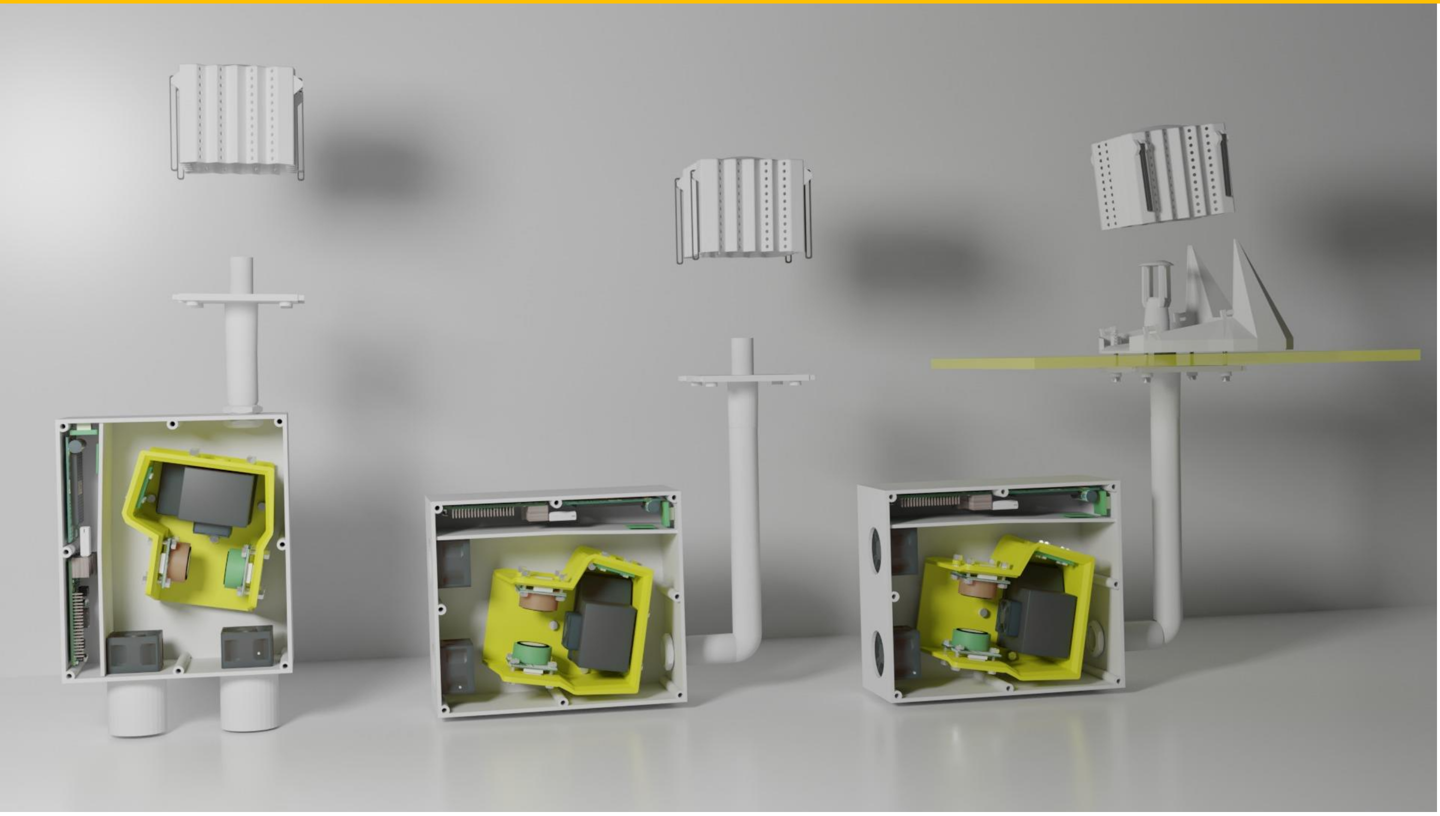
ExpoLIS

Assessment of Human Exposure to Air Pollution to Change the Way People Move in cities

LAYMAN'S REPORT



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The background

Monitoring airborne pollutants is of utmost importance to reliably assess the impact of air pollution on the human health.

Currently, air pollution is monitored by networks of static stations. These stations are highly reliable and able to accurately measure a wide range of air pollutants. However, their high acquisition and maintenance costs severely limit the number of installations.

