OPERATIONAL CONTEXT:NOISE MONITORING SYSTEMS

Sub- ACTION A1.2

Annex 2 of Abacus on operational context on Noise Low Emission Zone

Methodologies fOr Noise low emission Zones introduction And management

LIFE15 ENV/IT/000586

LIFE MONZA

Methodologies fOr Noise low emission Zones introduction And management

Technical Report - A1.2 Operational context: Noise Monitoring Systems

Deliverable	**Operational context: Noise Monitoring Systems** **Annex 2 of Abacus on operational context on Noise Low Emission Zone**
Action/Sub-action	Action A1 - Operational context for Noise Low Emission Zones (LEZ) detection and management Sub-action A1.2 - Operational context: Noise Monitoring Systems
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1. Introduction

LIFE MONZA project

The introduction of Low Emission Zones, urban areas subject to road traffic restrictions in order to ensure compliance with the air pollutants limit values, set by the European Directive on ambient air quality (2008/50/EC), is a common and well-established action in the administrative government of the cities and the impacts on air quality improvement are widely analyzed, whereas the effects and benefits concerning the noise have not been addressed in a comprehensive manner.

Currently, noise is a major environmental health problem in Europe and road traffic is the most dominant source of environmental noise with an estimated 125 million people[1] affected by noise levels greater than 55 dB L_{den}[2].

At this time, there is a lack of a comprehensive and integrated administration process about LEZs. The definition, the criteria for analysis and the management methods of a Noise Low Emission Zone are not clearly expressed and shared yet.

LIFE MONZA project (Methodologies fOr Noise low emission Zones introduction And management - LIFE15 ENV/ IT/000586) addresses these issues. The first objective of the project is to introduce an easy-replicable method, and related guidelines, for the identification and the management of the Noise Low Emission Zone, an urban area subject to traffic restrictions, whose impacts and benefits regarding noise issues will be analyzed and tested in the pilot area of the city of Monza, located in North Italy.

The second objective regards specific *top-down measures*, adopted by the municipality and able to turn up the area in a permanent Noise LEZ, concerning traffic management, road paving substitution and introduction of two pedestrian crossings. The third objective is to reduce the average noise levels in the pilot area of Libertà district, with positive complementary effects also on the air quality and benefits on wellbeing conditions of inhabitants.

The fourth objective is to involve people in an active management system of a more sustainable lifestyle choices *(bottom-up measures)*, related to the reduction of noise and the improvement of air quality and wellbeing conditions, in their living and working environment. In order to encourage the local community involvement and to strengthen the dialogue between citizens and public bodies, many activities will be carried out, as meetings in primary and high schools, in order to raise awareness about noise effects, and also ideas contests for Noise LEZ picture and logo and questionnaires on quality of life and noise perception. A mobile app to manage voluntary and sustainable actions and to measure benefits and concrete changes in people lifestyle will be developed.

In order to contribute to the implementation of the European directives, avoiding duplications and overlaps, detection of the synergies existing between the issues related to noise pollution and air quality will be tested during the project.

The methodology will contribute to the implementation of the EU Directive 2002/49/EC, related to the assessment and management of environmental noise (Environmental Noise Directive - END), which introduces noise action plans, designed to manage noise issues and effect, including noise reduction if necessary.

The END does not provide a definition of LEZ in relation to noise and it is not considered as action to take into account in noise action plan drafting. Annex V of the Directive, *Minimum requirements for action plans*, suggests some examples of actions that competent authorities should taken into account, as traffic planning and land-use planning and those issues are involved in Noise LEZ introduction and management. Project results, defining criteria for Noise LEZ introduction and management, and related guideline, will contribute to increase the types of actions to carry on for noise action plans set out in Annex V of the Directive.

[1] Noise in Europe 2014. EEA Report- No 10/2014 European Environment Agency

[2] Lden: day-evening-night Level

Action A1 – *Operational context for Noise Low Emission Zones (LEZ) detection and management*

Action A1 is structured in five sub-actions and it foresees a state-of-the-art review about the legislative and technical requirements on noise LEZ as well as the most up-to-date noise and air quality monitoring systems, including a scientific review on the suitable health indicators of the effects due to noise and air pollution and the analysis of the state of the art about possible interventions into LEZ areas and their effects on air quality, noise and health.

The beneficiary responsible for the implementation of the action is ISPRA. The action is divided in 5 sub-actions, each one coordinated by one associated beneficiary:

A1.1 Legal and Environmental framework for Noise LEZ introduction - MONZA

A1.2 Operational context: Noise Monitoring Systems - ISPRA

A1.3 Operational context: Air Quality Monitoring Systems - ISPRA

A1.4 Operational context: Health indicators - UNIFI

A1.5 Operational context: interventions and expected effects on air quality, noise and health – VIENROSE

The deliverable provided by the action A1 is an *Abacus on operational context on Noise Low Emission Zone*, structured in five sections devoted to the following topics: legal and environmental framework for noise LEZ introduction; operational context: noise monitoring system; operational context: air quality monitoring system; operational context: health indicators; operational context: interventions and expected effects on air quality, noise and health.

Sub-action A1.2 - *Operational context: Noise Monitoring Systems*

Sub-action A1.2 requires an update of the most advanced noise smart monitoring solutions, discussed in this report. LIFE MONZA project provides a noise monitoring phase planned in pilot area, in which the activities will be carried out referring to the standard methods, using sound level meters of class I precision, and also by developing and using a smart low-cost monitoring system.

The prototype system for smart monitoring activity of noise will be developed (*Action B.3 Prototype of monitoring system for Noise LEZ design - data analysis techniques definition*) and implemented, in order to be used as a continuous monitoring unit in the ex ante and ex post scenarios. A state of art about smart low-cost noise monitoring systems, in order to update the information on noise monitoring methods and to support the realization of the prototype, has been carried out by ISPRA and presented in this document, while the University of Florence will take care of the design of the system and VIE En.Ro.Se. will validate the network.

Noise pollution is a growing concern. Some of the key messages of *Noise in Europe 2014 Report* highlights that environmental noise causes at least 10. 000 cases of premature death in Europe each year and almost 20 million adults are annoyed and a further 8 million suffer sleep disturbance due to environmental noise. Also, over 900.000 cases of hypertension are caused by environmental noise each year and noise causes 43.000 hospital admissions in Europe per year. The directive 2002/49/EC, related to the assessment and management of environmental noise[3] (Environmental Noise Directive – END) focuses on the assessment of people exposed to environmental noise, drafting strategic noise maps; on preventing and reducing environmental noise where necessary and preserving acoustic quality where it is good, drawing up action plans; on ensuring public information on environmental noise and its effects.

Regarding the noise assessment, there is the need to compare data of noise strategic maps, but the lack of a common assessment method causes significant inconsistencies in noise exposure data of different Member States and between the two implementation steps of the directive. European Commission has organized the Common Noise aSSessment methOdS project (CNOSSOS-EU), defining assessment methods for road, railway, aircraft and industrial noise, in order to allow the comparability of results across EU Member States. Application of the CNOSSOS methods will be

[3] http://ec.europa.eu/environment/noise/directive_en.htm

mandatory for 2022 reporting round. Noise is caused by a large amount of sources and there are many standardization methods able to assess noise impacts, shared at international level and applied in national legislations. International and national standards provide requirements, specifications, guidelines and technical reports, able to ensure reliability and quality of the results. Technical specifications of noise monitoring systems and the comparability of the results are current and interesting issues.

At EU level, FONOMOC[4], the FOcus group On NOise MOnitoring Cities, aims to exchange knowledge and experiences on noise monitoring in cities. It is a subgroup of Working Group Noise EUROCITIES, the network of major European cities. The Group works on identification of critical points in noise assessment activities and on developments and innovations of monitoring systems. Some topics discussed in meetings are related to systems for noise sources identification, real-time monitoring and mapping of environmental noise, noise sensor network, use of smartphones with annoyance applications, measurements by smartphones equipped with a low-cost MEMS (Micro Electro-Mechanical Systems) microphone.

The traditional method of environmental noise monitoring employs long and short measurements time periods, using expensive equipment for measurements and data management, while new noise monitoring methods, able to permit lower costs, long time measurements and quality output data, have been developed.

Recent developments of low-cost microphones and computing devices, together with the availability of web resources, give the opportunity to create noise measurement devices networks, defining a *“smart low-cost sound monitoring approach”*, which have been applied particularly in urban context, allowing, particularly at local scale, an acoustic characterization of urban areas.

