Chapter

Environmental Noise Mapping as a Smart Urban Tool Development

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Abstract

Since the European Directive 2002/49, large transportation infrastructure along with large urban areas should have completed strategic noise maps (SNM) and the relative noise action plans (NAP). The majority of European Member States (MS) has enforced this directive and completed fully or, in some cases, partially, with European smart cities to use and share the same criteria and methodologies and along with transport operators to communicate to the public the relevant results and respective action plans by ensuring the citizen's awareness about the environmental noise, the quality acoustic environment, and their effect to their professional and everyday lifestyle. Today, 18 years after its first edition, the European Directive 2002/49/EC is needed to be reformulated to take into account all defects that have been identified and to adapt as well as possible to contemporary constraints. New methodology tools have been developed especially regarding soundscaping and environmental acoustic rehabilitation of urban areas, and the respective chapter will describe the progress being made on these smart developments of cities and infrastructures. This chapter will also evoke criticisms of these smart tools and will present results from several—state of the art—case studies especially regarding the practical and theoretical limits they face.

Keywords: noise mapping, European Directive 2002/49, smart tools, noise action plans, soundscapes

1. Introduction

The European Environmental Noise Directive 2002/49 [1] implemented in all EU Member States, almost 18 years ago, provided several smart tools to access and manage environmental noise and enhance cities' development. As the directive stipulates, "it is part of community policy to achieve a high level of health and environmental protection, and one of the objectives to be pursued is protection against noise. In the Green Paper on Future Noise Policy, the Commission addressed noise in the environment as one of the main environmental problems in Europe" [2].

This chapter offers, therefore, an analysis of the tools that have been created in the framework of this directive and aims to show how these specialized tools contribute to an intelligent development of European cities and wider urban territories. The analysis is based on a series of practical cases studies carried out in Greece (and in Europe) and will show how these smart tools had to adapt to the twenty-first-century environmental issues.

2. The environmental noise directive as a "toolbox" for smarter cities

The environmental noise directive concerns, since its enforcement in both European and national framework, not only the major agglomerations in EU Member States but also all main transportation infrastructure. Environmental noise is defined by the traffic noise from road, railway, and airport infrastructures combined with industrial sources. Each Member State has incorporated this directive, into its national legislative framework and therefore has the obligation to implement it in their relevant urban agglomerations and territories. This was an important step forward for the environmental noise both on national and European scales, because it created the appropriate framework for policy-makers, politicians, transportation engineers, urban planners, architects, and also every citizen to share information and interact on the definition of all appropriate regulation and mitigation measures. In other words, it allowed the Europeans to address in the same language their concern on the environmental noise issue. A strategic noise map (SNM) is therefore primarily requited allowing to visualize the "decibel" impact of the main sources of environmental noise either at the scale of an agglomeration or at the scale of an transportation or industrial infrastructure. As the next step, a comprehensive noise action plan (NAP) is therefore drawn with the involvement of transportation, planning, and acoustic engineers to access and specify the most appropriate means to achieve the needed noise rehabilitation by mitigation measures. The general framework and the basic homogenous methodology have been applied in the majority of the Member States, and now, 18 years later, we can see the important advantages emerging.

2.1 Smart tools for environmental noise measurement issue

As analyzed above, in this same legislative framework, transportation operators needs to measure and simulate the noise impact on the environment. The noise emitted by a vehicle or an airplane is a dynamic source that evolves in time and space. The environmental noise emitted by the traffic of the road traffic flow (including motorcycles and trucks) over a day is therefore an inexhaustible source of information that continues to evolve (big date issue) and which poses questions to traffic engineers for its measurement, its prediction, and furthermore its management. The European Directive introduces several smart tools in order to solve these problems.

