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INDOOR AND OUTDOOR AIR POLLUTION MONITORING DEVELOPMENTS IN THE MUNICIPALITY OF THESSALONIKI – PRELIMINARY ACTIONS FROM THREE EUROPEAN FUNDED PROJECTS

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Abstract

Air pollution has been one of the first environmental problems to be addressed by the EU and for this reason clean air is considered essential to good health. Information availability and understanding of the air quality issue is essential part of tackling it with efficiency. Having the latter in mind, the Municipality of Thessaloniki has considered relative environmental actions as an important priority and made significant efforts to include them in its short-term and long-term, already developed, strategies. Through these strategies the Municipality became partner in three important EU funded projects that are dealing with indoor and outdoor air pollution monitoring actions, namely CUTLER, AIRTHINGS, and LIFE SMART IN'AIR. The successful implementation of these projects will add to the knowledge of indoor and outdoor air quality in the City of Thessaloniki, whereas, at the same time, will improve the resilience of the city and the well being of its citizens.

Keywords: *Air pollution, environment, big data, Internet of Things, ICT, resilience.*

Περίληψη

Η ατμοσφαιρική ρύπανση αποτελεί ένα από τα πρώτα περιβαλλοντικά προβλήματα που αντιμετώπισε η ΕΕ. Για το λόγο αυτό, ο καθαρός αέρας θεωρείται απαραίτητος για την καλή υγεία. Η διαθεσιμότητα περιβαλλοντικών πληροφοριών και η κατανόηση των προβλημάτων της ποιότητας του αέρα αποτελούν βασικά στοιχεία για την αποτελεσματική αντιμετώπιση αυτών των προβλημάτων. Έχοντας υπόψη τα προηγούμενα, ο Δήμος Θεσσαλονίκης θεώρησε διάφορες περιβαλλοντικές ενέργειες ως σημαντικές προτεραιότητες και κατέβαλε σημαντικές προσπάθειες για να τις συμπεριλάβει στις βραχυπρόθεσμες και μακροπρόθεσμες στρατηγικές που έχει αναπτύξει. Μέσω αυτών των στρατηγικών ο Δήμος έγινε εταίρος σε τρία σημαντικά, χρηματοδοτούμενα από την ΕΕ, έργα που ασχολούνται με δράσεις παρακολούθησης της ποιότητας του αέρα εσωτερικών και εξωτερικών χώρων. Τα έργα αυτά είναι τα, CUTLER, AIRTHINGS και LIFE SMART IN 'AIR. Η επιτυχημένη υλοποίηση αυτών των έργων θα προσθέσει στη γνώση της ποιότητας του αέρα στην πόλη της Θεσσαλονίκης, ενώ ταυτόχρονα θα βελτιώσει την ανθεκτικότητα της πόλης και την υγεία και ευημερία των πολιτών της.

Λέξεις κλειδιά: *Ατμοσφαιρική ρύπανση; περιβάλλον; δεδομένα μεγάλου όγκου; διαδίκτυο των πραγμάτων; νέες τεχνολογίες, ανθεκτικότητα.*

1. Introduction

In 2014 Thessaloniki was selected to join the 100 Resilient Cities (100RC) network. Since then, the Municipality of Thessaloniki has developed its resilience strategy based on eight city values (Social Cohesion, Local Identity & Heritage, Environmental Management, Health and Wellbeing, Youth Empowerment, Multi-stakeholder Engagement, Technology Adaptation, Economic Prosperity), which represent the city's identity and guide about future planning. The values cut across four main goals that together form the basis of the strategy: i. Shape a thriving and sustainable city, ii. Co-create an inclusive city, iii. Build a dynamic urban economy and responsive city, and iv. Re-

discover the city's relationship with the sea (City of Thessaloniki, 2018). Within the aforementioned strategy, Urban Resilience is described as "the capacity of cities to function, so that people living and working in cities - particularly the poor and vulnerable – survive and thrive no matter what stresses or shocks they encounter". However, a number of, more or less, similar definitions for Urban Resilience, can be found in the literature (i.e., 100 RCs, 2018; Collier et al., 2013; Jabareen, 2013; Meerow et al., 2016; Spaans and Waterhout, 2017; The World Bank, 2015).