Hence, very little is known about the spatial distribution of air pollutants in urban environments and there is a lack of accurate urban air pollution maps. Up-to-date information on urban air pollution is of great importance, enabling urban planners to adopt and accurately evaluate new policies, and raise public awareness.

Recent studies have shown that implementing **wireless networks** of **low-cost sensors** can **increase the coverage area** and **spatial distribution** of monitoring systems, especially if deployed on mobile platforms.

Objectives

ExpoLIS aims to develop an air quality exposure sensing system, composed by a network of sensor nodes, and deploy it on public transportation to obtain the real-time air pollution distribution in urban areas. The project takes advantage of concepts like big data analytics and internet of things, and is a step forward into the smart city ideology.

The main innovative objectives of the project were:

- Design and development of sensor nodes, following the open-source software and hardware paradigms;
- Development of a route selection algorithm based on multi-criteria optimisation techniques to improve the spatial coverage of the sensor nodes;
- Integration and calibration of the air quality exposure sensing system with the existing static monitoring stations;
- Development of a module for continuous update of a data-driven predictive model capable of correlating pollution incidence with topology, environmental conditions, and traffic density. This model interpolates/extrapolates the temporal and spatial gaps of the sensing system;
- Deriving and online public sharing of real-time detailed spatio-temporal air quality road maps;
- Introduction of a health-optimal routing service, which helps citizens to reduce their exposure to air pollutants.

ExpoLIS project was carried out through a cooperation network between researchers from environment, transports, computer science and electrical engineering. It is a joint initiative of **IST-ID/C²TN** and **ISCTE-IUL/IT**, with collaboration of **Carris** (bus public transportation company) and **CCDR-LVT**.

What is the ExpoLIS system?

The ExpoLIS system is a **3 layered system**, whose purpose is to **collect**, **map**, and **predict geo-referenced air quality data in urban environments**, as well as to provide citizens with intuitive access to these data when **planning daily commutes**, fostering a **healthier lifestyle**.

ExpoLIS system's bottom layer

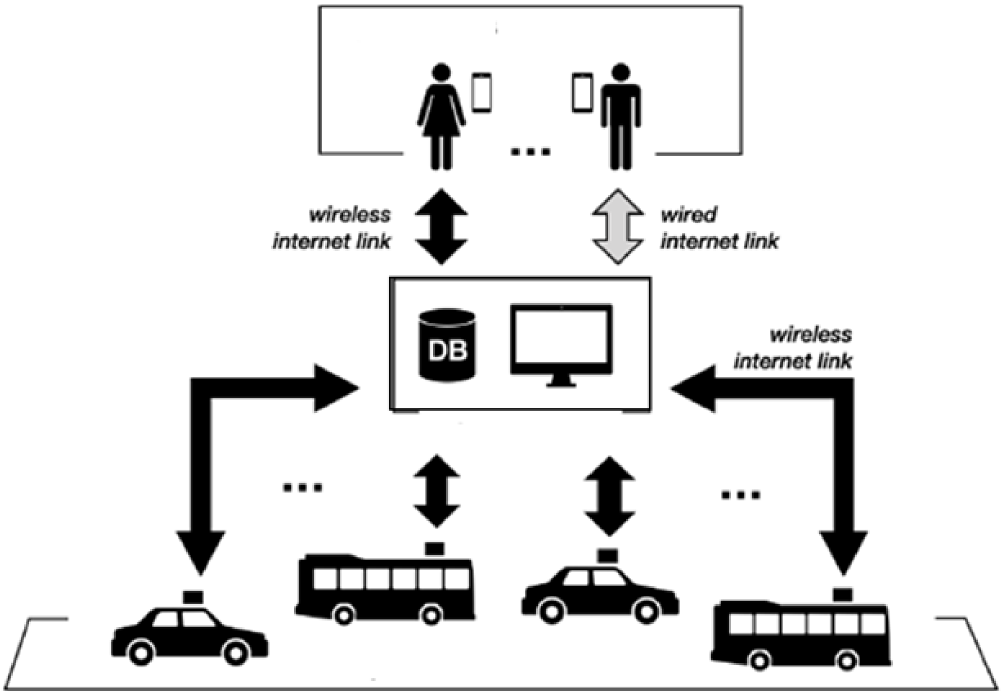
Includes all mobile sensor nodes, which are distributed across vehicles. The development of the sensor nodes followed an iterative participatory design approach with several intermediate prototypes being developed and tested. These sensor nodes sample the environment autonomously and communicate the gathered data to the ExpoLIS server via a wireless channel over the internet.