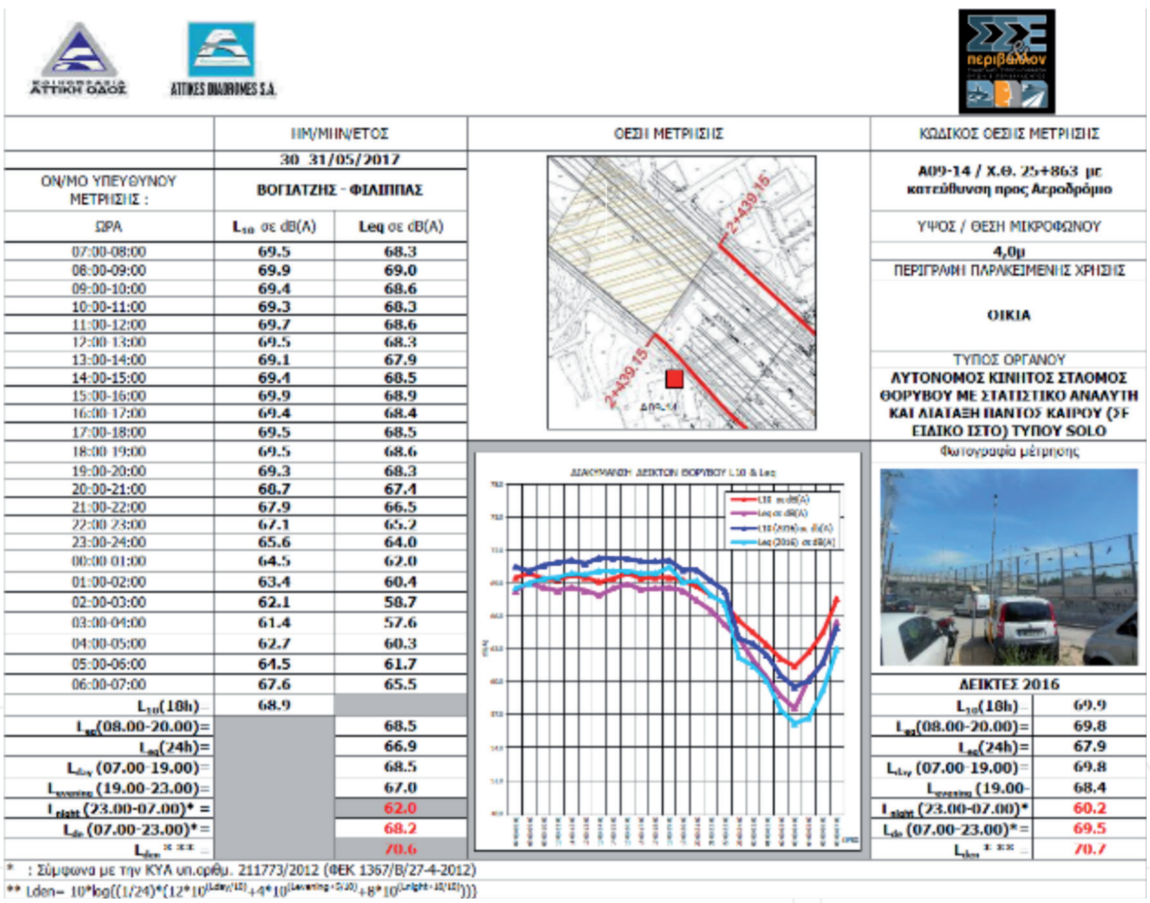
For example, Attiki Odos, the road operator for Athens Ring Road has been awarded in 2003 (Decibel d'Or, Ministère de l'Environnement en France) for its monitoring system with eight permanent monitoring stations that measure in real time road noise traffic (see **Figure 1**). In Attiki Odos, since its opening in 2004 for the Olympic Games, more than 250,000 vehicles are passing every day [3].

In order to achieve this goal, Members States are applying the directive by using the common indices L_{den} and L_{night}. The European Directive therefore is applied to environmental noise to which humans are exposed by introducing the above noise indicators that shall be determined by homogenous assessment methods. The definition of the L_{den} level (day-evening-night) is defined by the following formula:

$$L_{den} = 10\ \lg\frac{1}{24}\left(12 \times 10^{\frac{Lday}{10}} + 4 \times 10^{\frac{Levening+5}{10}} + 8 \times 10^{\frac{Lnight+10}{10}}\right) \quad (1)$$

where L_{den} is expressed in A-weighted decibel or dB(A); L_{day} is the A-weighted long-term average sound level as defined in ISO 1996-2: 1987, determined over all the day periods of a year; $L_{evening}$ is the A-weighted long-term average sound level as defined in ISO 1996-2: 1987, determined over all the evening periods of a year; L_{night}

Figure 1.
Permanent noise and air pollution monitoring systems deployed on Attiki Odos Ring Road, Athens, in use from 2001 to 2002: view of typical measurement stations and the CUBE measurement system (Dynacoustics & 01dB-ACOEM).



ΑΤΤΙΚΗ ΟΔΟΣ — ATTIKES DIADROMES S.A. — περιβάλλον

	ΗΜ/ΜΗΝ/ΕΤΟΣ	
	30 31/05/2017	
ΟΝ/ΜΟ ΥΠΕΥΘΥΝΟΥ ΜΕΤΡΗΣΗΣ :	ΒΟΓΙΑΤΖΗΣ - ΦΙΛΙΠΠΑΣ	
ΩΡΑ	L_{10} σε dB(A)	Leq σε dB(A)
07:00-08:00	69.5	68.3
08:00-09:00	69.9	69.0
09:00-10:00	69.4	68.6
10:00-11:00	69.3	68.3
11:00-12:00	69.7	68.6
12:00-13:00	69.5	68.3
13:00-14:00	69.1	67.9
14:00-15:00	69.4	68.5
15:00-16:00	69.9	68.9
16:00-17:00	69.4	68.4
17:00-18:00	69.5	68.5
18:00-19:00	69.5	68.6
19:00-20:00	69.3	68.3
20:00-21:00	68.7	67.4
21:00-22:00	67.9	66.5
22:00-23:00	67.1	65.2
23:00-24:00	65.6	64.0
00:00-01:00	64.5	62.0
01:00-02:00	63.4	60.4
02:00-03:00	62.1	58.7
03:00-04:00	61.4	57.6
04:00-05:00	62.7	60.3
05:00-06:00	64.5	61.7
06:00-07:00	67.6	65.5
L_{10}(18h)=	68.9	
L_{eq}(08.00-20.00)=		68.5
L_{eq}(24h)=		66.9
L_{day} (07.00-19.00)=		68.5
$L_{evening}$ (19.00-23.00)=		67.0
L_{night} (23.00-07.00)* =		62.0
L_{de} (07.00-23.00)* =		68.2
L_{den} ** =		70.6

