Mobile technologies and personalized environmental information for supporting sustainable mobility in Oslo: The Citi-Sense-MOB approach

Nuria Castell[1], Hai-Ying Liu[1], Mike Kobernus[1], Arne J. Berre[2], Josef Noll[3], Erol Cagatay[4] and Reidun Gangdal[4].

Abstract

Urban and peri-urban growth is increasing world-wide and Europe is now one of the most urbanized continents in the world. Oslo is one of the fastest growing cities in Europe. This creates pressure on its infrastructure, including traffic and environmental urban quality. Additionally, vehicular traffic is a major contributor to CO_2 emissions, which impacts climate change. It is recognized that air quality is a major factor for human health however, although different measures have been implemented, improving air quality and lowering carbon emissions still remains an unsolved problem in Oslo.

The main objective of Citi-Sense-MOB is to demonstrate how using innovative technology to continuously measure environmental data at the road level combined with innovative Information and Communication Technologies (ICT) can help to create a dynamic city infrastructure for real-time city management, access to personalized environmental information and sustainable development. The output from the project will be mobile services for citizens and authorities based on the use of near real-time data on air quality and CO_2 emissions at road level.

The societal importance of these services arises from a need to mitigate the effects of air pollution and climate change, and to combat respiratory diseases related to traffic-related air pollution.

In order to motivate citizens to use the information generated by the project, Citi-Sense-MOB will provide them with personalized environmental information, as for instance alerting systems when pollution levels exceed a critical threshold. Customized information will also be provided to authorities consisting of detailed air quality maps at high spatial resolution and an evaluation of possibilities to reduce CO_2 emissions by improving driving practices in public urban fleets.

1. Introduction

Air pollution is one of the factors negatively affecting quality of life within cities. Many areas of Europe still have persistent problems with outdoor concentrations of particulate matter (PM), nitrogen dioxide (NO_2) and ground level ozone (O_3).

In cities, road traffic is the dominant local source of pollution, along with domestic combustion, which has been growing over the last few years [1]. At the same time, private vehicle use in Europe is growing, and a further doubling of traffic is predicted by 2025 [2]. Studies show that traffic-related air pollution may cause major adverse health effects in the population living at or near air polluted roadways [3]. More studies are needed to characterize personal exposure to traffic-related air pollution, and to better understand the link between traffic-related air pollution and public health effects [4].

Additionally, traffic emissions also play a key role in carbon dioxide (CO_2) emissions. Energy consumption in urban areas – mostly in transport and housing – is responsible for a large

[1] NILU, Postboks 100, 2027 Kjeller, Norway, nuria.castell@nilu.no

[2] SINTEF, Postboks 124, Blindern, 0314 Oslo, Norway, arene.j.berre@sintef.no

[3] UNIK, Gunnar Randers vei 19, 2027 Kjeller, Norway, josef@unik.no

[4] Kjeller Innovasjon, Gunnar Randers vei 24, 2027 Kjeller, Norway, rg@kjellerinnovasjon.no

percentage of CO_2 emissions. Because of their larger consumption of fossil fuels, cities emit 76% of the world's energy-related CO_2 [5]. Consequently, cities are key players in efforts to reduce CO_2 emissions and mitigate the effects of climate change [5]. Monitoring road traffic and associated efforts to devise and evaluate strategies to reduce exhaust emissions from road traffic will benefit both air quality and climate change.

Oslo is experiencing rapid demographic growth. Today motorized traffic in Oslo creates problems with congestion, pollution and CO_2 emissions. Figure 1 shows the annual average concentration of NO_2 levels in Oslo and other 4 cities in Norway in the last years. Oslo has been persistently exceeding the annual limit value for NO_2 established in the EU air quality directive for health protection for the last ten years. The main source of NO_2 is road traffic. Sustainable and environmentally friendly mobility is an essential part of Oslo's new vision for green growth and improved quality of life. Developing tools to support green initiatives is crucial. The core objective of Citi-Sense-MOB is demonstrating innovative tools to support sustainable development in Oslo.