ExpoLIS system's middle layer

Includes the ExpoLIS server, which is responsible for collecting all sensor data, filtering it for smoothing and removal of outliers, storing in a geographical database, and to provide citizens with web-based access to these data. The server is also responsible for the coordination of the sensor nodes so as to ensure system-wise robustness.

ExpoLIS system's top layer

Includes all ExpoLIS users, which, through a set of graphical tools, access individual and spatiotemporal aggregated air quality data stored in the server's database



The ExpoLIS exposure sensing system was designed following the open-source software and hardware paradigms (i.e., all developed software, models for 3D printing, and electronic schematics are freely and publicly available online). This way, anyone wishing to expand or replicate the monitoring network (e.g., researchers, companies, hobbyists) can do it by building, extending, and deploying sensor nodes, as well the network's supporting information system.

If you are interested, contact us!

Sensor node prototypes

The design of the sensor node went through an iterative prototyping cycle, but from the begining, it was established that the following physical quantities should be measured:

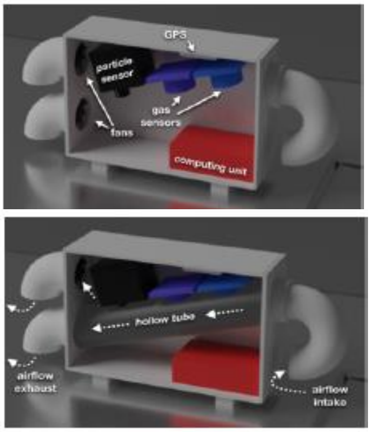
- Date and time
- Geographical location (GPS)
- Particulate Matter with diameter less than 1µm (PM1)
- Particulate Matter with diameter less than 2.5µm (PM2.5)
- Particulate Matter with diameter less than 10µm (PM10)
- Carbon Monoxide (CO)
- Nitrogen Dioxide (NO_2)
- Pressure
- Humidity
- Temperature

Two major prototypes of the system were built, each with some intermediate prototypes with minor adjustments.

External Sensor Box

The first prototype was designed to be installed outside the bus in its rooftop.

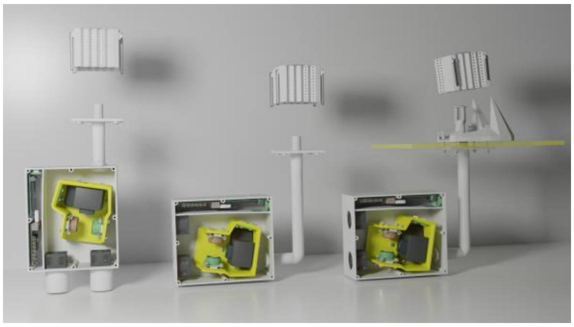
The sensor node was supposed to be continuously measuring the pollutants concentrations in the outdoor. In this way, it had to withstand adverse weather and impacts with foliage, which was considered in the development of the prototype.



Internal Sensor Box

Afterwards, it became clear that the sensor node would have to be located inside the bus. So, while the box itself was located in the interior of the bus, we developed a 3D printed sample collection device, which sits on the top of the buses.

Interestingly, this shift in the requirements resulted in three variations that allow the user to install the sensor node not only in buses (as proposed), but also in cars or bicycles.



Quality Accuracy and Quality Control

The prototype was developed considering the quality of the data produced and its capability of producing high temporally and spatially-resolved air quality data. However, low–cost sensors can have severe data quality problems compared to the conventional monitoring instruments.