ΘΕΣΗ ΜΕΤΡΗΣΗΣ

ΚΩΔΙΚΟΣ ΘΕΣΗΣ ΜΕΤΡΗΣΗΣ: Α09-14 / Χ.Θ. 25+863 με κατεύθυνση προς Αεροδρόμιο

ΥΨΟΣ / ΘΕΣΗ ΜΙΚΡΟΦΩΝΟΥ: 4,0μ

ΠΕΡΙΓΡΑΦΗ ΠΑΡΑΚΕΙΜΕΝΗΣ ΧΡΗΣΗΣ: ΟΙΚΙΑ

ΤΥΠΟΣ ΟΡΓΑΝΟΥ: ΑΥΤΟΝΟΜΟΣ ΚΙΝΗΤΟΣ ΣΤΑΘΜΟΣ ΘΟΡΥΒΟΥ ΜΕ ΣΤΑΤΙΣΤΙΚΟ ΑΝΑΛΥΤΗ ΚΑΙ ΔΙΑΤΑΞΗ ΠΑΝΤΟΣ ΚΑΙΡΟΥ (ΣΕ ΕΙΔΙΚΟ ΙΣΤΟ) ΤΥΠΟΥ SOLO

Φωτογραφία μέτρησης

ΔΙΑΚΥΜΑΝΣΗ ΔΕΙΚΤΩΝ ΘΟΡΥΒΟΥ L10 & Leq

ΔΕΙΚΤΕΣ 2016	
L_{10}(18h)=	69.9
L_{eq}(08.00-20.00)=	69.8
L_{eq}(24h)=	67.9
L_{day} (07.00-19.00)=	69.8
$L_{evening}$ (19.00-	68.4
L_{night} (23.00-07.00)*	60.2
L_{de} (07.00-23.00)* =	69.5
L_{den} ** =	70.7

* : Σύμφωνα με την ΚΥΑ υπ.αριθμ. 211773/2012 (ΦΕΚ 1367/Β/27-4-2012)
** Lden= 10*log((1/24)*(12*10^(Lday/10)+4*10^((Levening+5)/10)+8*10^((Lnight+10)/10)))

Figure 2.
A typical 24-h measurement in Athens Ring Road (2017) (accessed in three periods: day, evening, and night).

is the A-weighted long-term average sound level as defined in ISO 1996-2: 1987, determined over all the night periods of a year.

As a result, 24-h measurements on Athens peripheral can be presented as follows:

As presented, in **Figure 2**, these tools allows to sum up 1-year measurement in few values that takes into count the density of the road traffic depending on the hours of the day, the week, and the month. The formula shows that the road traffic is even more annoying at night and in the evening than at the hours of the day. Thatis why the formula introduces a weight system that gives more emphasis to noise sources that appears during the evening and during the night: a penalty of 5 dB(A) for the evening and for 10 dB(A) for the night period (see Eq. (1)).

It is one of the main smart tool since it can give at a specific point one value for a big data problem: if we take a measurement each second, it summarizes 1 year of measurement that is to say 60 s × 60 min × 24 h × 365 days, for example, 31,536,000 s of potential measurement period per year. Practically, these measurements based on 24-h periods can be repeated and used to calibrate acoustic models in order to simulate with the best accuracy the environmental noise propagation (from a road section scale to the whole agglomeration scale). For example, a part of the strategic noise map of Athens simulated on CadnaA software and calibrated with 24-h measurements is presented in **Figure 3**.

Scientific papers published by several teams have shown comparison from real in situ L_{den} 24-h measurements and the one simulated has a correlation index more than R > 0.91 [5] (see **Figure 4**).

The measurement indices, therefore, can be simulated with high precision, and in its average, it resists the qualitative and quantitative variations of the yearly average traffic. Another word, with the above strategic noise map correlation methodology, measurements and simulations of the noise indices are energetically correct and express the quantity of noise than a monitoring station may record during the whole year at a specific point (something that is practically and financially impossible to do).