Safeguarding the traditional standards of techniques and methods, mandatory by laws for noise monitoring activities, the smart monitoring systems, equipped with low-cost sensors, seem to be competitive, in some situations and under defined conditions.

Urban areas, as Noise LEZs, should be the correct scale for sensors networks applications and LIFE MONZA project, providing noise monitoring activities in pilot area conducting by traditional method and also by a prototype of smart low-cost monitoring system which will be developed, will give a contribute, analyzing the efficiency of the monitoring system and allowing data comparison.

This report focuses on analysis of smart low-cost noise monitoring systems experiences and procedures, carried out in Europe, in order to allow updated information for the definition of the operational context related the noise monitoring issue and also to give advices for the development of the prototype of monitoring system for Noise LEZ provided by Action B.3 of LIFE MONZA project. Data sheets containing the main information covered by the discussed topic are reported in the deliverable *Abacus on operational context on Noise Low Emission Zone.*

[4] https://workinggroupnoise.com/fonomoc/

2. Operational context: Standard Noise Monitoring Systems

This report focuses on analysis of smart low-cost noise monitoring systems experiences and procedures, but, firstly, a brief description of the main characteristics related to standard noise monitoring systems, is following described.
The need of measurements in the field of environmental noise has led to develop a technical standardization upon devices, usually employed in monitoring systems too, whose architecture depends on the kind of source under investigation as well as the measurement time requested. Generally, two types of noise monitoring are considered:

– Short-time measurements (spot), by means of sound level meters;
– Long-term monitoring, carried out with fixed station consisting of cabinet, power supply and sound level meter.

The microphone is the transducer that transforms the mechanical pressure into electrical signals. In the field of metrology, condenser microphones are commonly used: these devices are based on the voltage variation at the terminals of a capacitor having one of the two armatures fixed and the other is constituted by the microphone membrane itself, both provided with a certain amount of charge electricity. Being constant the charge, the variations of the distance between the plates due to the vibration of the membrane cause a variation in the electrical voltage across the capacitor. The so-called "*electret microphones*" is provided with a dielectric material keeping inside the electrical charge and therefore the microphone does not need to be powered.
The basic characteristics of a microphone are the following:

– sensitivity: electric voltage in mV generated by 1 Pa sound pressure level;
– dynamic: the difference between the maximum sound pressure level and equivalent level of background noise;
– sensitivity variation with frequency (bandwidth);
– sensitivity variation with the angle of incidence: there are microphones having a linear frequency response in free field conditions and others with the same characteristics for diffused field conditions.

The sound level meters allow processing the electric signals generated by the microphone, in order to obtain the numerical values of the typical descriptors used in the field of environmental noise. The sound level meters basically work as follows:

– frequency weighting
– calculation of the Root Mean Square (RMS) value;
– time weighting of the RMS value by means of one of the exponential time constant (i.e. Fast, Slow, Impulse)
– time averaged RMS value for the calculation of the equivalent sound pressure level Leq.

Nowadays, in the field of sound level meter specifications, the most technical important reference is given by standard IEC 61672 that provides tolerance limits for the frequency response of the devices, self-generated noise and linearity.
Two main classes of precision instruments, and related sets of specifications, are defined:

– Class I: maximum linearity error of ±1.1 dB for around 1 kHz and linear operating range shall be at least 60 dB and linear amplitude deviations shall not exceed ±0,6 dB.
– Class II: maximum linearity error of ±1.4 dB for around 1 kHz and linear operating range shall be at least 60 dB and linear amplitude deviations shall not exceed ±0,8 dB.

Class I (Precision) must be employed for accurate sound measurements in laboratory and in field, while Class II (General Purpose) could be used for general measurements in field.

3. Operational context: Smart Low-Cost Noise Monitoring Systems experiences and procedures

The increasing availability of low cost computing devices, microphones and wireless connectivity allows the capability to define a system able to detect, analyze and streaming noise data, giving the possibility to develop different kinds of systems, having smart and low-cost characteristics.
Smart low-cost noise monitoring systems allow a widespread and continuous noise monitoring, defining, in an adequate territorial scale, as urban areas, a network able to ensure a high quality output measurement data.
It is possible to classify the systems according to different characteristics, as network typology, data transmission procedures, microphones, etc. There are sensor networks microcontroller based, as many of the common noise monitoring systems complaint to Class I IEC 61672 standard and, also, there are networks embedded pc based, consisting of low cost mini pc, equipped with a sound board, with Wi-Fi capabilities (or GPRS/3G/4G), and a signal analysis software able to process data from the sound data, using low cost microphone, as MEMS.
Focusing on types of microphones and their development during the years, becoming high performing and available at low cost, it’s possible to consider the prepolarized condenser microphones (electret microphone), which have been developed since 1960’s, and MEMS (Micro Electro-Mechanical Systems) microphones, introduced at the beginning of the year 2000. Both are accessible as low-cost productions and they could be applied according to standard IEC 61672 requirements, in Class I or Class II, depending on devices’ technical specifications. There is still not a wide employment of MEMS in outdoor measurements, particularly for their lack of stability over the time, due to the deteriorative effects of weather conditions. There is a growing interest towards these kinds of devices, since MEMS performance seems to be competitive compared to microphones used in Class I instruments, under certain conditions, especially for very low noise levels. Sensors characterized by more and better features are continuously developing, whereas the old ones become obsolete in a very short period.
Experiences about smart low-cost noise monitoring systems, carried out in Europe, are following presented, focusing on procedures, technical characteristics, microphones specifications, pilot areas where the system has been implemented, noise indicators used and results.
A brief mention is dedicated to *participatory monitoring projects*, related to the collection and sharing of data, in order to allow the public participation and to increase the awareness about environmental issues.

3.1 DREAMSys

DREAMSys[5] (Distributed Remote Environmental Array & Monitoring System) is a project to develop a new environmental noise monitoring system and mapping using new kind of sensors. It is a project involving research and technology organizations, manufacturers and environmental noise experts, sponsored by the Technology Strategy Board, a business-led executive non-departmental public body, established by the British Government, in order to support research and technology innovation for UK economic growth and quality of life improvement. The system has been developed by an industrial group[6], led by NPL (National Physical Laboratory[7]).
In order to give a contribution to the implementation of Directive 2002/49/EC, particularly on noise mapping process, an array of low-cost environmental noise monitoring units, using wireless

[5] http://projects.npl.co.uk/dreamsys/
[6] QinetiQ Ltd, Hoare Lea Acoustics and Castle Group Ltd.
[7] http://www.npl.co.uk/

transmission of measured data has been developed and tested. Monitoring data can be used for noise mapping, using bespoke developed software. A key point of the process is the use of low cost MEMS microphones (Micro-Electro-Mechanical Systems), which allow a large number of monitoring stations working simultaneously. The considerable growth of portable electronic consumer products such as mobile phones and notebook computers has stimulated the development of MEMS microphones in the last years. The system may be used for strategic noise mapping, action planning, environmental and workplaces noise assessments, permitting a wide-scale distributed measurement. The project, started in 2007 and concluded in 2010, developed a system which has been tested in laboratory and in situ measurements.

DREAMSys project develops high performance microphones suitable to carry out precise noise measurement data in every weather conditions and powered by rechargeable battery packs in order to run for more than two weeks.

The specifications for MEMS microphones are shown in the following table, such as the minimum detectable sound pressure level, acoustic frequency range and dynamic range.

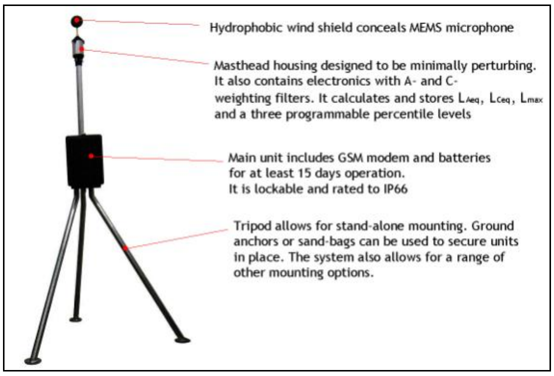
The most important targets are minimum detectable sound pressure levels, considering that 40 dB(A) level is seen as being workable and 20 dB(A) is considered the ideal value; the acoustic frequency range from 20Hz to 20kHz and the dynamic range of 70 dB. It is also considered ideal to have a temperature measurement of better than 1° C.