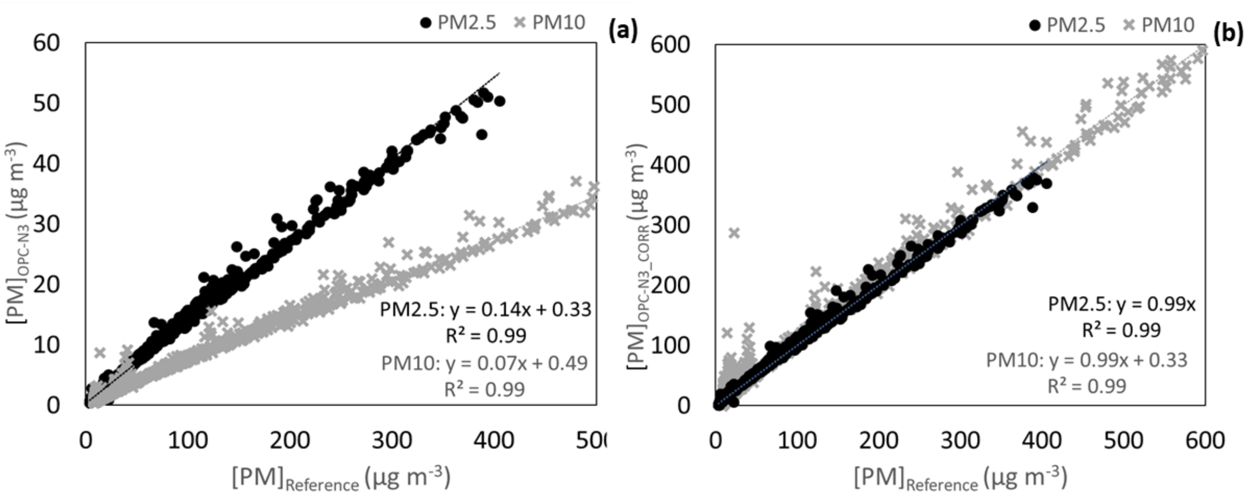
Low-cost sensors need to be calibrated and corrected against several factors, to guarantee the quality of the data produced. For example, the complexity of PM, concentration ranges and environments in which the sensors are used led to the development of different calibration methods. The calibration of low-cost sensors may be developed at a laboratory or on-field. Laboratory calibration is often seen as the most appropriate method since it is possible to exploit how different factors influence the sensors' response. On the other hand, on-field calibration can be the most appropriate method as it is carried out under the conditions in which the sensors will be used, although without the opportunity of studying to what extent different factors influence the sensors' measurements. In both cases, calibration is usually performed by placing a low-cost sensor next to a reference equipment.

The quality control of the ExpoLIS system was extensively performed through 3 approaches:

- **Laboratory calibrations**: tests in controlled conditions to evaluate the low-cost sensors without interferences.
- **On-field calibrations**: sensors were evaluated at an Air Quality Monitoring Station, where the influence of relevant factors (such as temperature and relative humidity) was evaluated.
- **Measurements in motion**: sensor nodes were installed in the indoor and outdoor of buses to demonstrate their capacity to characterize the spatial and temporal variation of air pollutants concentrations and to provide the citizens information about their exposure.

In laboratory conditions, the PM sensor underestimated the concentrations (a), which was solved through a simple linear regression approach (b).

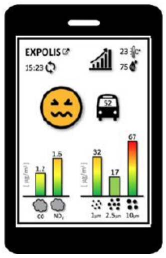
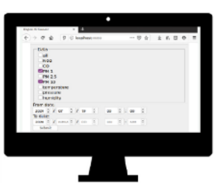
In field conditions, the temperature and humidity affected the sensor readings and therefore other calibration techniques had to be used.



ExpoLIS User Interfaces

ExpoLIS project developed seven interactive user interfaces depending on the target audience: information-seeker, learner, expert, and developer.

An iterative participatory design approach was followed to refine requirements and interfaces, as well to perform formative tests intertwined with heuristic evaluations.

Target Audience	Tool	
Information -seekers		Interface to derive urban air pollution road maps with a detailed spatio-temporal resolution and a health-optimal routing service that weights travelling distance and air pollution exposure.
Learners		Game-like air quality data visualization tool based on the Unity game engine.
		Serious game representing the ExpoLIS sensor network through which children can learn about pollution monitoring.
		Augmented reality serious game through which children can learn about air pollution by tangibly interact with ExpoLIS sensor nodes.
Experts		Web component incorporated in the ExpoLIS server through which users can search and subscribe to sensor data. An expert can search for sensor data, and receive a link to download the data as a CSV file.
Developers		Custom graphical user interface developed in Python that allows local/remote supervision/control/maintenance of each sensor node.