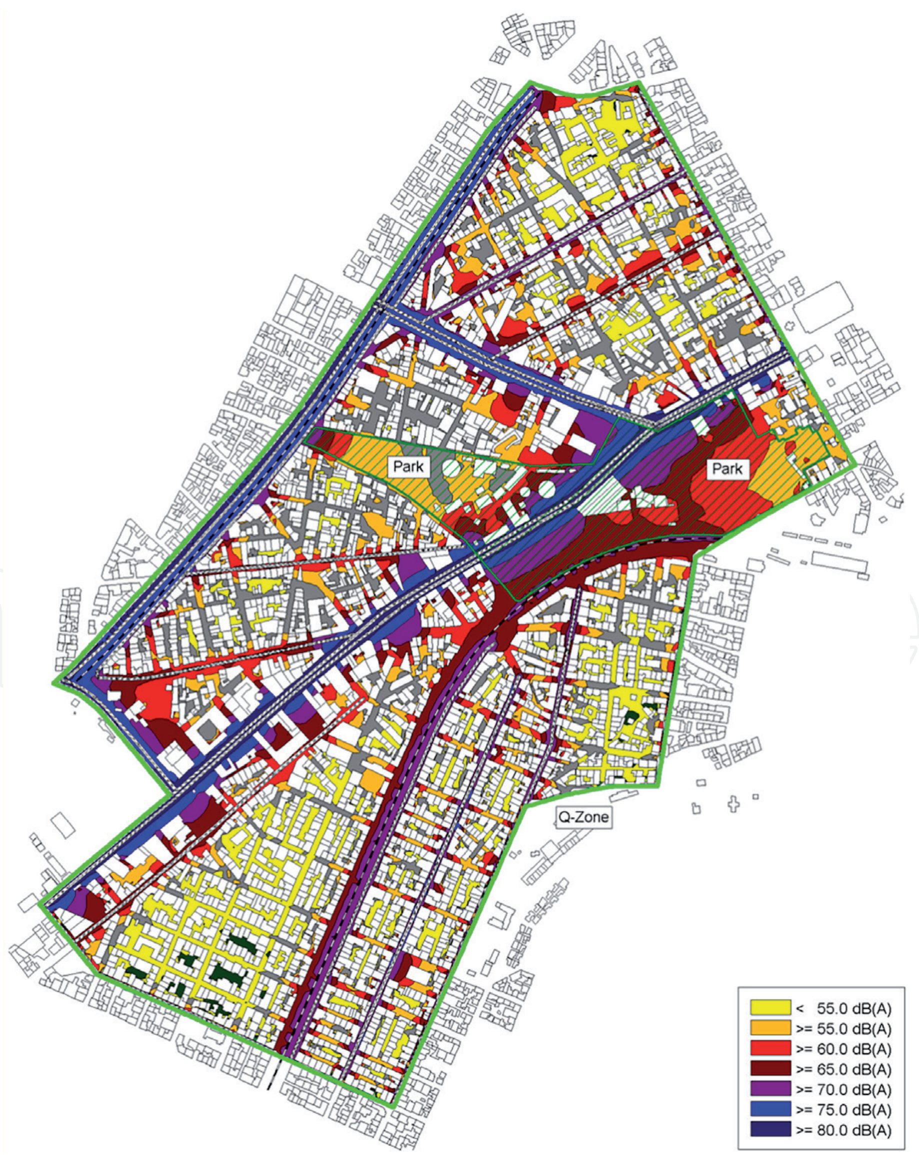


Figure 3.
Part of the strategic noise map of Athens (2016) [4].

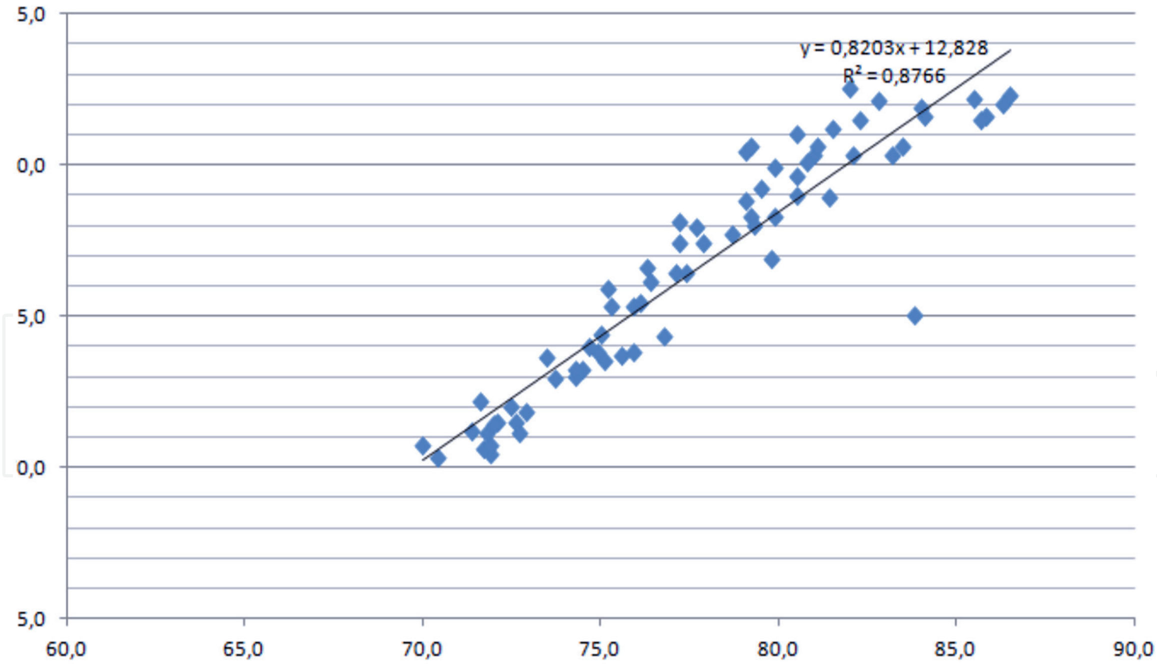


Figure 4.
L_{den} index (Athens SNM). Correlation measured vs. calculated levels [5].