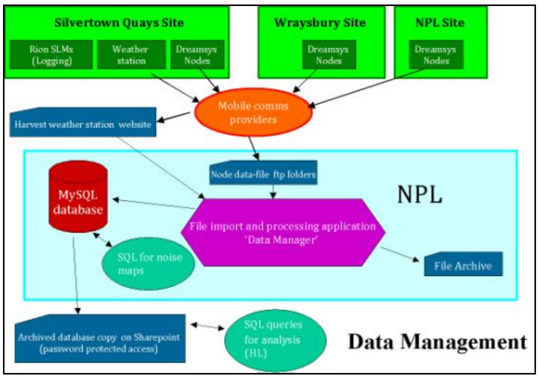
Table 1: MEMS microphones specifications for use in DREAMSys environmental noise measurement sensor nodes. Source [4]

MEMS microphones specification	
Acoustic dynamic range	70 dB
Minimum detectable sound pressure level	40 dB(A) could be workable 30 dB(A) would be useful 20 dB(A) would be ideal
Maximum detectable sound pressure level	110 dB(A)
Acoustic frequency range	20 Hz to 20 kHz
Mechanical membrane resonant frequency	> 30 kHz
On-chip temperature measurement accuracy	< 1 °C
Operating voltage	3.3 V
Operating current	few mA
Analogue voltage range	≈ 1 V
Size of PCB assembly	10mm < x < 10 mm
Shape of PCB	Optimized to avoid diffraction effects

The outputs of the project are the production of MEMS microphone with measurement grade specifications, suitable for outdoor use; the development of a large wireless sensor array (DREAMSys) and analysis software; the application of system in different locations and the development of best practice guidance.

The prototype and the architecture of the system are shown in the following figures.





Figures 1-2. On the left, prototype and on the right, the system architecture. Source: [5]

Characteristics about typical statistical distributions of the pressure response sensitivities of the 100 microphone samples have been analyzed, and also the effects of windshield, the effect of stem diameter, self noise and temperature have been tested.
At the aims to assess the distributed measurement approach, four test sites have been identified and DREAMSys method applied with the results following reported.
The site at NPL (National Physical Laboratory, Teddington, UK) was the first case study to evaluate the performance of the new equipment. Seven units have been deployed, investigating mounting configurations, calibration and monitoring of reliability. A comparison between industry standard equipment based on type 1 sound level meter and DREAMSys monitoring system has been also made. The following Figures 3-4 show two mounting options, deployed at NPL, on left, and Wraysbury Reservoir, on right.

Figures 3-4 – On the left, DREAMSys measurements instrument deployed at the NPL site and, on the right, measurements instruments mounting solutions at Wraysbury Reservoir. Source: [6]

The area is characterized by the presence of different kind of sources: part of the site is located close to a busy road, other are near a park and sports fields and it is in the take-off flight path of Heathrow airport. Another location is Wraysbury Reservoir (Staines, UK), characterized by noise features, a high degree of exposure to weather, presence of wildlife. The Figure 4 display a solution for the installations used. The site is close to Heathrow airport and a major motorway. The monitoring system considered 6 units deployed at Wraysbury for a period of 3 weeks in June 2009.
Distributed noise measurements at Festival Square in Edinburgh were also carried out to study the relationship between sound perception and the physical level of noise. The monitoring campaign considered some units integrated into the surroundings (e.g. mounted in bushes or attached to railings and other fixtures), while a small number of others mounted on tripods in open area. The

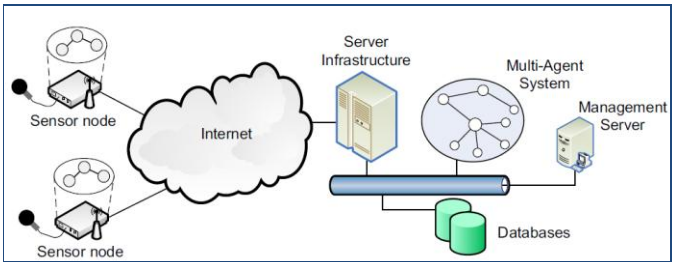
reasons for this choice were to cover the area of the square and also to test the people reaction to the equipment, that was generally positive.
Measurements were carried out over 3 consecutive days in October 2009, with the instrumentation being removed from the square overnight, consisting of 8 units, 6 around the boundaries and two in the square. The fourth area was Silvertown Quays, no public access area, located in the direct take-off path of London City airport and, despite this, the area is selected for residential development. It is also close to the Docklands Light Railway, a major road with the presence of commercial activities. Using the tripod arrangement, 39 units have been deployed at the area.
The noise indicators used by Dreamsys units are both A-weighted and C-weighted equivalent continuous sound pressure levels (L_{Aeq}; L_{Aeq}), over a pre-defined temporal period of 10 minutes as typical setting. Also, a number of statistical parameters, as the maximum A-weighted level and three percentile levels (L_{A10}; L_{A50}, L_{A90}). The typical measurement system is composed by 5 to 100 units. The output data of the monitoring campaigns carried out in the different sites have been used for noise maps of the areas and the results, for the Wraysbury Reservoir, are consistent with the predictions, ensuring an adequate long measurement period. Also considering Silvertown Quays area, despite the presence of different and important noise sources, data of units located near the aircraft flight path are consistent with predictions.
Further tests and measurements have been carried out during the project and, after this, the research on low cost noise monitoring network, based on MEMS applications, was continued, particularly by NPL, and mainly on the evaluation of the performance, on the assessment of stability and on the development of a self-calibrating microphone system.

3.2 Smart Monitoring networks - Ghent University

The research Group Waves[8] (wireless, acoustics, environment and expert systems) of Ghent University, is working on smart monitoring networks and its competences are focused on the following activities: application of models for machine listening and auditory cognition into smart sound meters and acoustic sensor networks; deployment of large-scale networks of sound monitoring stations in Ghent, Antwerp, Brussels, Rotterdam and Paris; mobile sound measurements combining GPS data allow to map larger areas with fine spatial resolution; development of dynamic noise mapping techniques. Many research projects have been undertaken and a spin-off company[9] for the development of smart sensor network solution has been created. Noise smart monitoring systems are employed for noise measurements, allowing the calculation of the main noise parameters, for soundscape analysis, for sound recognition, for source localization, for noise mapping, in fixed and also dynamic configuration.
A smart sound monitoring project has been carried out in the Rotterdam harbor zone, in 2013, focused on sound events detection and characterization. A measurement campaign using 12 noise smart measurement devices has been started, jointly with an online survey on sound events and sleep quality. Low-cost computing devices and microphones, jointly with wireless transmission, allow the possibility to use a large number of monitoring stations to be deployed in urban area, defining a well structured and dense network, able to give more details about the noise sources and events. Also, the acoustic characterization of the local area allows a more effective identification of the noise policy to be undertaken. The project carried out in Rotterdam aims to study an effective combination of objective measures and subjective perception, expressed by people in an online survey, in order to detect sound events and to estimate the impact on well-being and health. The area, 1,18 km^{2,} is located in Rotterdam harbor zone, with about 4.500 inhabitants. Focused on monitoring approach adopted, it was based on 12 cost-effective sensor nodes, placed on the façades

[8] http://www.wica.intec.ugent.be/
[9] http://asasense.com/

of the buildings on voluntary basis. Sensor nodes are composed of a single board computer, equipped with a CF card, a sound card, an ethernet card and a microphone, inside a weatherproof box. Sensor nodes could be adopted and used by inhabitants of the area. The sensor nodes are *plug-and-measure*, that is the device is directly connected to the internet and the sensor has no buttons nor display (Figure 5). If plugged in, the sensors nose start and continue to measure 1/3 octave band levels, with a temporal resolution of 125 ms. The levels were sent to the server infrastructure, in Ghent, to be processed. Sensors have also the possibility to record and transmit short audio contributions and to save data internally. Data were processed and managed and the results stored in a warehouse database (Figure 6).