ExpoLIS Mobile App

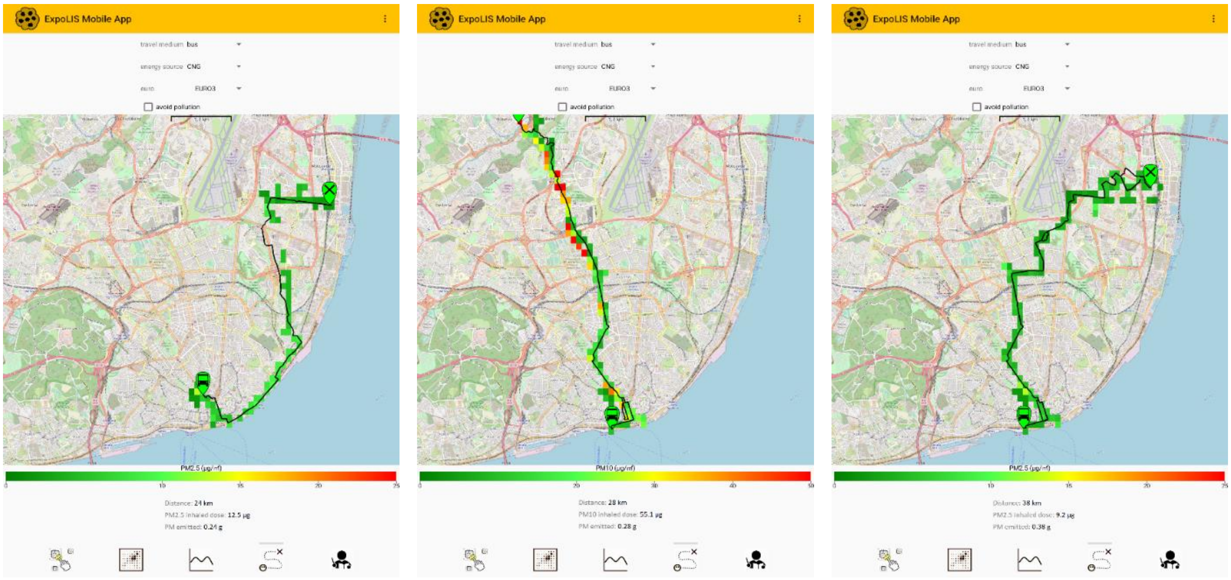
An Android app was developed with the main goal of increasing the citizens' awareness for air pollution, by sharing emissions and air pollution data from their city.

- For a location chosen by the users, the app provides the meteorological conditions data (temperature and humidity) and the pollutants concentrations associated to a color to distinguish the different air quality levels;

- The users can select different air pollution visualization interfaces: 1) map with the aggregated data during a time interval; 2) plot with pollution in a circular area during a time interval and 3) plot with the pollution along their commuting route.

- Commuters can program their daily routes in the **Heathy Routes Planner.** This functionality enables the users to, by adding a starting and ending point know what's the best route to follow, considering time, distance and the minimization of the exposure to air pollutants.

Example of the maps produced by the ExpoLIS Route Planner functionality in the ExpoLIS App



ExpoLIS System Deployment

ExpoLIS performed detailed **measurements of outdoor and indoor pollutant concentrations** during vehicle commutes (**buses, cars, metro, train and bicycle**) to assess the impact of commuting on the daily exposure, determine the penetration factors that were used in the health-optimal routing system, and understand the factors affecting exposure during commuting.

Impact of commuting on the daily exposure

Although the **small amount of time** that people spend commuting, the **high concentrations of pollutants** in this micro-environment lead to an **important contribution of commuting to the human daily exposure to particles**.

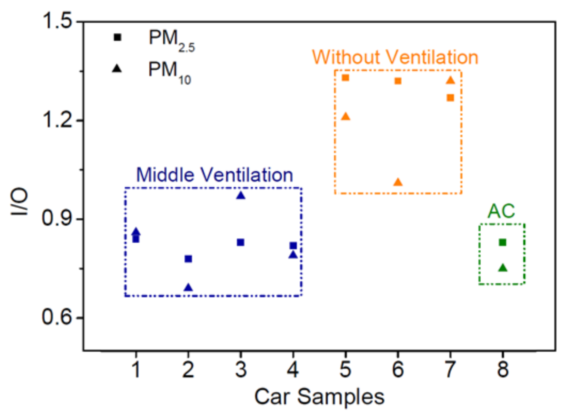
$$Exposure = time \downarrow \times Concentration \uparrow$$

Determination of the penetration factors in cars and buses

In-vehicle pollutant concentrations are clearly affected by **ventilation mode** and **type of cabin filter** used.