As a result, the use of both L_{den} and L_{night} indices appears to be an adequate and quite adapted even intelligent tool that allows transportation operators and urban municipalities to assess the environmental noise impact of the development of cities on a "long term" (yearly operation). In Europe, the majority of municipalities with more than 100,000 inhabitants and the major transport operators (cars, trains, and planes) produced strategic noise maps, updated every 5 years, according to the directive; however their implementation has in several cases been delayed. Besides the fact that in some European countries the administration did not keep up with this pace, we need to underline that in some cases the early implementation of permanent surveillance systems was introduced (e.g., the Athens Ring Road and the Athens International Airport) [5, 6].

2.2 Smart tools for environmental noise exposure

As per the previous analysis, the relevant European acoustic criteria, which can be measured and predicted, are smart tools for expressing simply the amount of acoustic energy received at a point exposed to different sources of environmental noise. It is thus possible to edit strategic noise maps and link them to the relevant geographical information systems. Thus, these maps become strategic because they can easily express the amount of people exposed to different sound levels. These noise classes has been standardized (in dB(A) and a corresponding color in the map, as per **Figure 3** where the noise classes for L_{den} and the relative color code were used as standardized by European Directive 2002/49).

GIS systems can easily cross statistical inhabitants' localization with SNM and bring to the light the number of people exposed to several noise levels. Based on the European Directive-introduced noise indices, each Member State has the right to adapt in their national legal framework specific limits to define the level of noise pollution (see **Table 1**).

One might criticize the fact that not all European countries have the same limit values [7]. Indeed, as shown in **Table 1**, GR requirements are less demanding (therefore easier to reach) than those recommended by the European Union as a min population exposure level. This is rather a delicate subject that deserves some

Environmental noise levels	L_{den}	L_{night}
Greece (GR)	<70 dB(A)	<60 dB(A)
Europe (min exposure levels for SNM)	<55 dB(A)	<50 dB(A)

Table 1.
National regulations concerning maximum values of noise pollution indicators (i.e., for L_{den} and L_{night}) in Greece compared to European recommendations for population exposure [7].

explanation since European standards are often proposed by Northern Europe Member States for which the economic and social development is often considered more advanced than for Southern Europe Member States. It is the intelligence of the directive and its criteria that gives the possibility of each Member State to adjust its limit levels according to its own geography, climate, lifestyle, social structure, and economy. The GR limit levels may seem extremely easier to achieve than the German ones. It must be understood, however, that Greece, Spain, or Southern Italy are characterized by Mediterranean climate conditions and lifestyle that are quite different from those of, for example, Berlin, Copenhagen, or Stockholm. The periods of the typical day expressing the levels of noise correspond rather to lifestyles of Northern and Western Europe than to Southern Europe. Although it is less and less the case in national capitals and large urban agglomerations (e.g., Madrid, Athens, Nicosia, Rome, or Naples), the peaks of activities are, for example, often 2–3 h after Paris relevant ones. The clipping 07:00–19:00 for L_{day}, 19:00–23:00 for $L_{evening}$, and 23:00–07:00 for L_{night} are not quite adaptable for Greece or Cyprus, for example. The evening in a GR city is maybe the noisiest period of the day, with GR people working—in the private sector especially in commerce—until 21:00, and going for dinner toward 22:00 or even 23:00; therefore the relevant noise measurements will weigh more in the general formula of the L_{den}, as per the penalties introduced in Eq. (1).

Following the European common methodology as per the latest update of the Annex II introduced recently by the European Directive 2015/996 [8], many agglomeration and transport operators present and share their results on the European portal of the European Environmental agency, the noise Observation and Information service for Europe [7]. Main results of most of the main cities and infrastructure of the majority of European members States member states are available. With a simple "click," it is easy to get the following information: total of people exposed to noise from road traffic (but also railway and airport traffic are available), during the day and during the night. It shows how much people are exposed to high level of noise and present graphics that describes the statistical partition of this exposure.

For example, in **Figure 5**, main results are presented for Amsterdam (Haarlem) and Berlin. The web site, trough popup windows, explained clearly how much people are disturbed by noise traffic in the two cities: almost 600,000 inhabitants for both cases with approximately 50,000 more for Berlin. These data, from the noise exposure point of view, are comparable because they describe the same family of criteria (L_{den}, L_{day}, L_{night}), because methodology to measure, calculate, or simulate these values is also standardized. Surely, such comparison is quite helpful for law makers, in each country, to organize their policy for noise mitigation. Noise issues, even if they concern almost the same amount of people in Berlin or in Amsterdam, cannot be dealt in the same way when one knows the specificity of each country concerning town planning, building density, urban sprawl, etc.