Environmental Management is one of the key values of Thessaloniki's Resilience Strategy and Thessaloniki has engaged into several activities supporting this value (City of Thessaloniki, 2017a, b). Within this context, air pollution is one of the main environmental concerns of the Municipality of Thessaloniki. Therefore, the Municipality established a Network of 6 Air Pollution and 9 Meteorological Monitoring Stations, in order to monitor air pollutants and meteorological parameters, since 1990 (Kassomenos et al., 2011; Kelessis et al., 2006; Samara et al., 2014; Tzoumaka, et al., 2008; Vlachokostas et al., 2012; Vouitsis et al., 2015). The stations are distributed within the limits of the Municipality and cover a wide range of air pollution station types, according to the EU relevant directives. At these stations some fundamental meteorological parameters are also measured (Fig. 1).

The monitoring and recording of the measurements of the Municipal Network is systematic on 24-hour basis. The air pollutants measured are particulate matter (PM_{10} and $PM_{2.5}$), carbon monoxide (CO), sulphur dioxide (SO_2), ozone (O_3), nitrogen monoxide (NO) and nitrogen dioxide (NO_2). All the analyzers are compliant with the EU standards for air quality monitoring and are calibrated monthly with gas cylinders of standard concentration and multiple concentration calibration devices. Additionally, measurements of BTEX have been performed at two sites and their monitoring has been added to the monitoring schedule. The meteorological parameters measured are ambient temperature, relative humidity, wind velocity, wind direction and atmospheric pressure.

Having all of the above in mind, the aim of the present article is to present the current developments regarding indoor and outdoor air monitoring actions that the Municipality of Thessaloniki has taken in order to increase its resilience

towards values described in its strategy such as Environmental Management, Health and Wellbeing and Technology Adaptation.

2. Study area and Project(s) Description

2.1. Study area

The study area is located in northern Greece and includes the Municipality of Thessaloniki, which is the 2nd largest municipality in Greece with 325,000 inhabitants (Fig. 1). The past years the Municipality of Thessaloniki has developed short-term (5-year operational program) and long-term strategies (Thessaloniki, 2030, Resilience Strategy), in which has set several environmental issues as top priorities (City of Thessaloniki, 2017a, b, 2018).

In the previous years, the Municipality of Thessaloniki was a partner-beneficiary in more than 45 projects that received funding, either from National Regional or Sectoral Programmes or from other funding tools (i.e., LIFE Programme, CIP-ICT PSP Programme etc.) with a total, initial budget that was over 100 mil. Euros (City of Thessaloniki, 2017b). Building on this experience, the Municipality continued becoming a partner in proposals, seeking funding from various sources; thus, seeking to add knowledge to issues that are considered crucial for the Municipality, such as air pollution, digital services, resilience and others. These proposals were built upon the partnerships of previous years and resulted in several of the proposals being accepted for funding, concerning various sections (i.e., mobility, migration etc.).

Three of these projects are dealing with issues such as outdoor air pollution, indoor air pollution, IoT, governance, co-creation and resilience, in general. These projects are entitled CUTLER, AIRTHINGS and LIFE SMART IN'AIR and are described in detail in the following sections.

Fig. 1: Map of the study area.