Figures 5-6. On the left, a sensor node, placed on a windowsill of a building and, on the right, the scheme of the smart sound monitoring sensor network architecture. Source: [10]

The acoustic parameters, calculated on a 15 minutes basis are $L_{Aeq,15\ minutes}$ and the standard deviation of the level, percentile levels (L_{A90}, L_{A50}, L_{A10}, L_{A01}), the number of sound events, indicators for the temporal structure of the sound, psychoacoustic indicators (loudness, sharpness), spectral indicators as the centre of gravity of the average 15-minute spectrum, the presence of tonal components and aggregate indicators. Sound recognition process is also developed and tested. The indicators M_{60} and M_{70} count the number of times that the A-weighted instantaneous sound level exceeds the threshold values of, respectively, 60 dB(A) and 70 dB(A), whereas the indicator N_{cn} counts the number of times that the A-weighted instantaneous sound level exceeds L_{A50} with at least 3 dB for at least, 3 seconds, in order to detect sound events from background level.
The long-term distributed approach, using 12 sensor nodes, allows analyzing the area, continuously and in real time conditions, giving the opportunity to investigate in detail the acoustic characterization of the area. In Table 2 the sensors nodes technical specifications[10] are summarized. The research group has also developed an approach for dynamic noise mapping relies on a sound source emission and propagation model. A method for calculating dynamic noise maps using fixed and mobile sound measurements has been developed and tested. The increasing availability of low-cost devices has led to the use of distributed sound measurement networks that can be applied to create dynamic real-time noise mapping, in order to validate the accuracy of traditional monitoring systems. Moreover, acoustic sensors networks allow to improve the spatial and temporal accuracy of the calculations. Both fixed and mobile sound measurements extend the spatial resolution of noise mapping, as mobile ones allow to complete the study area allowing a better characterization of the spatial distribution of the sound sources.

[10] B. De Coensel, D. Botteldooren. Smart sound monitoring for sound event detection and characterization. In Proceedings of the 43rd International Congress and Exposition on Noise Control Engineering (Inter-Noise), Melbourne, Australia (2014).

Table 2: Sensors nodes technical specifications. Based on information available on [10]

Sensors nodes technical specifications	
Short /long term noise measurement	long term noise measurement
Embedded pc monitoring system /Units with microcontroller and digital signal processor	embedded pc monitoring system
Temporal resolution	125 ms
Acoustic indicators	$L_{Aeq,15\ minutes;}$ L_{A90}, L_{A50}, L_{A10}, $L_{A01;}$ the number of sound events (M_{60}, M_{70}, $N_{cn)}$ indicators for the temporal structure of the sound, psychoacoustic indicators (loudness, sharpness), spectral indicators as the centre of gravity of the average 15-minute spectrum, the presence of tonal components and aggregate indicators.
Spectral data	1/3 octave
Others	
Weatherproof	weatherproof box
Connectivity	connected to internet - *plug-and-measure* approach
Possibility of audio recording	fragments of audio recording
Pilot area of implementation	
Urban/suburban	urban
Territorial scales	1,18 km^2
Number of sensor nodes	12

3.3 SENSEable Pisa

In order to promote citizens' participation in noise policy as requested in European directive 2002/49/EC, in the city of Pisa an experimental monitoring system for noise mapping was created, called SENSEable Pisa. It has been launched by a non-profit organization called *DustLab*.
The pilot project aims at developing a sensor network prototype in Pisa, based on *Real Time City* concept, for the collection and analysis of data to be used in urban planning processes.
SENSEable Pisa started in January 2011 and the system uses low cost wireless prototype noise sensors, based on a reuse of electronics of the old personal computers installed in the house of citizens (Figure 7), with the aim of sharing noise measures in a virtual community.


Figures 7-8. On the left, Zigbee transmitter with a solar panel and a microphone installed on a balcony (2011). Source: [12]; On the right, microphone of a monitoring station for anthropic noise assessment. Source: [14]

Noise levels measured in building facade are shown in real time in the website[11] of the project and also on Facebook and Twitter social networks to inform participants and the followers of the project, whilst all historical noise data are collected in a central remote server.
Eight sensors were installed at houses of volunteer citizens to register noise in different areas of Pisa and send the data to the central server. A first new aspect of the project has consisted of an application of a sensor network technology in order to provide reliable low cost measurements in real time, with high spatial sampling and without any need for wiring. So the resulting monitoring system has got superior characteristics in comparison with conventional monitoring stations.
It is possible to install more sensors for the detection of physical agents on the same transmission platform and also detect data regarding different pollutants. The system structured in this way allows to:

- verify noise emissions from temporary events (project sites, shows, etc.);
- evaluate the long-term effects related to the adoption of new noise reduction technologies (electric cars, sound-absorbing asphalt and facades, etc.);
- real time monitoring of sensitive receptors (schools, hospitals);
- timely act on noise issues from the competent authorities.

Moreover the system allows to involve citizens both using social networks, as a tool for dissemination of the project, and gathering feedback and comments on critical issues relating to noise in the city even for the positioning of the of wireless detection station. This design method, called *crowdsourcing*, could give a contribution to the implementation of the Directive 2002/49/EC, related to the assessment and management of environmental noise, about the requirement concerning the participation and the involvement of citizens to the noise action plan process.
Currently, about the technical characteristics, the devices are based on micro controller technology and the data recorded are sent by wireless transmission system (“ZigBee” transmission protocol) to a remote server and collected into a database.
The sound is measured by ¼-inch low cost microphones, with a waterproof cover and connected to a preamplifier circuit with analog filter bank.
The system has a dynamic range of 70 dB (A); the resulting measurement range has been used to work in an optimized manner between 30 dB (A) and 100 dB (A).
The system acquires the sound levels in dB(A) on a time basis of one second. The monthly average Leq levels were calculated and data due to the occasional sound events, rain and wind are removed. Weather information was acquired by a weather station, based on five minutes periods. Sensors nodes characteristics are reported in Table 3.
Mean noise values respectively of L_{den} and L_{night} indicators related to the months of June and July and at the previously identified locations are reported in Table 4. The values were compared with those of strategic mapping of Pisa.

Table 3: Sensors nodes characteristics. Based on information available on Source: [12]

Sensors nodes characteristics	
Dynamic range	70 dB (A)
Time basis acquisition	1 sec
Microphone	¼-inch low cost microphones
Wireless transmission system	“ZigBee” transmission protocol
Digital filters	Low-high-band pass, A-ponderation
Event detection	Yes
Indicators (equivalent level)	LAeq. Lden, Lnight
Others:	waterproof cover weather data based on five minutes periods

[11] http://www.senseable.it/

The table 4 shows how the data from SENSEable Pisa (columns "*Sense*") are fully comparable with data of the strategic noise mapping of the city published on the website of SIRA (columns *"Sira"*), the regional institutional information platform of noise mapping data. The differences are due to the morphology or to anthropic noise of the urban areas.

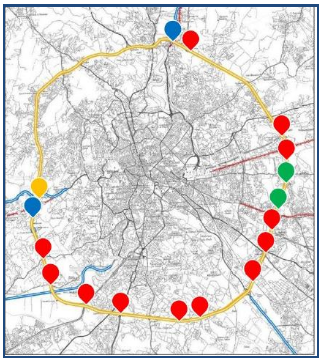
Table 4. SENSEable Pisa output data. Day and Night mean noise levels for the first five sensors during the months of June and July 2011 and comparison with data of the strategic noise mapping of the city published on the website of SIRA. Source: [12]

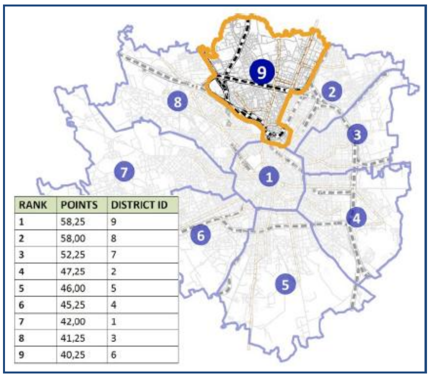
Sensor	*Lden Sense*	*Lden Sira*	*Lnight Sense*	*Lnight Sira*
1	70.2	70.1	62.2	61.3
2	64.8	66.1	56.6	56.1
3	65.6	65.9	57.7	56.1
4	68.8	65.8	60.8	56.8
5	79.7	60.5	74.1	51.0

SENSEable Pisa is a tool complying with the Environmental Noise Directive 2002/49/EC requirements, allowing data acquisition in real time and high spatial resolution, and providing public involvement.
Subsequently, the SENSEable network has been applied in a study on evaluation of anthropic noise effects on health citizens, in historical entre of Pisa. Homogeneous acoustic urban areas have been identified and six stations have been located in citizens' buildings.