Even so the portal is missing information for some Member States, it is already a huge step forward in order to understand the noise issue at the national and European scale. Data are comparable (they use the same criteria), and the map

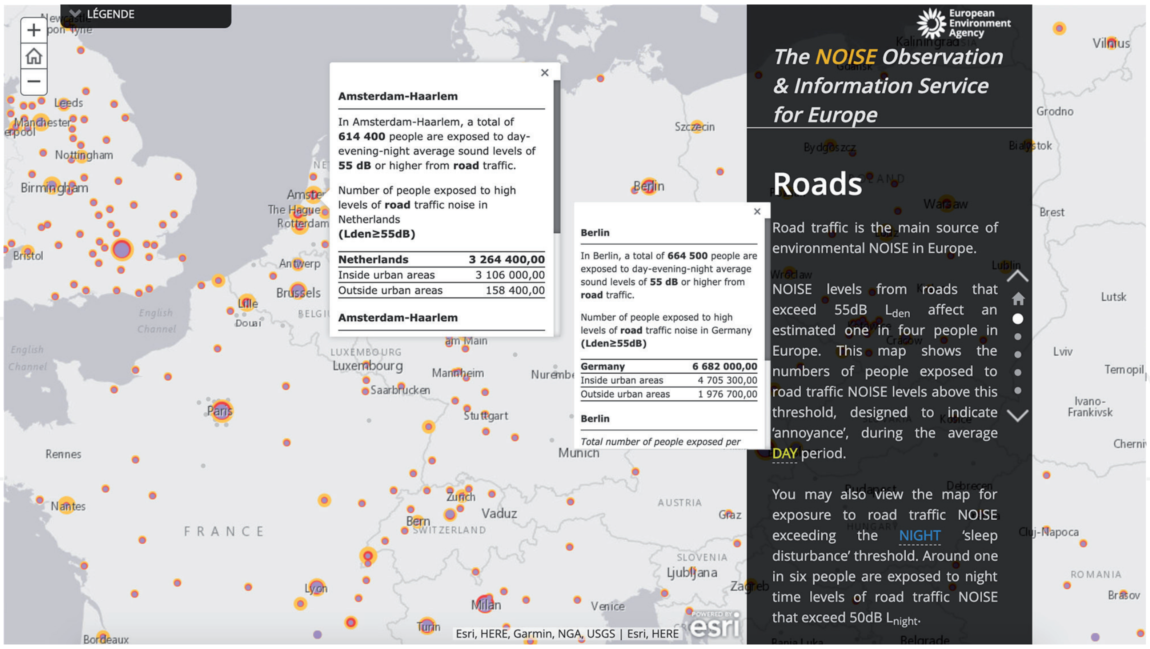


Figure 5.
Visualization of the number of people exposed to high level of road traffic (more than L_{den} > 55 dB(A)) in Amsterdam (Haarlem) and Berlin agglomerations (source: European Environment Agency portal) (noise observation and information service for Europe web site—http://noise.eea.europa.eu).

representation of this data allows also transversal analysis regarding noise exposure, data traffic, and territorial properties.

In the same idea, airports have been mapped, and their strategic noise maps and have shown their influence on the city they border, as in Alikarnassos municipality close to Heraklion International Airport Nikos Kazantzakis in Crete in Greece [4]. The use of L_{den} and advanced prediction models calibrated with in situ 24-hour measurements allows to predict, with high precision, the environmental noise levels in any agglomeration. In this example, the main idea of an appropriate and effective noise action plan was to relocate the international airport from this area to a less built environment almost 20 km far away from the city center (project in execution stage).

In the example above, the comparison of the two SNM presents the impact of the environmental noise generated by the air traffic and especially its influence on the whole neighborhood studied here. This tool intelligently reinforces the scenario for moving the airport to a less developed area [9, 10]. Therefore by providing a common framework, the EU Member States have introduced intelligent tools that allow the simple translation and assessment of a large number of sources of environmental noise.

These tools are accessible to all the graphic representations, and the results are shareable with all the main decision-makers in a given agglomeration who ensure their participation in the decisions aiming to address the sustainable development of the acoustic environment of the cities.

2.3 Smart tools for city development

According to the European Directive, after the execution of SNM, appropriate noise action plans have been drawn in agreement with the existing and foreseen local policies. Those action plans as also the relevant SNMs are linked with geographical information system, so the smartness of the criteria is very much linked with its capacity to correlate the acoustic data with any data within the GIS database of the strategic noise maps and noise action plans, even if they are represented in two dimensions, with a common height level of 4 m. They are actually calculated in full three-dimensional geographical system in order to simulate properly the sound