2.2. CUTLER

The project's full title is "*Coastal Urban developmenT through the LEnses of Resiliency*" and is funded under the Horizon 2020 Programme. The project's total budget is 5,080,125.00 €, while the Municipality of Thessaloniki has 241,250.00 € assigned to its budget. The project's duration is 36 months and the consortium consists of 15 partners, namely, CERTH (Greece, coordinator),

DRAXIS Environmental S.A. (Greece), Universitaet Koblenz-Landau (Germany), Eurosoc Digital GGMBH (Germany), Sampas Bilisim Ve Iletisim Sistemleri Sanayi Ve Ticaret A.S. (Turkey), Katholieke Universiteit Leuven (Belgium), Oulun Yliopisto (Finland), Democritus University Of Thrace (Greece), DELLEMC (Ireland), iMEC (Belgium), Byrne Looby Partners Water Services Ltd (Ireland), Antalya Büyüksehir Belediyesi (Turkey), Stad Antwerpen (Belgium), Cork County Council (Ireland), and, of course, the Municipality of Thessaloniki (CUTLER, 2018a).

CUTLER project is strongly connected with the concept of Urban Resilience. With this project an effort is being made to shift the existing paradigm of policy making, which is largely based on intuition, towards an evidence-driven approach enabled by big data. The basis of the project is the sensing infrastructures offering big data. Methods for big data analytics are used to measure the economic activity, assess the environmental impact and evaluate the social consequences. The extracted pieces of evidence are used to inform, advice, monitor, evaluate and revise the decisions made by policy planners.

The Municipality of Thessaloniki is the lead partner of Work Package 9 (WP9), "Preparation, execution & evaluation of city pilots for urban development through resiliency". As a pilot action, the Municipality has chosen to use the CUTLER platform to design, implement, monitor, and evaluate a new Controlled Parking System (CPS) in the 1st, 3rd and 5th Municipal Districts of the city.

2.3. AIRTHINGS

The full title of the project AIRTHINGS is "*Fostering resource efficiency and climate change resilience through community-based Air Quality Internet of Things*". The project is funded under the Balkan – Mediterranean 2014-2020 – Interreg V-B" (BalkanMed) Programme. The total budget of the project is 1,417,322.66 €, out of which 227,390.00 € are assigned to the budget of the Municipality of Thessaloniki. The project has a duration of 24 months and its consortium, apart from the Municipality of Thessaloniki, consists of Sofia Municipality (Bulgaria, coordinator), Aristotle University of Thessaloniki

(Greece), Centre for the advancement of research and development in educational technology ‘CARDET’ LTD (Cyprus), Tirana Municipality (Albania), and State Environmental Inspectorate of the Former Yugoslav Republic of Macedonia (FYROM).

The AIRTHINGS project will leverage the emerging technologies through Internet of Things intelligent air quality measuring sensors providing new, real time data through internet - forming network of connected cities jointly monitoring air quality, cloud based "Open data" system with predictive analytics and advanced machine-learning capabilities enabling public bodies’ timely actions. The partners will take advantage of the latest available technologies and trends for monitoring a class of chemicals e.g. volatile organic compounds and a range of various other substances of varying toxicity, air temperature and humidity, along with levels of dust particles, nitrogen oxides and carbon monoxide, by installing smart IoT air sensors.

The AIRTHINGS project has the potential to allow researchers, policymakers, developers and residents to work together and take specific actions that will make the cities healthier, more efficient and more livable. All gathered data will help make participating cities a truly “*Smart cities*” allowing them to operate their resources more efficiently and realize cost savings by anticipating and proactively addressing potential problems. Alongside an “*Open data*” platform with smart applications will be developed, helping citizens and businesses to make better and information-based decisions. The project is innovative, taking into consideration the *Internet of Things* /IoT/ enormous potential currently and in the upcoming years.