3.4 LIFE DYNAMAP project

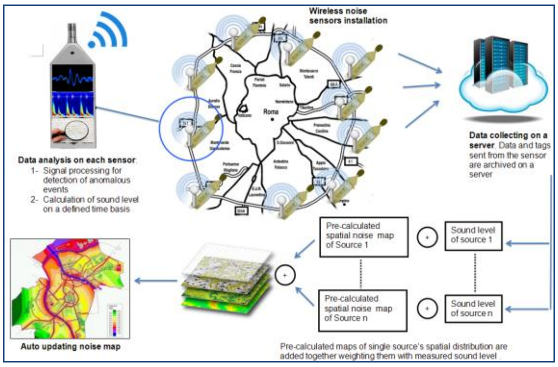
DYNAMAP (*Developing of low cost sensors networks for real time noise mapping*) is a LIFE+ project aimed at developing a dynamic noise map able to represent in real time the noise impact of road infrastructure. The main objective is to facilitate and reduce the cost of the updates of noise maps, as required by the European Directive 2002/49/EC. In order to achieve this purpose, an automatic monitoring system, based on high-quality and low-cost sensors and a software tool implemented on a general purpose GIS platform, will be developed and applied in two pilot areas located at the large ring road of Rome and in the agglomeration of Milan. The project is started in 2014 and it will be concluded in 2019.
Further objectives of the project are related to the demonstration that the dynamic mapping process is able to ensure a significant reduction in the resources needed to update noise maps, in time, costs and dedicated personnel; to the improvement of public information, providing different system access levels and also to the availability to provide additional information about meteorological conditions and other environmental topics, as air quality.
DYNAMAP system will be tested in two pilot areas, as examples of zones belonging to an agglomeration and to a major road infrastructure, as defined by END. The first pilot area is a significant part of the city of Milan, located in North of Italy, including many complex urban scenarios, and the second pilot area (Figures 9,10) is located in Rome, along the ring road A90, a major road surrounding the roman agglomeration.





Figures 9-10. On the left, pilot area in Rome, along the ring road A90 and critical areas highlighted in different colors. On the right, pilot area in Milan and outcomes of the selection process.
Source: [15]

The system will be composed by low-cost sensors measuring the sound pressure levels emitted by the noise sources and of a software tool based on a GIS platform for real-time noise maps updating. A method for the identification of anomalous noise other than traffic noise (ANED) will be also developed.
The functional scheme (Figure 11) consists of monitoring stations detecting the noise levels and hosting the ANED algorithm, able to remove anomalous events. The stations will provide a classified output with a time frequency of one second. Data will be sent to a central server, using wireless data communication as GPRS or 3G, to be analyzed, processed and used for noise maps.



Figures 11-12. On the left, Functional scheme of DYNAMAP system. On the right, a low cost measuring device used for noise monitoring campaign. Source: [15]

Environmental noise monitoring campaigns have been conducted in May 2015 in pilot areas, implementing two demonstrative versions of systems, in order to acquire representative data about traffic conditions and to test ANED algorithm. The measures have been carried out using a low cost sensor developed by Bluewave (Figure 12) and a standard Class I sound level meter (Bruel & Kjaer 2250), with the intention of validating the output data of low cost sensor.
The prototype of the sensors network uses embedded computers, allowing remote access for running proper audio processing scripts and also, they permit to process data on sensor board, using the ANED algorithm, sending to the central server selected in advance and most accurate information.
A set of basic specification for monitoring station has been defined and reported in Table 5. Noise monitoring stations will be subjected to a periodic calibration, analyzing the changes of frequency

response during the years. It is also provided to periodically store the minimum narrow band spectrum, referred to day period, in order to assess the values, and their changes in time, of the electrical noise level of the measuring chain.

Table 5. Set of basic specifications for monitoring stations. Sources: [15-18-19]

Basic specifications for monitoring stations	
Broadband linearity range	40-100 dB(A)
Working range	35-115 dB
Noise indicator	Leq(A), 1 second time base
Others	Possibility of audio recording
	Internal circular backup data storage of calculated data
	VPN connection
	GPRS/3G/WiFi connection

Focusing on the low-cost sensors, an evaluation of low-cost microphones performances over time has been developed within the frame of the project, in order to detect markers able to indicate the measuring chain specifications which don’t comply with the standard IEC 61672. The purpose was to analyze the changes that took place following exposure to physical and chemical agents that may be encountered in urban and suburban conditions. The test has been carried out measuring electrical floor noise distribution and frequency response in different hard stress conditions, inside a salt spray chamber, using a set of four Knowles MEMS and four Panasonic electret microphones.
The results show that MEMS microphones have a better stability to salt spray. After the artificial aging process, MEMS frequency response does not present relevant changes. Only a microphone presents 0.3 of difference in high frequency range. The electret microphones presents offsets belonging to 0.25 dB (for low-frequency region) - 0.75 dB (for most of the spectrum) range.

3.5 Barcelona Noise Monitoring Network

Over the past few years Barcelona has been working hard to be one of the smartest cities in the world and is promoting the use of innovative solutions to manage its services and resources to improve its citizens’ quality of life.
The municipality started to build up a noise monitoring network of Class I sound level meters in 2006 and, in order to increase the number of measuring points, in 2012 started to use noise sensors.
One of the Smart City projects is the strategic deployment of *Sentilo*, a sensor data management and a platform that allows the city to become smart, efficient and to improve the environmental sustainability. *Sentilo* system is designed to create a link among sensors, actuators and the applications to manage urban services. Barcelona Noise Monitoring network is made up of a main network of class I sound level meters and a complementary sound sensors network. The network (Figure 13) is structured into two independent networks that communicate in different level: main and complementary noise control networks. The main difference between them is the quality of the measures in terms of characteristics and costs and the final uses are also different.

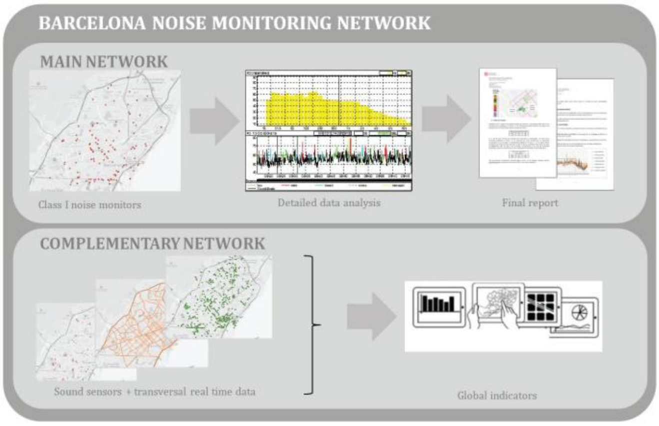


Figure 13. Noise monitoring network basic structure. Source: [22]

The main network consists of Class I 25 noise monitors, in fixed and mobile measuring points, and will have 31 in the future. The main objectives of the network are to estimate noise levels in critical areas, to evaluate the noise reduction due to the implementation of noise action plans, to update the noise map and to identify noise sources. The noise monitors technical characteristics are reported in the following Table 6.

Table 6. Main network: Class I noise instruments technical characteristics. Source: [22]

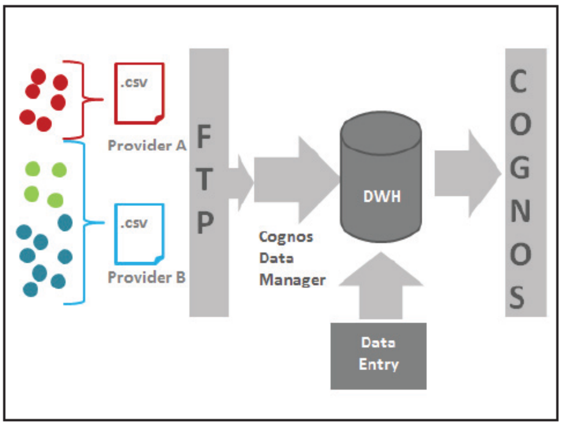
Class I noise instruments technical characteristics	
Type approval	CEI-61672 Class I certification
Integration time	1 second
Acoustic indicators	LAeq; LCeq; LZeq; LAIeq; LAFMAX; 1/3 octave spectrum; 10 Hz – 20kHz
Tolerance	CEI-61672 Class I
Measure range	23-137 dB(A)
Calibration and verification	Verification of the calibration of the sensor must be able to be undertaken in situ using an acoustic calibrator which fulfills the requisites established under IEC 60942
Others	Weatherproof 19h battery (charging time:5 h) 3G connectivity Audio recording

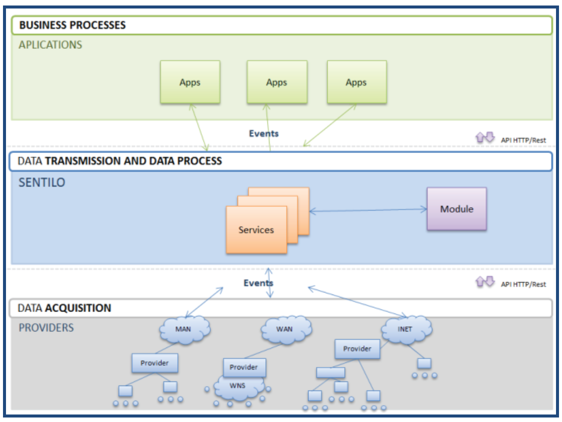
The development of the complementary sound sensor network started in 2012. Sound sensors were installed in two construction work areas and the quality of the measures of two kinds of low- cost sensors was tested, with not positive results. In 2014 the Noise Control Department defined the minimum technical specifications of the sound sensors (Table 7) and a control system able to validate the quality of the sound measurements before the installation of the sensors in urban areas has been carried out.