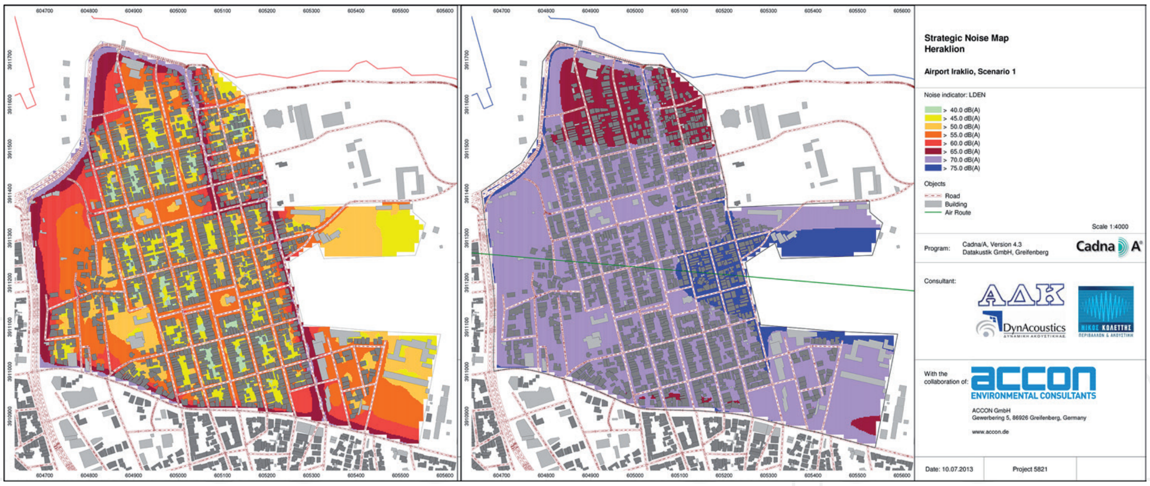


Figure 6.
NAP for Alikarnassos district in Heraklion area adjacent to the International Airport Nikos Kazantzakis: on the left: L_{den} road and on the right: L_{den} road and air traffic [9, 10].

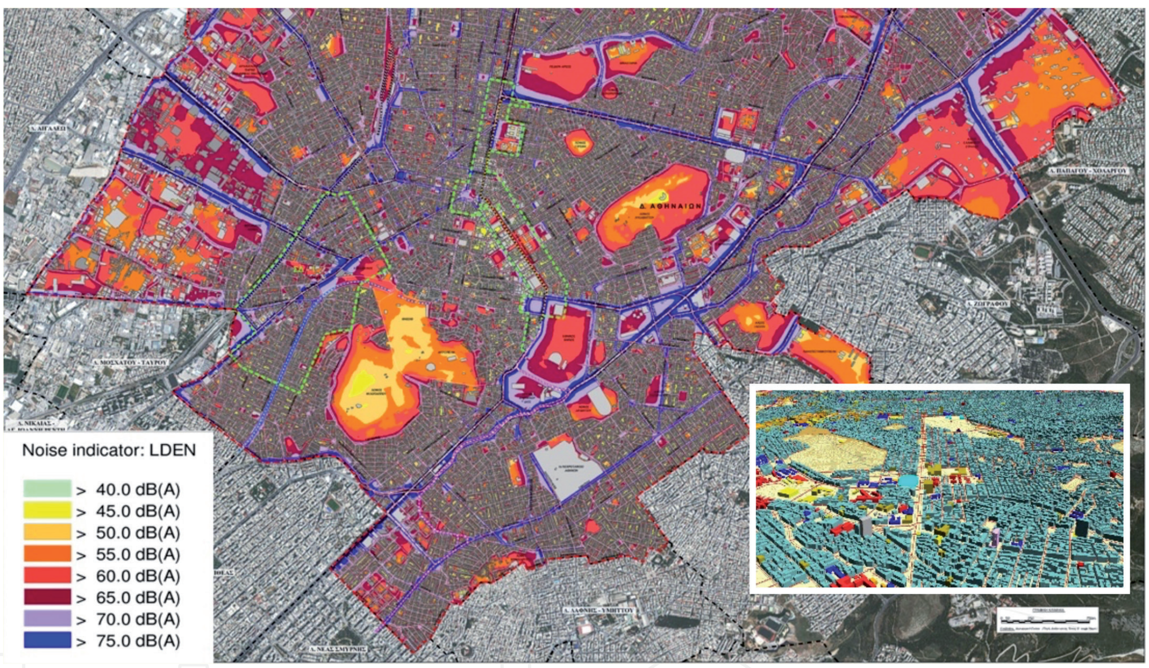


Figure 7.
L_{den} strategic noise maps for South Athens agglomeration (2017) and partial view of the GIS 3D model.

propagation in a complex city 3D environment. Tools have been built in order to integrate the exact topography of the relevant study area and of course the influence of the built space on noise propagation (the building in its three dimensions including reflection characteristics). Therefore it is very efficient for all actors (politicians, mayors, town planners, engineers, acousticians) to represent the data on a map on a satellite view of the city, where a distinct color palette represents the accessed noise class (for every 5 dB) as per **Figures 4** and **6** and as also per the South Athens SNM relevant indexes hereafter (**Figure 7**).

By building the acoustic model on a complete GIS environment, it is also possible to calculate the exact number of people exposed to relevant levels of noise. It is also possible to zoom in the model and see if a specific building depending on its orientation is exposed or not to high level of noise. GIS contains a set of full data regarding the number and the geolocalization of the points of interest and sensitive receptors, for example, hospitals, education buildings, religion buildings, parks, and quite zones. So it is quite easy, after the superimposition the noise level contours on the GIS platform, to execute a quantitative analysis on the exposure factor. Previous studies have shown that, on Athens Ring Road (see **Figure 2**), noise exposure needs to be monitored for more than 170 points of interest as hospital, clinics, maternity, childcare, education buildings, cultural uses, and worship places [4]. Thus, for a municipality, it is possible to prioritize and focus accordingly on appropriate public and private policies and launch mitigation programs aiming to improve the acoustic environment enveloping these sensitive receptors.