2.4. LIFE SMART IN’AIR

The full title of the project LIFE SMART IN’AIR is "*Smart indoor air monitoring network to reduce the impacts of pollutants on environment and health*". The project is funded under the LIFE 2014 - 2020 Programme. Its total budget is 3,919,777.00 €, while the Municipality's budget is 63,001.00 €. The duration of the project is 50 months and the consortium consists of 10 partners, namely, In'Air Solutions (France, coordinator), Advanticsys (Spain), Energy

Agency of Plovdiv (Bulgaria), Município de Faro (Portugal), Centre National de la Recherche Scientifique (France), Centrale Lille (France), Institut Scientifique de Service Public (Belgium), Comune di Padova (Italy), Municipality of Thessaloniki (Greece) and Thurmelec (France).

Over the last decade, public awareness on outdoor air quality issues has grown and several initiatives have been implemented to tackle it. However, EU citizen spend 90% of their time in indoor environment. Indoor air pollution is present in all buildings and is a complex issue to address because it depends on several factors such as exchange between indoor and outdoor air, emissions from the building and its equipment (paintings, furniture, heating and cooling system ec.) or human activity (e.g., cooking, cleaning). Scientific evidences of the negative impacts of indoor air pollutants on health have been demonstrated: cancer, asthma precursor, allergic response, leukaemia etc. Amongst these pollutants, BTEX (Benzene, Toluene, Ethylbenzene, Xylenes) and formaldehyde are considered as very dangerous so that threshold values of 5 and 30μg m^{-3} respectively, for benzene and formaldehyde have been defined.

3. Discussion

3.1. CUTLER

The Department of Environment of the Municipality of Thessaloniki has a large dataset regarding the air quality of the city, which is available through its open data portal and it will be used to make a first assessment of the new Controlled Parking System (CPS) on the air quality of the city. Data are referring to daily and yearly data of air pollutants' concentration (SO_2, PM_{10}, CO, NO, NO_2, O_3) from six air quality monitoring stations installed in the city from 1990 to 2017, and the maximum hourly values and daily means of air pollutants' concentration from six air pollution stations from 2003 till today (CUTLER 2018b). The Department of Environment of the Municipality will use the platform that will be developed by the technical partners of the project to evaluate the environmental impact of the new CPS on the quality of the ambient area. This will be achieved by examining and comparing air pollutants' trends for selected periods (Fig. 2), first with Key Performance Indicators [(KPIs - Indicators

showing the change in concentration levels of air pollutant from Y (the year that the parking measure was applied) to a future year X (after the application of the measure)] and finally with an Air Quality Index adapted for the urban Thessaloniki area (CUTLER 2018b, 2018c). The values of the KPIs and Air Quality Index will be visualized in various formats including line charts and bar charts, tables and maps (Fig. 3).

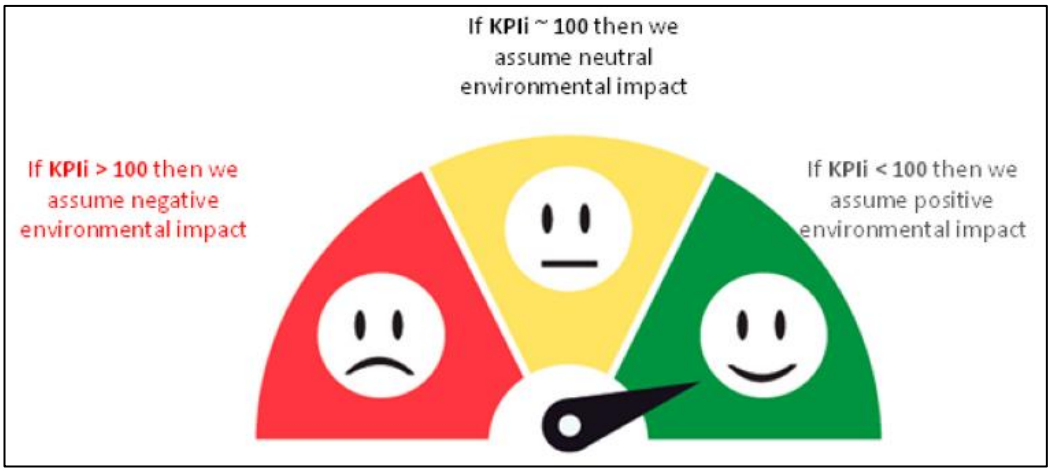
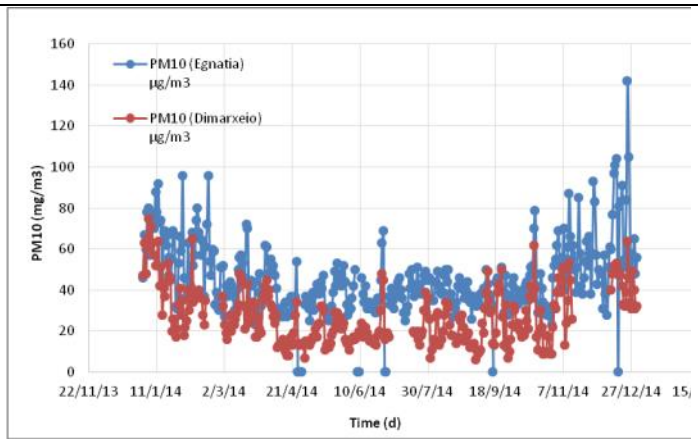