Table 7. Minimum sound sensors technical characteristic. Sources: [22]

Minimum characteristics of sound sensors	
Type approval	-
Integration time	1-15 minutes
Acoustic indicators	LAeq
Tolerance	LAeq ±2 dB(A)
Measure range	40-100 dB(A)
Calibration and verification	Verification of the calibration of the sensor must be able to be undertaken in situ using an acoustic calibrator which fulfills the requisites established under IEC 60942
Others	Weatherproof LAN/3G connectivity

The aim of this low-cost monitoring network, initially formed by 11 sensors and integrated in *Sentilo* platform, is to increase the number of measuring points in order to take over the environmental noise changes.
Concerning the data transmission, two different protocols, one for the main Class I sound level meters network and the other for the low-cost complementary network, have been designed.
About the main network, in order to unify the data management as well send information, all the providers uses the same template file (.csv) created by the Noise Department of the Barcelona City Council. The data have been stored, on a daily basis, in an FTP server and are loaded in the COGNOS system (Figure 14). The user can input extra-data to the system by the Data Entry platform.





Figures 14-15. On the left, noise monitors data transmission for the main network. On the right, *Sentilo* structure. Source: [22]

The complementary sound-sensors network is a part of the City Sensors Network which uses *Sentilo* as the platform able to link sensors and actuators and to manage urban application and services (Figure 15). *Sentilo* is a tool designed for cities that want to control the deployment of sensors and actuators in a centralized and common way. The platform is open source and has no licensing costs.
Barcelona, in order to manage noise issues, uses two different reporting interfaces: IBM *Cognos Query Studio*, used to make a detailed data analysis, and a corporative platform called *Situation*

Room, used to obtain an overall view of the city status in real time (Figure 16) as well as to integrate and share information about the city and its services.

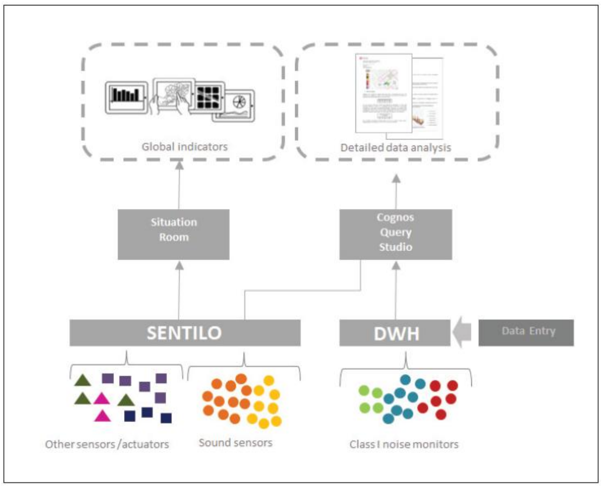


Figure 16. Management and reporting interface. Source: [22]

Cognos Query Studio allows the analysis of data coming from both noise monitoring networks, the main with Class I monitors and the complementary with sound sensors. The *Situation Room* platform permits only the management data of the sound sensors, but it also consents to link these data with information from other sources, allowing real time recognition.

3.7 Low-cost noise monitoring system based on smartphone devices - Regional Environmental Agency of Piedmont.

Many studies regard the use of smartphone, equipped with adequate instruments, as noise measurements tools, and there many mobile applications able to allow noise measurements through smartphones. The results of the comparison between smartphone sound measurement applications and Class I sound level meters have been detected by different tests, using various types of devices and analyzing the accuracy of output data. Many studies suggest that the use of certain application could be suitable and appropriate for noise measurements. Following the experiences carried out by the Regional Environmental Agency of Piedmont about these issues are reported.

The Regional Environmental Agency of Piedmont, in order to study the accuracy of environmental noise measurements using smartphone and to investigate the possibility of using low-cost devices, has carried out two different types of tests, comparing output data of five different smartphones (Android and iOS) and a Class I sound level meter, in an anechoic room, and carrying out, for more than three months, a long term environmental noise monitoring, using a smarthphone and a Class I sound level meter.

Then, a prototypal low-cost noise monitoring system based on smartphone devices has been developed and applied, in collaboration with the Municipality of Turin, in San Salvario area, in order to assess noise level caused by *movida* phenomenon.

Considering the tests, the first one has been carried out in an anechoic room, comparing output data of different five smartphones[12] and apps, relative to the response to white noise at different sound pressure levels. The noise meters developed based on Android are provided with the free application *Noise Meter*[13] available on Google Play.

[12] Samsung @chat GT-B5330 (Android v.4.0.4); Samsung Advance GT-I9070P (Android v.2.3.6); HTC Desire 601 (Android v.4.4.2); iPhone 4S (iOS v.8.0.2); iPhone 5S (iOS v.8.1.3

[13] Version 2.8.1

The technical characteristics are listed as following:

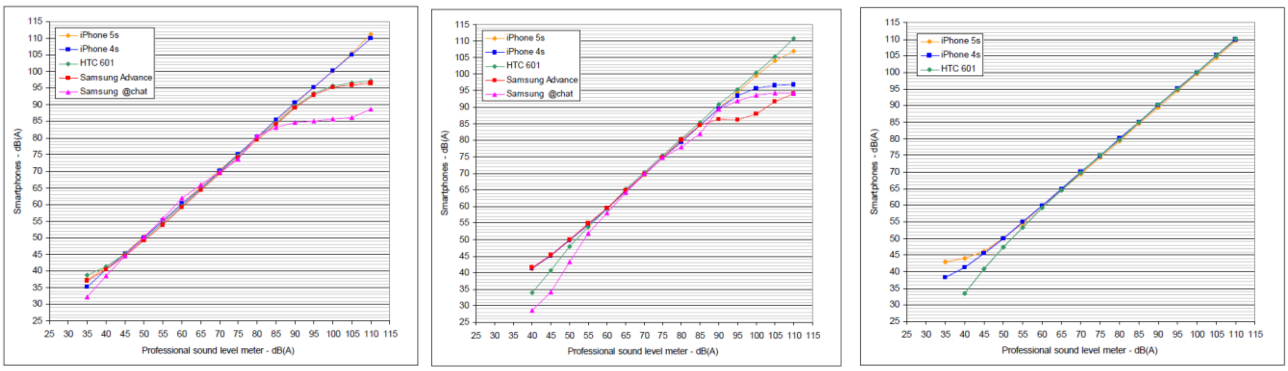
- sampling frequency adjustable: 8000, 11025, 22050, 44100, 48000 Hz;
- 1 dB steps gain, in the range -40 - +40 dB;
- integration period from 1 sec to 10 minutes;
- events detection;
- digital filters: low-high-band pass, A-ponderation;
- data capture: peak, minimum, maximum, arithmetic average, energetic average (equivalent level).

Data can be saved in a text file and the frequency spectrum cannot be developed. The on-sale app *Noise Immission Analyzer* for iOS[14] was used, but currently, it is no more available. It is not possible to save noise data in a text file nor to measure frequency levels.

The characteristics[15] are listed as following:

- sampling frequency: 44100 Hz;
- calibration with a known signal;
- digital filters: A-B-C-linear ponderation, fast, slow;
- data capture: minimum, maximum, energetic average (equivalent level);
- audio file record up to 20 seconds.