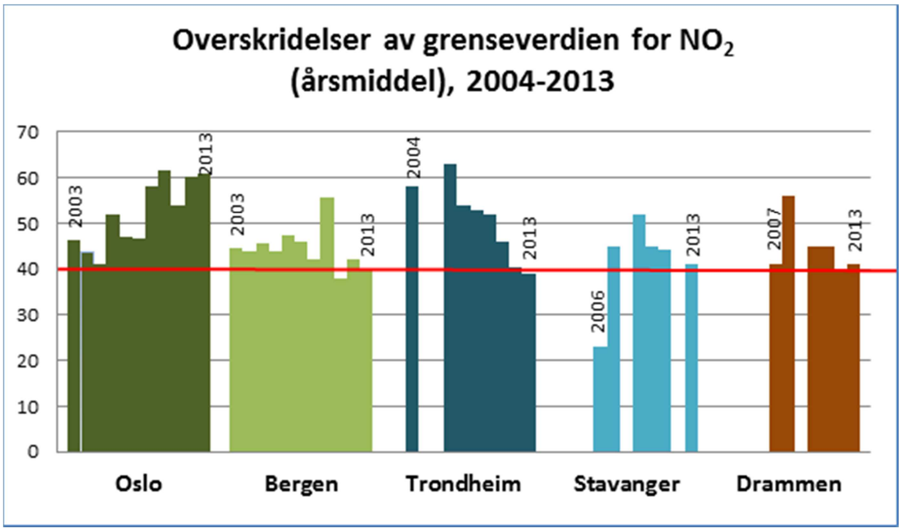

Figure 1. Annual average concentration of NO2 in five main cities in Norway. The red line marks the annual limit of 40 μg/m^3 established in the EU legislation for health protection. Data Source: http://www.miljodirektoratet.no/

The Citi-Sense-MOB project will develop the infrastructure to continuously monitor environmental data at street level using micro-sensors mounted on mobile platforms, such as buses and bicycles. The project will enable citizens to participate in monitoring their environment by using sensor equipped bicycles, data collected from sensors mounted on buses and by providing their own feeling about the air quality in their surroundings. All data collected will be available to the citizens in a user-friendly and visually informative layout, using both web services and mobile phone apps. The output from the project will be mobile services for citizens and authorities based on the use of near real-time data on air quality and CO_2 emissions at road level.

The project will contribute to raising public awareness on the links between climate change and air pollution, and on the impact of air pollution on health. In addition, the project focuses on promoting behavioural changes designed to foment less polluting transportation methods and to help citizens to chose less polluted routes when walking or commuting in the city.

In order to motivate citizens to use the information generated by the project, the project will provide them with personalized and customized information specific to themselves. Such services will include alerting systems when pollution levels exceed a critical threshold, individual exposure along a track and advice on how to mitigate the effects arising from adverse environmental conditions. Citizens will also be able to report how they feel the air quality in their surroundings following a colour scale from green meaning “I don’t have any symptoms” to red meaning “I have severe symptoms and I can’t perform my normal activities”.

The major benefit for the citizen will be access to timely knowledge of air quality levels in their immediate surroundings or at selected locations. This knowledge will help the citizen make the decisions needed to maintain and improve their quality of life.

Customized information will also be provided to authorities consisting of detailed air quality maps at high spatial resolution and an evaluation of possibilities to reduce CO_2 emissions by improving driving practices in public urban fleets.

Citi-Sense-MOB will collaborate with the ongoing project CITI-SENSE[5]. CITI-SENSE aims at enabling citizens to contribute to, and participate in, environmental governance by using novel technological solutions. CITI-SENSE will employ static sensors deployed in cities and personal sensors carried by people. The data from CITI-SENSE and Citi-Sense-MOB will be integrated within a common data processing system, utilising an open data approach.

Citi-Sense-MOB will also test the technological solution for urban fleets developed in the framework of the UrVamm project in Spain [6], which combines the collection of air quality information and driving patterns. This solution aims to encourage continuous learning towards more efficient driving practices with a consequent reduction in fuel consumption and CO_2 emissions.

Section 2 provides an overview of the project architecture and the data management, from data collection to data dissemination; section 3 discusses the methodology, implementation details and first preliminary results. Finally, Section 4 provides conclusions and details of further work building on the results from Citi-Sense-MOB.

2. Citi-Sense-MOB Architecture

The main objective of Citi-Sense-MOB is to demonstrate how using innovative technology to continuously measure environmental data at the road level combined with innovative Information and Communication Technologies (ICT) can help to create a dynamic city infrastructure for real time city management, personalized information and sustainable development. The output from the project will be mobile services for citizens and authorities based on the use of near real-time data on air quality and CO_2 emissions at road level.