Fig. 2: Illustration of environmental impact based on the value of KPINO[THESS], KPINO_2[THESS], KPICO[THESS], and KPIPM_{10}[THESS].

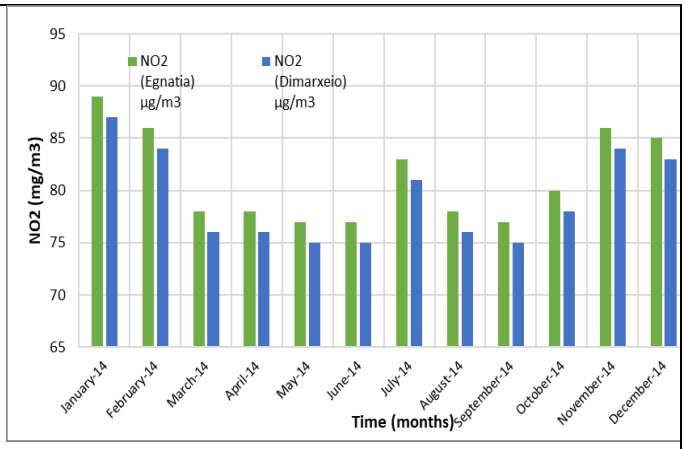
The final environmental goal will be to provide evidence to decide if there has been an improvement, deterioration or no change of state in the environmental conditions due to the proposed parking policy. In case of insignificant change or in case of deterioration, the next actions will be to analyse the possible reasons and propose policy changes, depending on the case. In those cases, a few proposed changes in policy (actions) will be:

- Create an app through which the driver will be able to see available parking spots, so that he spends less time driving while looking for an available spot.
- Distribute maps in the municipal departments where the controlled parking system is imposed upon, so that both residents and visitors are aware of the locations of white and blue sectors.
- Spatial and temporal modification of the CPS (modify the time period of application of the CPS during the day or the limits of the controlled area).

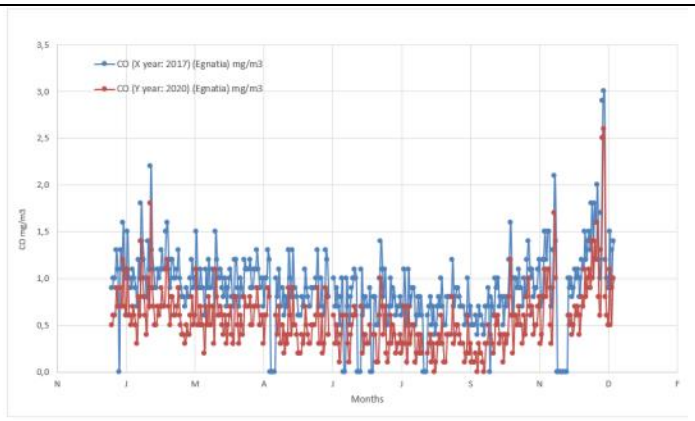
- Take into consideration the results of the Sustainable Urban Mobility Plan of the Municipality, which is expected to be completed in 2019.
- Select different pricing in different periods of a day or year so as to redistribute traffic.