The laboratory test was conducted comparing the response to white noise, at different values of SPL, by the smartphones and a Class 1 sound level meter and using different microphones, the internal microphone of the smartphones, the original headphone microphones and a MicW microphone, plugged into the smartphones. In Figure 17 the results obtained using the internal microphone of the smartphones[16]. The results show equal responses of data coming from the five different smartphones, in the range 45-80 dB(A), with differences of 2-3 dB. The iOS phones result is under 1 dB difference up to 110 dB(A). Figure 18 shows the results using the original headphone microphones[17]. In the range 60-80 dB(A) the responses are quite equal for all the devices, and in the 40-85 range there is a deviation of 2-3 dB) for the iOS and the Samsung Advance. In Figure 19 the results using a MicW microphone[18], plugged into the smartphones. The iOS show good results, compared to the output data using professional Class I sound level meter, in the range 40-110 dB(A), while HTC phone for the range 55-110 dB(A)[19].



Figures 17-18-19. On the left, comparison results, using the internal microphone of smartphones; the central figure shows the results using the original headphones of the smartphones. On the right, comparison using the MicW microphone plugged into the smartphones. Source: [23]

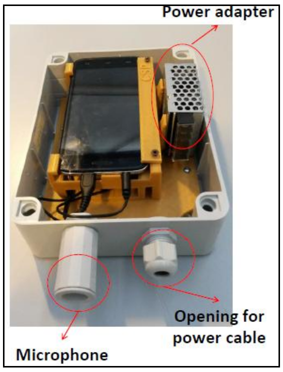
[14] developed by WaveScape Technologies GmbH (http://www.wavescape-technologies.com/)
[15] Version 2.0.1
[16] The phones were calibrated at 70 dB(A); the gain of the Android devices was set at 10 dB for the HTC, 9 dB for the Samsung Advance and 6 dB for the Samsung @chat.
[17] The gain of the Android phones was set at 47 dB for the HTC, 14 dB for the Samsung Advance and 15 dB for the Samsung @chat.
[18] i436 Omni Mic model (http://www.mic-w.com/)
[19] The gain of the HTC was set at 45,5 dB. The test was not made for the Samsung phones.

An additional test for the evaluation of the frequency response, using Samsung Advance smartphone and measuring pure tones, in the range 50-10.000 Hz and with variable intensity, in comparison with a Class 1 sound level meter, has been carried on. The obtained data comparing the global equivalent noise levels, because *Noise Meter* does not allow the frequency spectrum, highlight good responses in the frequency range 160-5000 Hz, up to 80 dB(A) level.
The second test, regarding road traffic monitoring, has been carried out for 100 days, using a Samsung Advance smartphone, with headphone microphone and a Class 1 sound level meter. The standard deviation of the differences between the two instruments is always smaller than 1 dB.
In Table 8 the values of the average, the minimum, the maximum and the standard deviation of the differences, are shown. Data are based on 5-minute LAeq series, calculated for the monitoring period of 104 days.

Table 8. Statistic analysis of the difference between the two measurements (5-minute LAeq for 104 days). Source: [23]

Reference Time	**LAeq Class 1sound level meter – LAeq smartphone dB(A)**		
	Day	Evening	Night
Minimum	-3.3	-1.9	-1.6
Average	-0.5	0.3	-0.1
Maximum	1.6	2.5	1.3
Standard deviation	0.8	0.7	0.5

The laboratory tests show good linearity for all smartphones in the range 45-80 dB(A); the long term measurement gave also good outcomes, with a standard deviation between levels measured less than 1 dB.
Based on these results, further experiences have been carried out, concerning a self-built low cost noise level meter, using digital MEMS microphones, and a self-built app for Android. The free and open application OpeNoise Meter, in Android environment, able to be used with smartphone and a low-cost noise device, has been developed[20]. OpeNoise Meter, free available on Google Play, allows a real-time A weighted sound pressure level; minimum and maximum levels; third octave and FFT analysis; log file storage; sampling time setting; gain setting. Further laboratory tests have been conducted and the results confirm the good linearity for all smartphones in the range 45-80 dB(A), extended to 35-105 dB(A) for some devices; the linear frequency response for all smartphones is 200 Hz-5kHz (45-80 dB(A)), extended to 100-8000 Hz for some devices.



Figures 20-21. Hardware set-up for outdoor noise measurements, using smartphones. Source: [24]

[20] Team composed by ARPA, Politecnico di Torino and Istituto Superiore Mario Boella.

A hardware set-up has been developed, for outdoor noise measurements and test to be conducted in situ (Figures 20-21). Six real-time noise level meter stations have been installed in the area of the San Salvario in Turin, in order to send real time data to the regional platform Smartdatanet[21], developing a smart low cost noise monitoring network.

3.8 Progetti di monitoraggio partecipativi

This report is focused on update of smart low-cost noise monitoring systems experiences and procedures but a brief note has to be dedicated to the participatory monitoring projects. *Participatory monitoring* (or participatory sensing) means the collection and public sharing of data, usually about environmental themes, aimed at creating people involvement, in order to raise awareness of environmental issues. It belongs to the *citizens' science* topic and the involvement of local communities in environmental monitoring activities is often a part of the management of local processes and action plans. Many projects on participatory monitoring have been carried out and following, some important experiences, relevant for themes treated in this document, are briefly described.

3.8.1 Smart citizens project

The Smart Citizens project[22], developed by Fab Lab Barcelona at the Institute for Advanced Architecture of Catalonia, is a platform aimed to generate participatory processes of people in urban areas. This platform connects people with their environment and their city to create more effective and optimized relationships between resources, technology, communities, services and events in the urban environment. This purpose is achieved connecting data, people and know-how, based on geolocation, the Internet and free hardware and software for data collection and sharing.
In particular, the Smart Citizen Kit is a piece of hardware comprised of a sensor and a data-processing board, a battery and an enclosure. The first board carries sensors that measure air composition (CO and NO2), temperature, humidity, light intensity and sound levels. Once it is set up, the device will stream data measured by the sensors over Wi-Fi using the FCC-certified, wireless module on the data-processing board. The device's low power consumption allows for placing it on balconies and windowsills. Power to the device can be provided by a solar panel and/or battery. The Kit is compatible with Arduino and all the design files are open-source (schematics and firmware).

3.8.2 NoiseWatch

The European Environment Agency (EEA) maintains the official data base[23] related to strategic noise maps delivered in accordance with European Directive 2002/49/EC (Environmental Noise Directive END), related to the assessment and management of environmental noise.
Additionally to this information, in the past few years, the need to make available most recent data about environmental noise, having different characteristics compared to official institutional data collected in accordance with END, has been highlighted.
To this purpose, NoiseWatch[24] Service, has started to be implemented by EEA in 2011, making available both noise information from official scientific sources, as measurement networks of European cities, and crowdsourced observations from citizens.

[21] www.smartdatanet.it
[22] https://smartcitizen.me/
[23] NOISE - Noise Observation and Information Service for Europe- http://noise.eionet.europa.eu/
[24] http://discomap.eea.europa.eu/map/NoiseWatch/

The service, currently not updated, allowed people to submit observations on sound environment and rate the acoustic quality of the area and also to use mobile device application for iPhone and Android for mobile measurements, converted to a rating.
The service was structured in different map layers, related to the various use and different kind of information: *Citizen observations*, containing ratings by users either via web app or mobile device app and *Citizen rating aggregation*, including aggregation of users' observations; *Near real time noise measures*, including unofficial near real time data from permanent official noise monitoring stations located in Dublin; *Noise agglomeration* - modeled data, yearly updated, for a number of European cities, concerning transport infrastructures and industries.
NoiseWatch is an example of citizen-based information, useful for people involvement, for raising noise awareness, for availability of output data coming from different sources and users and adopting different protocols and procedures. One of the key output of the project is that, comparing ratings with END official data, the road traffic noise emerges as the most important noise source for both the data bases, whereas industrial noise, the source with least people exposure based on END data, results, based on ratings, the second important source after road transport[25].

3.8.3 Noisetube

NoiseTube[26] is a research project, aims at proposing a participative approach for monitoring noise. It started in 2008 at the Sony Computer Science Lab in Paris and it is currently maintained by the Software Languages Lab at the Vrije Universiteit Brussel. The system allows the download of applications for mobile phones (iOS, Android, Java ME), able to turn phones into noise measurements instruments. Collected data could be uploaded to a server and shared, creating noise maps. NoiseTube software allows the A-weighted equivalent sound levels per second, for defined time intervals and, in order to ensure the accuracy of data, a calibration procedure must be implemented, according to sound pressure and frequency, for each smartphone model. The accuracy and precision, in different parts of the process, are continuously maintained and improved. The calibration process, for different mobile phones, is ensured, as the spatio-temporal density in noise maps drafting. Accuracy and comparison of noise maps based on participatory sensing data and official one are analyzed and many experiments have been carried out. An evaluation tool is also provided and NoiseTube can collect citizens' perceptions on sound environment through a questionnaire. A privacy-preserving system for participatory sensing, based on cryptographic techniques and distributed computations in the cloud, able to ensure security both to users and data management providers, has also been validate in the context of NoiseTube.

