the HAQT system can be sold as they are, or higher-level services can be built on them and then sold. Selling expert analyses on these data is also an option. Combining these environmental service sales with instrument sales would provide additional value for both.

Finally, the participating organizations can use the sensor calibration results and HAQT pilot system as a reference for their instruments and expertise. Depending on the organization and their role in the implementation of the pilot, the reference can be anything from modeling and measurements to prototype software development.

Utilization in research

Similarly to business utilization, there are a number of ways how the project results can be utilized in research. The following routes were identified by the consortium:

1. Calibration methods for sensors
2. Funding opportunities
3. Model development

The HAQT laboratory tests provided important information about calibration methods and the challenges related to calibration of the low- and medium cost sensors. Based on these results, improved calibration methods have been created and will be utilized in the subsequent HOPE project.

The HAQT pilot system is readily applicable to other types of environmental data, other geographical areas and to new types of services. These all offer new funding opportunities. Indeed, one other project heavily exploiting the HAQT results have already started: Nanjing Air Quality Testbed (NAQT) funded by Business Finland. Further, the HAQT results will be exploited in the ongoing Healthy Outdoor Premises for Everyone (HOPE) project in Helsinki funded by EU.

The HAQT pilot provides easily accessible, constantly running test case for validating the performance of the forecast models employed. By identifying situations where the models do not perform satisfactorily, they can be improved. Such improvements feed positively back to the usefulness of the services based on the HAQT pilot or other future implementations of the platform. Further, the pilot could be expanded by introducing new models for forecasting other environmental parameters and used similarly to aid the development of those models.

Societal utilization

Finally, the HAQT pilot provides environmental data that can and, indeed, already are exploited as societal services. The following utilization avenues have been identified:

1. High-resolution air quality forecasts for urban areas
2. Historical air quality maps

3. Urban road maintenance

The HAQT pilot provides high-resolution forecasts of air quality for the Helsinki metropolitan area. An online air quality map service (Ilmanlaatukartta; https://www.hsy.fi/fi/asukkaalle/ilmanlaatu/Sivut/ilmanlaatukartta.aspx) was implemented in the project to visualize these data over Helsinki and neighboring areas. The same data are also shown on the info screens of trams and the subway. The data are open and freely available for third-party applications, some of which were sketched already during the project. One example of a possible new service is a clean-air route map.

Although the HAQT pilot only shows the air quality 12h forward and backward in time, these data could be collected and stored to generate historical air quality maps. For example, monthly and yearly maps could be generated. Such maps could be exploited, e.g., in city planning and real estate business, and would be highly valuable for special groups such as people suffering from respiratory and cardiovascular ailments when purchasing housing, choosing schools etc. HSY has already started collecting such data.

The data provided by the HAQT pilot are useful also to optimize road maintenance in the Helsinki region. Indeed, they are already utilized in guiding the removal and binding of dust through the Apuri application.

Post-project activities

The HAQT pilot will continue to run after the project, allowing the “Ilmanlaatukartta” service to be available also in the future. Likewise, the forecast air quality data will continue to be openly and freely available, allowing possible third-party services to emerge.

Regarding the research institutes participating in the project, the Finnish Meteorological Institute and the University of Helsinki, future activities related to HAQT are largely dependent on the availability of suitable future funding. Such funding will be actively sought after. Indeed, two such projects are currently active: the EU-funded HOPE project and the Business Finland -funded NAQT project, both of which will build on the HAQT heritage. Regarding HOPE, both the FMI and UHEL are participating in it, as well as Vaisala and HSY. The HOPE project is more aimed at citizen observations and activation, but the air quality forecast data provided by HAQT pilot or similar system will be in a central role. The current plan is not to use the HAQT pilot as is, but to build a new cloud-based implementation of the system. This implementation would recycle many components from the HAQT pilot, while offering some benefits from the cloud-based implementation. The details are, however, as of yet to be finalized. Likewise in the NAQT project, both the FMI, and UHEL are participating, along with Vaisala (prime). In NAQT, a city-wide air quality measurement network and a pilot very similar to HAQT will be built. In this case the HAQT pilot components will also be recycled, and the HAQT roadmap will be exploited and tested against a real-life deployment of the system in another country. More projects building on the HAQT heritage are expected in the future.