The Figure 2 shows the architecture of Citi-Sense-MOB. The measuring system is composed of sensors mounted on mobile platforms (i.e., buses and electrical bicycles) to monitor atmospheric gases concentrations at road level (i.e. NO_2, NO, O_3, CO, SO_2 and CO_2). The buses will have an additional sensor to gather data on driving practices (e.g. instant speed, acceleration, etc.). The continuously gathered data are then transmitted to a server for processing (e.g., automatic quality control, generation of maps and graphics, etc.). The data from the sensors is complemented with other available data as for instance data from the air quality reference monitoring network, air quality models, sensors from the sister project CITI-SENSE and pollen data. The processed data are presented in a user-friendly and visually informative layout using both web solutions and mobile phone applications. Citizens will also be able to use their mobile phone to upload information on how they feel the air quality in their immediate surroundings. That information will allow citizens to visualize both air pollution and pollen levels and how they are affecting the people.

[5] http://www.citi-sense.eu

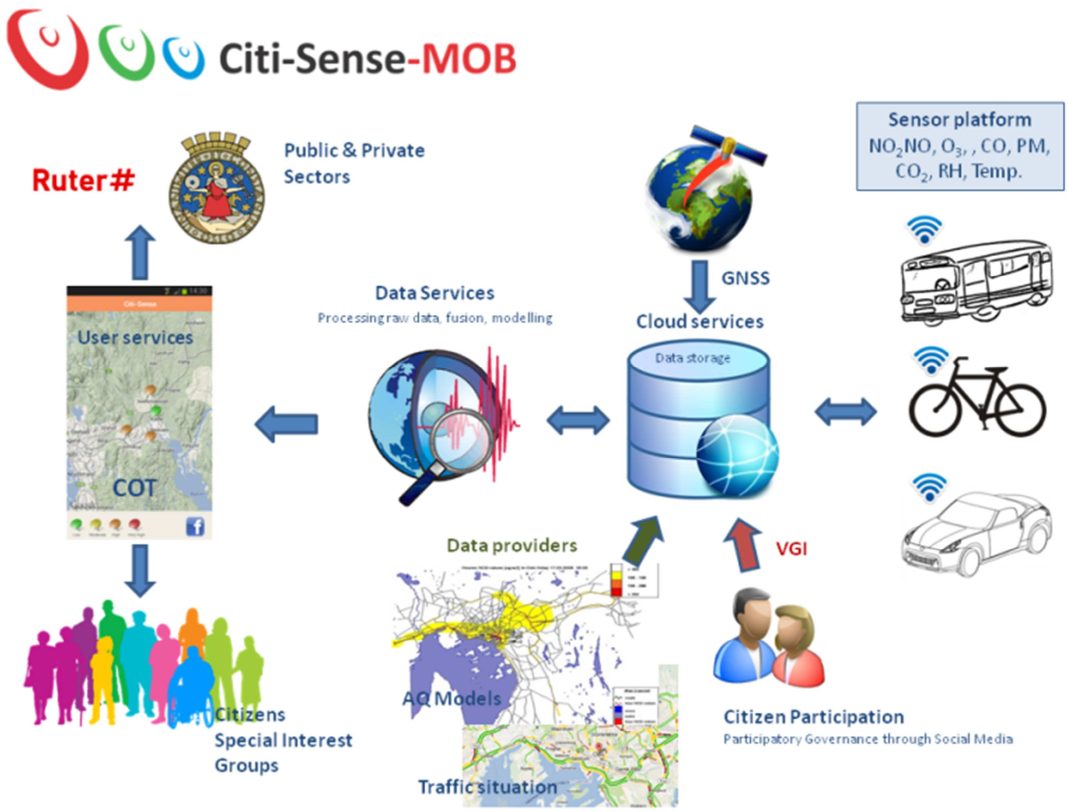

Figure 2. Citi-Sense-MOB system overview.

Involving and empowering citizens in environmental monitoring and decision-making is regarded as increasingly important by scientists and policy-makers, aiming to improve our opportunities to observe, understand and take concomitant actions to protect the environment.

Citi-Sense-MOB will develop a series of applications and services with focus on environmental management. In order to understand and address the needs of citizens, local authorities and transport agencies, the project has involved different target groups of users (e.g. health, transport and environment authorities, cyclists, etc.) to provide feedback on the services.