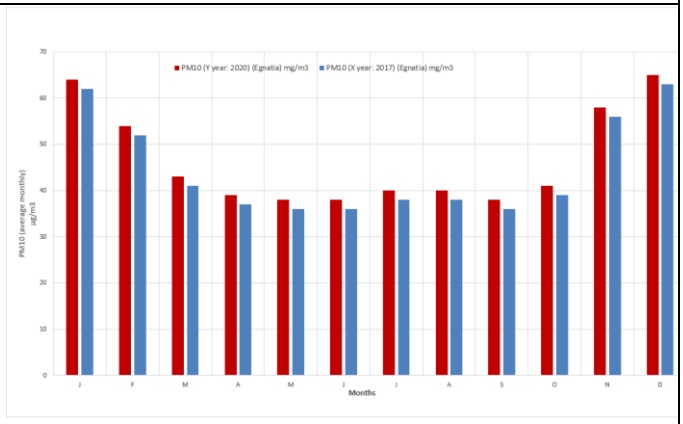
Daily values of $i_{PM10\ [THESS]}$ (µg/m^3) measured at Egnatia station and at Dimarxeio station both located at 1st Municipal District of Thessaloniki for a selected period



Monthly average values of iNO_2 [THESS] (mg/m^3) Egnatia station and at Dimarxeio station both located at 1st Municipal District of Thessaloniki for year 2014



Line graphs showing the daily values of i_{CO} (mg/m^3) for year X and year Y measured at station Egnatia located at 1st Municipal District of Thessaloniki



Bar charts of monthly average values of i_{PM10} (µg/m^3) for year X and year Y measured at station Egnatia located at 1st Municipal District of Thessaloniki

Fig. 3: Graphical representations of the environmental data monitoring through the CUTLER platform.

3.2. AIRTHINGS

Under the AIRTHINGS project, three important technologies will be disseminated among the Balkan countries:

- IoT Sensors Grid: A grid of 91 IoT Sensors will be distributed and will start measuring air quality in the cities of Sofia (22), Thessaloniki (22), Cyprus (19), Tirana (17) Skopje (11)
- Open Data Platform for sharing online information obtained from the sensors
- 61 chimney filters for biggest domestic heating emitters (chimney filter reduces PM emissions with 60% on average).

All the above actions will help the project partners to combine state of the art technologies and know-how into synergic unity that will result in sustainable development and urban resilience. Relying on the community-based approach the partners will pilot demonstrate the capabilities of new real-time monitoring node network, thus providing local communities with information which is not being available previously (Fig. 4).