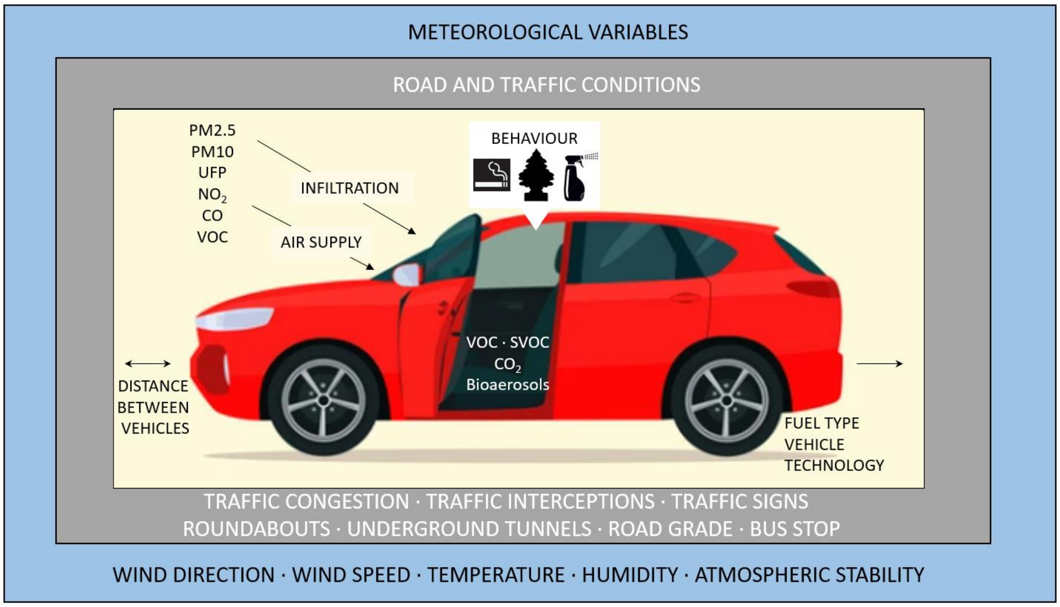
Outdoor **pollution can enter in-vehicles** through windows, doors, air vents and other openings.

In buses the **high indoor PM concentrations** are mainly associated to the **resuspension of particles**, created by the **passengers' movement** and the **air flowing in and out** when the doors are open



Factors affecting exposure during commuting

The exposure varies considerably within and between the different modes of transport, due to disparities in the **vehicle characteristics**, **ventilation settings**, **road typology**, **atmospheric conditions**, **temporal variations**, and **user habits**.



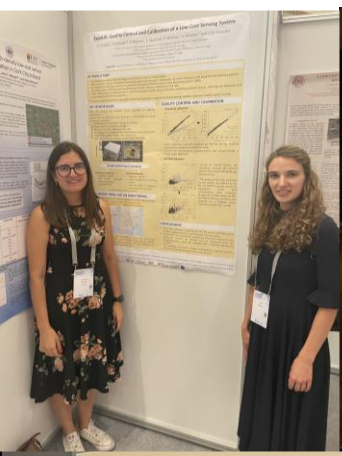
Involving citizens for better air quality

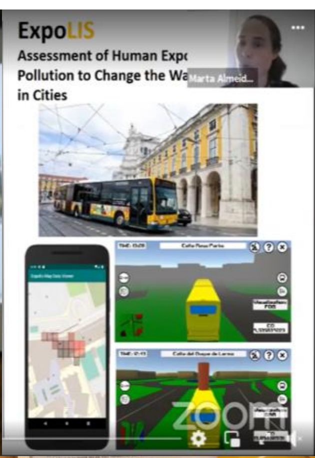
Increasing public awareness about the health benefits of clean air and increase citizens' involvement is essential for changing behaviours, improving social acceptance and supporting air quality management measures.

ExpoLIS project engaged companies, authorities, scientists, students, and the wider community fostering a transformational change of behaviours in the spirit of citizen science.

Activities developed by ExpoLIS to engage citizens

- 8 awareness campaigns in universities
- 5 stakeholders meetings
- 4 events targeting the national, regional and local authorities
- 18 works in international conferences
- 5 events for the general public
- 3 serious games about air quality targeting children





ExpoLIS

In numbers

1 Health optimal routing service

2 Sensor nodes prototypes

3 Serious games for awareness

1 Pilot city

27 Dissemination events

19 Communications in conference

10 Publications in scientific journals

1 Book chapter

3 Technical reports

1 PhD students

7 MSc students

6 Internships

KEEP IN TOUCH!

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