An example of the services of interest of transport agencies and environment authorities is fostering eco-driving practices. Transport agencies are interested in reducing fuel consumption while the environment authorities are interested in reducing CO_2 emissions from urban fleets. The sensors deployed in the bus will provide continuous geo-temporally referenced environmental and eco-driving data on fuel consumption and estimated CO_2 emissions. This generates feedback to the user, encouraging drivers to drive in a manner that creates less pollutant emissions as well as providing savings in fuel consumption.

A second example of services of interest of citizens will be the possibility of getting personalized air quality information on the mobile phone. The user will be able to check the air quality in their immediate surroundings, select less polluted routes to walk or cycle, and track their individual exposure while moving in the city. To do that, we will link data from the position provided by the GPS of the user mobile phone with air quality data from sensors and air quality models to estimate personal exposure to air pollution or provide information of air quality at the specific user location with the possibility of configuring alerts, for instance when the current Air Quality levels exceed certain thresholds defined by the user. An innovative service is the possibility for the citizens to report on “how they feel”. Table 1 shows the colour scale for the Air Quality Index that will be computed using the data from the sensors, the Pollen Index and the feelings and symptoms reported by citizens. The same colour scale will be followed for the three indexes, facilitating their interpretation by the user. The analysis of the big data set generated will help clarify relationships between air quality, pollen, meteorology and health. In the future, the identification of what particular patterns trigger symptoms in a person will help to personalize people's information and provide them with pre-alerts to help them to take the necessary measures to minimize symptoms.

Colour scale	Meaning AQI	Meaning Pollen	Meaning Feeling
Green	Good	Low	I don't have any symptoms.
Yellow	Moderate	Moderate	I have mild/moderate symptoms. I can do my normal activities.
Orange	Unhealthy for sensitive groups	High	I have moderate/severe symptoms as eye irritation, problems breathing, etc. It is affecting my normal activities.
Red	Unhealthy	Very high	I have severe symptoms. I can't do my normal activities.

Table 1. Colour scale employed to represent the pollution levels, the pollen levels and people reported feelings, and its meaning.

The data gathered will allow us to develop statistics on air pollution along routes, perform comparative studies between alternatives commuting lanes to improve travel times and lower environmental impact of travelling or create a more detailed map of air pollution highlighting the green and hot spot areas regarding air quality. The goal is to motivate citizens and other stakeholders in the measurement of air quality. These measurements can thus be an input to help citizens to select healthier routes, or for city managers to plan cycling paths and kindergarten and school locations, having air quality in mind. Though piloting with a smaller number of transport vehicles, we expect that air quality measurements will become commonplace as part of future transportation systems.

The project will address privacy concerns. The user will control de data about themselves, and they will agree in the terms and conditions the data can be used. Moreover, the data collected won't be related to sensitive personal information but to an agent number. When creating the collective maps a similar solution that the one followed by Drosatos et al. (2014) will be developed creating aggregated maps that respect user-privacy.

3. Methodology and preliminary results

3.1. Road trials

Citi-Sense-MOB will obtain air pollutant concentrations at road level. To do this, it will install low-cost sensors on mobile platforms, namely, buses and electrical bicycles.

Buses have been selected because they have a very well maintained vehicle infrastructure. Any malfunction on the platform can be detected and fixed when the bus is in the garage. They have well-known routes through the city, facilitating the analysis of the data as it is possible to compare pollution patterns over time. The buses work continuously, thus generating a large amount of data for data analysis algorithms. The data collected can help increase our knowledge about pollutant concentrations at road level.

Additionally, road traffic is one of the main contributors to CO_2 emissions. Local authorities and transport agencies have green agendas that aim for a reduction in CO_2 emissions. The monitoring platform installed on buses, combining a system for air pollution data collection and monitoring of driving efficiency, will empower the drivers to adopt a more environmentally friendly driving behaviour, helping the bus company achieve fuel savings and the environment authorities to accomplish with the green agendas. Due to the number of buses running continuously in the city, reductions in their emissions should provide significant reductions in urban greenhouse gas emissions.

In addition to the vehicular platforms, sensors will be also mounted on electrical bicycles. Bicycles can cover parts of the city that are not accessible by car, for instance parks and pedestrian areas. Furthermore, bicycle lanes often run alongside the main roads. This will allow to study for instance the gradient between measurements at the centre of the road, and on the side of the road, used by pedestrians.

To guarantee the quality of the data and the near-real-time communication between the sensor platform and the database, a testing phase with a suitable number of sensor units is currently being developed. During the test phase, one air quality sensor is tested on an electrical bicycle and two sensors from UrVAMM have been mounted on buses and tested in their daily routes. This test phase will be a “live” test to identify unexpected issues and verify that the whole system functions as expected before the full deployment study. In the full deployment it is expected to have 10 buses and two electrical bicycles.