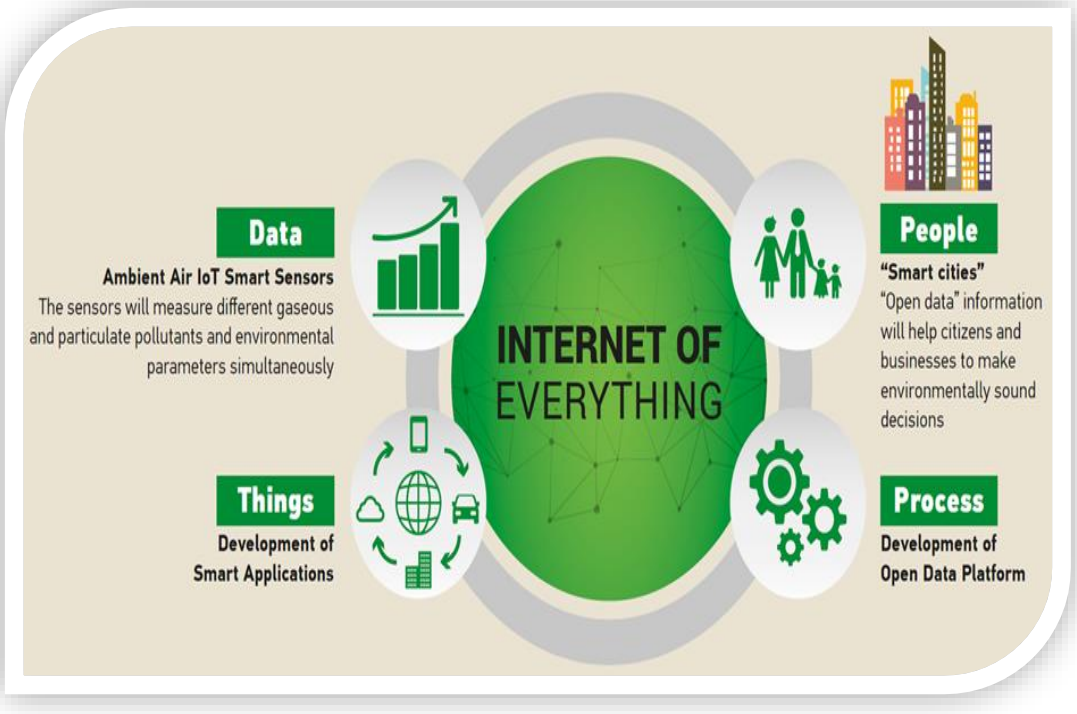


Fig. 4: *Measuring Air Quality through Internet of Things*.

3.3. LIFE SMART IN'AIR

The LIFE SMART IN'AIR project's main objective is to provide a complete and smart solution to monitor and improve In Air Quality (IAQ). This will be done through innovative micro-analysers for BTEX and formaldehyde connected to a user-friendly web and smartphone interface to easily treat the data, link them with risks on human and environment health and implement actions to reduce this pollution. The project falls under chemicals topics 1 and 2 of the "*Environment and Health, including chemicals and noise*" thematic in the 2017 "*LIFE Environment and Resources Efficiency*" priority area. The project is also addressing the main goal of the 7th Environmental Action Programme of the European Union which states that the EU shall achieve levels of air quality that do not give rise to significant negative impacts on, and risks to, human health and the environment by 2020 (EC, 2014; EP, 2013). For these levels to be achieved, it is important to develop solutions able to monitor air quality, but also improve the use of chemical monitoring data.

The LIFE SMART IN'AIR project will demonstrate a method that hasn't been applied and tested before: sensitive, fast and easy-to use micro-analysers for real-time detection of 2 types of hazardous Volatile Organic Compounds (VOCs): formaldehyde and BTEX (Benzene, Toluene, Ethylbenzene and Xylenes). These microanalysers will be connected to a user interface for data interpretation (e.g. link between pollutants concentrations and alert and health) and implementation of practical measures for improving IAQ.

To reach these goals, three specific objectives are targeted:

1. Demonstrate the technical feasibility of miniaturization of existing formaldehyde and BTEX analysers by a factor 5 and develop a portable calibration system

2. Make the data measured available, accessible, comparable and interoperable and link them with health and to assess the pollutant exposure effects

3. Identify the sources of pollution and implement actions and best practices to reduce or eliminate them.

The Municipality of Thessaloniki will use its expertises to implement the demonstration of the LIFE SMART IN'AIR project in one school. It will be responsible to use chemical data monitored by the micro-analyzers to improve the indoor air quality of the school and to implement good practises. The Municipality will also be involved in the communication and dissemination activities (Fig. 5).