3.8.4 CITI-SENSE

CITI-SENSE is a project co-funded by the European Union's Seventh Framework Programme for research, technological development and demonstration, started in 2012. The main aim of the project is to develop "*citizens' observatories*", in order to improve people involvement in environmental processes, developing sensor based Citizens' Observatory Community, for improving quality of life in the cities. The three pillars of the project are: technological platforms for distributed monitoring, information and communication technologies and people involvement. Three pilot case studies concerns the environmental issues related to combined environmental exposure and health associated with air quality, to noise and development of public spaces and to indoor air at schools. The projects in pilot areas have been designed in collaboration with citizens' groups and decisions have been based on data collected by people, using low-cost reliable

[25] EEA- Noise in Europa 2014
[26] http://www.noisetube.net/index.html#&panel1-1

microsensor packs. Citizens involved used a toolkit to collect objective information about some environmental conditions of the analyzed area and, and also they gave their personal perceptions. The toolkit is composed by smartphone (apps and camera), microphone, windscreen and equipment to measure thermal conditions. Thermal comfort, acoustic comfort, urban landscape, general satisfaction and perceived health and emotions have been measured and/or evaluated, considering objective and subjective information. The toolkit (Figure 22), composed by tools for subjective and objective monitoring of environmental quality, consists of a Kestrel 4000 Pocket Weather Meter, a Sensor Data Storage, a Sense-It-Now app and a dedicated noise sensor and CityNoise app. Focus on noise, CityNoise is the application for android smartphone, able to provide sound pressure levels and detects sound events.

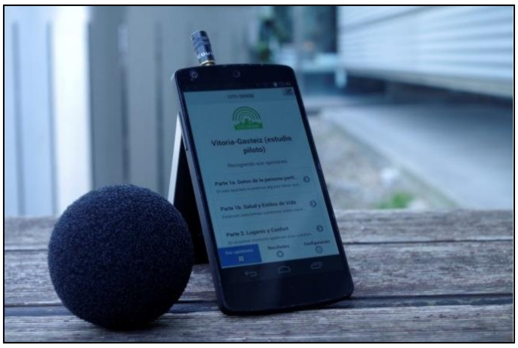


Figure 22. Toolkit for environmental measurements. Source: [27]

A measurement protocol has been developed, defining the exact time to be dedicated to observe, measure, comment and take photos. A monitoring session takes time of about 15 minutes, measuring noise levels, wind speed, humidity and temperature, giving meantime a perception of the place and, at the end of the session, taking photos.
For downloading the collected data, the SensApp web services can be used and data are available at the web page: http://vitoria.citi-sense.eu/en-gb/citisense.aspx

4. Prevalent requirements, advantages and limitations of smart low-cost noise monitoring networks

The analyzed projects highlight strengthens and weaknesses of smart low-cost noise monitoring adoption. The availability and the continuous development of smart low cost computing devices, microphones and connectivity opportunities give the chance to create and use noise monitoring sensors, able to be employed for widespread and long-term noise assessment activities.
Compared to standard noise monitoring networks, adopting Class I sound level meters, the lower costs of the instruments are evident, even if the installation, maintenance and quality control costs are important items of the total budget, due to the long term period of measurement and, particularly, to the lack of reliability and stability of the measuring devices. The relative low cost, the possibility to build the sensors, assembling the different parts, with low manufacturing cost, the small size of the elements and the opportunity of long-term and extensive measurement employment are the main advantages of smart typologies of devices. Long-term stability, defined by difference between the measured values obtained at the beginning and at the end of a defined measurement period, mainly due to the effect of prolonged outdoor exposure, is the most disadvantage of the smart sensors. Research activity is particularly focused on MEMS (Micro-Electro-Mechanical-Systems) microphones, which become competitive compared to standard measurement equipment, and on development of techniques able to improve their quality. Many

methods have been developed related to the anomaly events detection and to self-calibration techniques. Noise monitoring sensors need to be periodically recalibrated, requiring maintenance visits and, in order to avoid measurement data inaccuracy due to deviations from the calibration value, self-calibration methods have been developed. A method related to a statistical technique based on linear regression has been built up by the National Physical Laboratory (NPL), which also tests a macro sized MEMS microphone cluster prototype, able to be used for assessing autonomous calibration algorithms. This statistical method for the assessment of stability in noise monitoring networks is a variation of the Chow test. It is based on the linearity and time invariance properties that characterize any part of measurement equipment and it has been applied between monitoring sensors located in different areas, particularly it was tested using data set of SenseAble Pisa project, resulting a very useful tool. The main common characteristics arising from analyzed projects are reported in Table 9. The results show that it is possible to find a satisfactory frequency response in the range from 20 Hz to 20 kHz and floor noise value of 30-35 dB(A). The low-cost sensors show very frequently their congruence with Class II requirements, according to IEC 61672-1 standard.

Table 9. Smart low cost noise monitoring systems - main characteristics arising from analyzed projects.

Smart low cost noise monitoring systems	
main characteristics arising from analyzed projects	
Short /long term noise measurement	long term noise measurement
Embedded pc monitoring system /Units with microcontroller and digital signal processor	Embedded pc monitoring system
Type of microphones	MEMS microphones ¼ - inch condenser low cost microphone
Time basis acquisition	Different values. In most frequent cases =1 sec;
Acoustic dynamic range	70 dB
Acoustic Measure range	Different ranges. 30 (40)-100 (110) dB(A)
Acoustic frequency range	20 Hz-20 kHz
Floor noise value	30-35 dB(A)
Tolerance	LAeq ±2 dB(A)
Acoustic indicators	In all cases studies: L_{Aeq}, L_{A10}, L_{A50}, L_{A90}; In some cases studies: $L_{A01;}$ L_{Ceq}, M_{60}, M_{70}, N_{cn}
Spectral data	1/3 octave
Calibration	Periodic calibration
additional characteristics	
weatherproof	Applied in all case studies
connectivity	Wifi/3G/4G
possibility of audio recording	Applied in some case studies
other properties	Extensible with temperature/humidity sensors, air pollution monitoring sensors, GPS logging etc; battery for energy storage.
Size of PCB assembly	10mm < x < 10 mm
Shape of PCB	Optimized to avoid diffraction effects
pilot area of implementation	
Urban/Suburban	Urban and sub-urban areas
Territorial scales	Different dimensions, from medium to large scale; ((most frequent dimension in urban area: ≈1,00 km^2)
Number of stations	Different situations. For areas of medium spatial dimensions, in most cases, from 5 to 20 units

Smart low-cost noise monitoring systems, allowing an extensive and long-term noise monitoring, in medium sized territorial scale as urban area, seem to be able to ensure an appreciated quality output measurement data.
LIFE MONZA project foresees a noise monitoring campaign in pilot area of Libertà district, conducted using sound level meters of class I precision, and also using a smart low-cost monitoring system developed within the project (*Action B.3 Prototype of monitoring system for Noise LEZ design - data analysis techniques definition*). The main characteristics of the prototype system for smart noise monitoring activities, to be used as a continuous monitoring unit in the ex ante and ex post scenarios, have been shared with UNIFI (University of Florence), partner responsible of the development of the prototype. The main technical specifications are as following reported:

- acoustic parameters: overall A-weighted continuous equivalent sound pressure level, L_{Aeq} and continuous equivalent sound pressure level, L_{eq}, as 1/3 octave band spectrum data;
- timing for data recording: data will be registered 1 second based to permit the recognition of unusual events will be advisable in the post analysis phase;
- timing for data transmission: data will be sent every hour;
- data transmission network: will be assessed according to parameters like distance among sensors;
- power supply: solar panel (expected size 20cm x 30cm) and battery for energy storage;
- sensors location: on streetlight, height 4 m;
- ¼ or ½ - inch condenser low cost microphones;
- floor noise = 35 dB(A)
- weather protection

These requirements will be subsequently defined in detail and they could be modified, if some other better conditions will be detected.

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