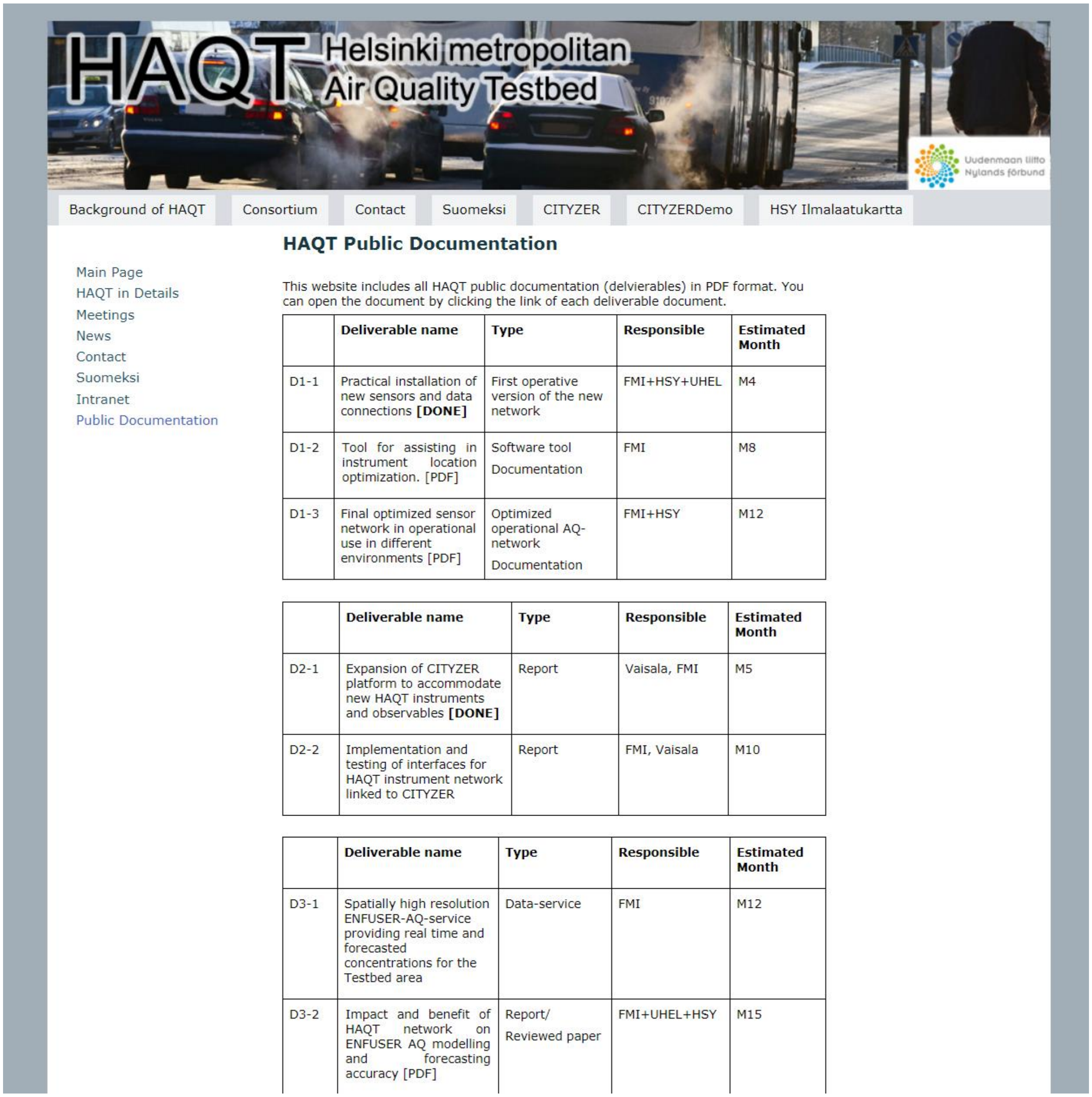
The municipal partner in the project, HSY, will continue utilizing AQT420 (Vaisala) and AQ Urban (Pegasor) sensors in air quality monitoring as they provide valuable information for air protection actions. For instance, the better spatial observational coverage obtained by AQT420 sensor data is valuable for optimizing street dust mitigation actions. LDSA data from AQ Urban sensors provide important information on ultrafine particles originating from small-scale wood combustion and traffic. HSY will also maintain and develop “Ilmanlaatukartta” forecast service in the future. For instance, air quality map service with monthly and annual mean data is now under development. Furthermore, HSY will actively participate in new air quality projects, aiming to further improve air quality monitoring and communication methods as well as air protection actions (e.g. HOPE by EU and BC Footprint by Business Finland).

Regarding the commercial partners in the project, Vaisala will utilize the HAQT project as a reference and case example for a concept of a new air quality management tool consisting of a compact sensor network and associated air quality modelling. Many of the HAQT scientific results (for example related to high resolution modelling) can also be used for the promotion of this type of a network concept. This information and evidence will be used for strategic marketing purposes to promote business expansion from sensors only – business to delivering total air quality network solutions and associated services.

Pegasor uses the HAQT case with its publications and developed capabilities as a reference and starting point for further actions (e.g. in BC Footprint project). The key results are also already in commercial development in projects with customers and partner companies.

Project documentation

The public project documentation is located on the project website (http://haqt.fmi.fi) under "Public Documentation" –page (see Figure 1). Confidential documentation is only for project partners and funding organizations. The layout of the documentation page is below. FMI will preserve the page(s) for the nonce and ensure the availability of documents at least for the next 10 years, as requested.



HAQT Helsinki metropolitan Air Quality Testbed

Uudenmaan liitto Nylands förbund

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HAQT Public Documentation

This website includes all HAQT public documentation (delvierables) in PDF format. You can open the document by clicking the link of each deliverable document.

	Deliverable name	Type	Responsible	Estimated Month
D1-1	Practical installation of new sensors and data connections **[DONE]**	First operative version of the new network	FMI+HSY+UHEL	M4
D1-2	Tool for assisting in instrument location optimization. [PDF]	Software tool Documentation	FMI	M8
D1-3	Final optimized sensor network in operational use in different environments [PDF]	Optimized operational AQ-network Documentation	FMI+HSY	M12

	Deliverable name	Type	Responsible	Estimated Month
D2-1	Expansion of CITYZER platform to accommodate new HAQT instruments and observables **[DONE]**	Report	Vaisala, FMI	M5
D2-2	Implementation and testing of interfaces for HAQT instrument network linked to CITYZER	Report	FMI, Vaisala	M10

	Deliverable name	Type	Responsible	Estimated Month
D3-1	Spatially high resolution ENFUSER-AQ-service providing real time and forecasted concentrations for the Testbed area	Data-service	FMI	M12
D3-2	Impact and benefit of HAQT network on ENFUSER AQ modelling and forecasting accuracy [PDF]	Report/ Reviewed paper	FMI+UHEL+HSY	M15

Figure 1: Screenshot of the HAQT web page with the documentation repository.

The public documentation comprises of the project deliverables. The documents can be downloaded by following the links on the page. Note that some deliverables did not include a written part and are listed only for the sake of consistency.

Signature and date