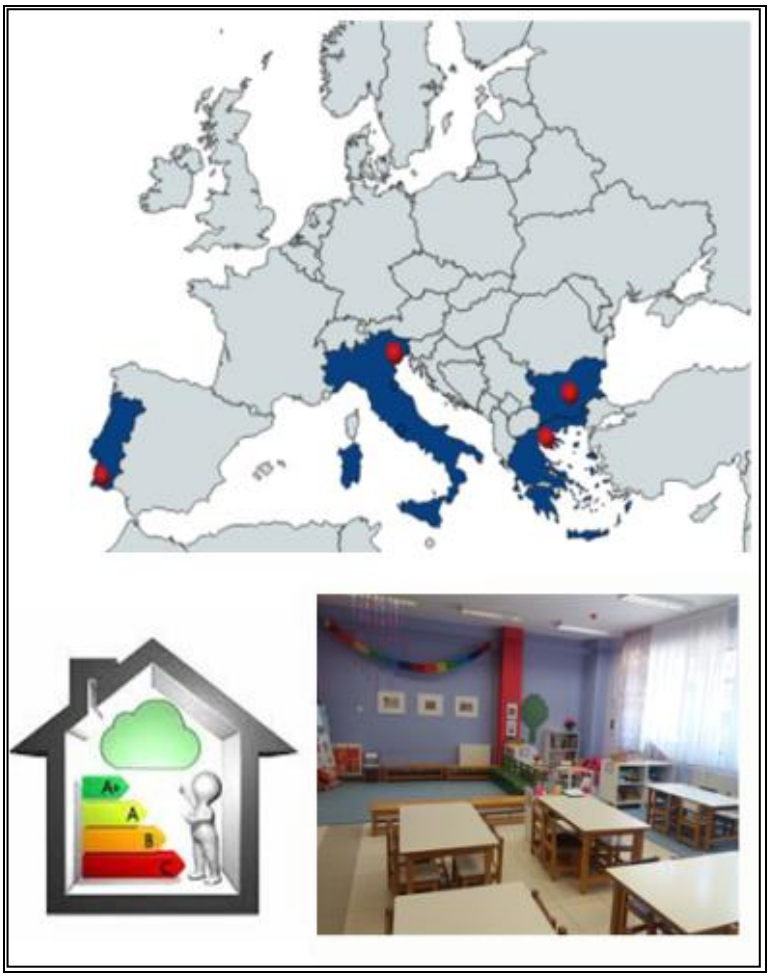


Fig. 5: Schematic representation of the actions that will take place during the LIFE SMART IN'AIR project.

Some of the expected results of the project are:

- The production, demonstration and optimisation of 2 ultra-miniaturized analysers of formaldehyde and 2 ultra-miniaturized analysers of benzene, as well as 2 innovative miniaturized calibration instruments

- The development of one web application that will allow managing the accumulated data but also to process or reprocessing them on Android and IOS. It will also deliver to the user the direct risks on human health
- The reduction of the pollution of 25-30% for both BTEX and formaldehyde in the 4 demonstration classrooms, thanks to implementation of corrective actions following first set of analysis, leading to improve the health state of 20%.
- The direct involvement of at least 150 stakeholders, including 120 pupils for the one-month
- Demonstration in 4 EU countries
- The direct analysis of the IAQ situation of the 4 schools monitored during the demonstration
- The delivery of a White Paper to enhance EU legislation and standardisation on IAQ.

4. Concluding remarks

With air pollution being one of the first environmental problems to be addressed by the EU, clean air is considered essential to good health. Hence, all available information and understanding of the air quality issue is essential part of tackling it with efficiency.

The three funded projects (CUTLER, AIRTHINGS, and LIFE SMART IN'AIR) that the Municipality of Thessaloniki is a partner of, are trying to provide complete knowledge regarding a sensitive matter, and all future accomplishments that will come through their successful implementation will be a step forward towards a better understanding of the problem, an increase in the city's resilience and in the well being of the city's population.

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