The Figure 3 shows normalized CO levels generated during several bus routes. The methodology for the analysis of air quality in Citi-Sense-MOB is based on the generation of a high volume of routes that cover as much of the city as possible. The data gathered will allow assessment of the spatial-temporal distribution of pollutant concentrations in a variety of environments where data are not available, and will help identify areas where elevated pollutant concentrations may occur. The data gathered by the air quality sensors and the position will be used to generate air quality maps at street level.

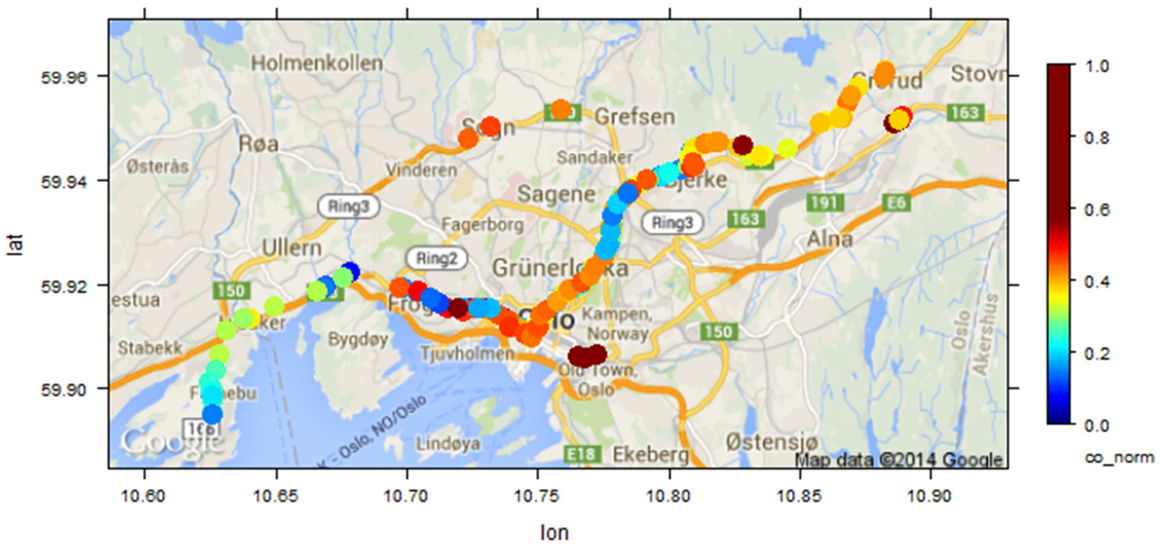

Figure 3. Normalized CO levels generated during several bus routes.

3.2. On-line data visualization

Citi-Sense-MOB will collaborate with CITI-SENSE and all the information from the sensor platforms will be collected in a central database to be further processed, e.g., automatic quality control of the data, data assimilation, and calculation of air quality indexes. The database will include data from fixed sensor units deployed in the city, mobile units mounted on buses and bicycles, and personal units carried by people. The Information and Communication Technology

(ICT) architecture will be aligned with the Global Earth Observation System of Systems (GEOSS) architecture in order to potentially make that available also through this.

The storage service is designed to support multiple input and output structures. For instance, the storage service must be capable of collecting data from different types of sensors, which may sample different variables and have different data formats. Currently, the central server is based on a Web Feature Service Interface Standard[6] (WFS) server and can support various access mechanisms.

The visualisation of the data will be performed using a variety of techniques. Online Visualisation will be implemented using the open source GIS (geographic information system) Server GeoServer application which will be the backend for both web-based and mobile mapping of the data provided by the project. Initially, for the online visualisation to be carried out in near-real-time, the users will be provided with maps showing the locations and measurements of all currently active sensor nodes. The sensor observations will be shown as points overlaid on a street map (e.g., Google Maps or OpenStreetMap), and thus will provide measurement location information to the users.

The feelings reported by the citizens will also be overlaid on a street map together with the information from the sensors employing a different symbol allowing the users easily differentiate between sensor data and citizen reported data.

For many of the planned applications of the Citi-Sense-MOB project, such as finding the least polluted route through a city or estimating the personal exposure, it is necessary to compute a gridded raster of urban air quality. This can be accomplished by interpolating the individual observations in an intelligent and objective way. In order to be able to produce on-line near real-time maps a technique that can be fully automated and does not require long computational time is required. A data fusion technique using a base map generated with an air quality model and the real-time data from the sensors will be employed.

The visualisation of the data should be user-friendly and easy to understand. It is an objective of the project to provide citizens with the means to understand how air pollution data relates to them personally. This is of special significance for health interest groups, as they need a tool that enables them to take actions to mitigate the adverse effects of air pollution on their health.

3.3. Social networks

Citi-Sense-MOB develops various social media platforms to foster communication between the project's partners, stakeholders and users, and to facilitate citizens' engagement, participation and network building. These social media platforms are all about engagement, participation, relationship building and dissemination. Every platform encourages its users to take part, by commenting on what they see and getting involved in conversations with others. This makes it a particularly useful vehicle both for informing users and for gaining their feedback.

The project is using on-line platforms as Facebook, Twitter, YouTube, LinkedIn, Forums and Blogs to disseminate the information and get feedback from citizens. Additionally off-line modes as meetings and workshops, newspapers and magazines, television, brochures and scientific publications are also used to reach people that is not using internet or other stakeholders easier to be reach by off-line modes (e.g. authorities and scientific communities).

For Citi-Sense-MOB, social media is one of the tools for succeeding with collaborative participation and citizens' empowerment. Citizens' empowerment in Citi-Sense-MOB can be regarded as a continuum, from low involvement where citizens receive relevant information to

[6] http://en.wikipedia.org/wiki/Web_Feature_Service

relatively high involvement, where citizens contribute by carrying sensors and reporting information.

4. Going forward

The Citi-Sense-MOB project is setting the stage for innovative developments in air quality monitoring and individual exposure assessment. By demonstrating the feasibility of mounting sensor units on mobile platforms and exploring how these data can contribute to a more comprehensive understanding of air quality monitoring, we hope to show that complementing existing air quality monitoring networks is not just feasible, but highly desirable.

Through the direct involvement of citizens, allowing subjective observations as well as contributing with sensor measurements riding the Citi-Sense-MOB bicycle, we both raise awareness and potentially foster a more planned approach to transport usage that will help citizens mitigate exposure to air pollution.

Citi-Sense-MOB is currently within the integration phase and is expected to have the first major results from the ‘road trials’ of the mobile sensors by the second half of 2014. From autumn 2014 to the end of 2015, full deployment of the sensors will be conducted, and we expect to have the final results and overall evaluation of the project by the end of 2015. At that time, the full potential for ubiquitous, mobile sensor deployment and their integration into static monitoring networks will be known and we expect to demonstrate positive results for both citizen engagement, exposure assessment and city management.

Acknowledgements

Citi-Sense-MOB (http://www.citi-sense-mob.eu) is a collaborative project partly funded by The European Mobile and Mobility Industries Alliance (EMMIA) strand II: Large-scale demonstrators in support of GMES and GNSS based services. Citi-Sense-MOB is also possible thanks to the support from Oslo Kommune, Ruter and Nobina.

References

[1] *Air quality in Europe-2013*. Environmental European Agency, Copenhagen, EEA Report No 9/2013, 2013.

[2] *Reclaiming city streets for people. Chaos or quality of life?*, Office for Official Publications of the European Communities, 2004.

[3] *Traffic-related air pollution: a critical review of the literature on emissions, exposure, and health effects*, Panel on the Health Effects of Traffic-Related Air Pollution, Boston, Massachusetts: Special Report 17, 2010.

[4] Liu, H.Y., Skjetne, .E, Kobernus, M., “Mobile phone tracking: in support of modelling traffic-related air pollution contribution to individual exposure and its implications for public health impact assessment”, *Environmental Health*, vol. 12, no. 93, 2013.

[5] *Cities of tomorrow. Challenges, visions, ways forward*, European Commission, Directorate General for Regional Policy. Publications Office of the European Union, Luxemburg, 2011.

[6] Rionda, A., Marín, I., Martínez, D., Aparicio, F., Alija, A., García Allende, A., Miñambres, M., X. G. Pañeda. UrVAMM – A Full service for Environmental-Urban and Driving Monitoring of Professional Fleets. In *2013 SmartMILE, International Conference on New Concepts in Smart Cities*.

[7] Drosatos et al., 2014.“Privacy-Preserving Computation of Participatory Noise Maps in the Cloud“. *Journal of Systems and Software*, vol 92, pp 170-183.