Similar conclusions were drawn specifically for the airport noise exposure. For example, in Heraklion, within the relevant NAP, specific studies were completed in order to access the cost for the acoustic insulation and the rehabilitation of both public and private buildings in the case of a "no-moving" scenario for the international airport [4]. In this case the relevant costs of implementing an effective acoustic insulation regulation in buildings and maintaining the airport activity were calculated, in order to improve the acoustic environment of the district of Alikarnassos.

In this perspective, noise action plans have been accessed in order to minimize the population noise exposure. More than 3000 m^2 of noise barriers have been completed on the Athens Ring Road during the last years [11]. Their implementation

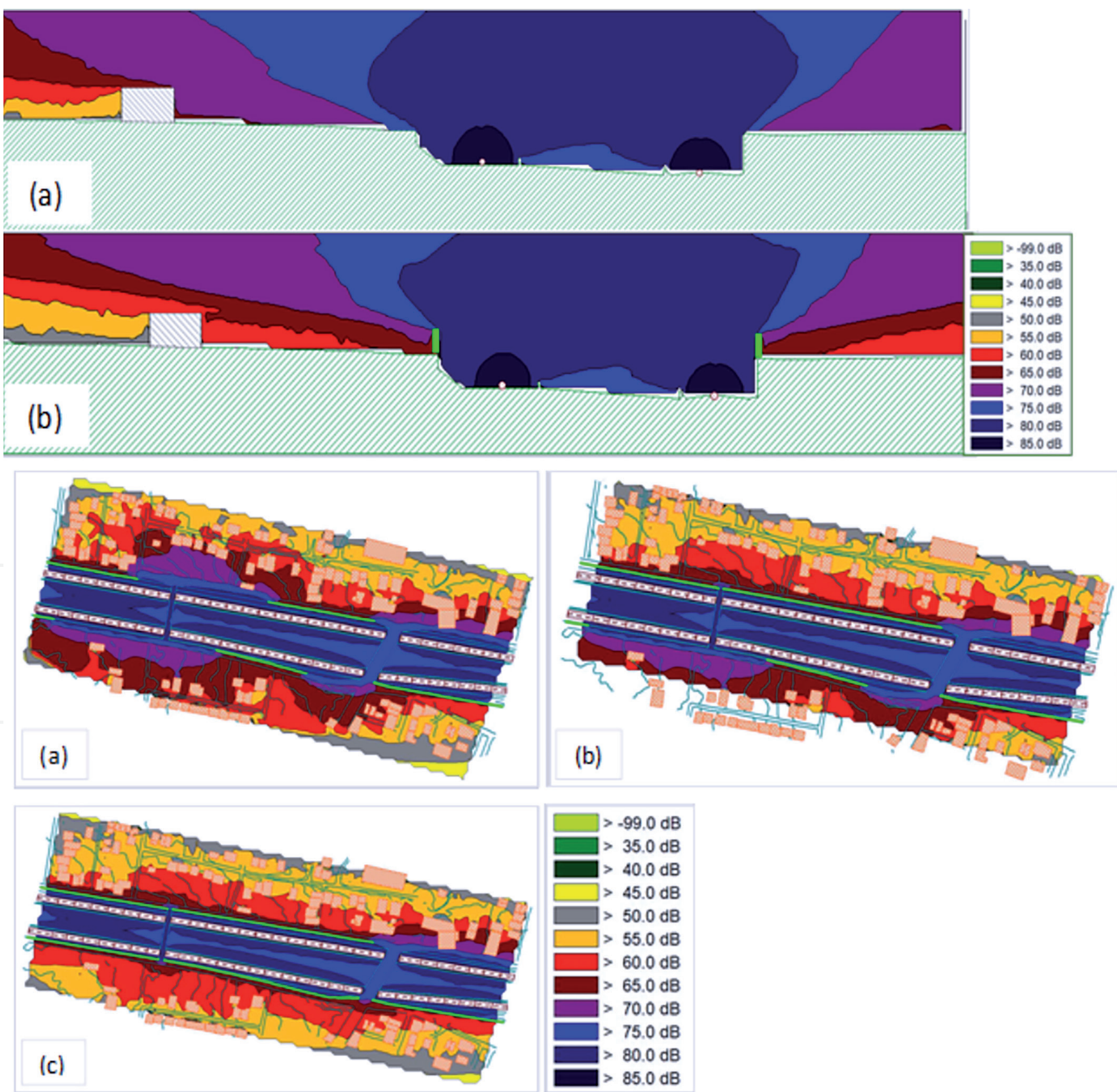


Figure 8.
Athens Ring Road NAP (2017) [11]. Vertical grid—noise index L_{den}: (a) condition with no mitigation measures, (b) condition with the mounting of noise barrier. Horizontal grid—noise index L_{den}: (a) first scenario with no mitigation measures, (b) second scenario with barriers in two receptors, and (c) third scenario with barriers in three receptors (fully covered area).

was based on the provisions of the European Directive 2002/49, and the GR legal framework introduced max thresholds for the relevant indices L_{den}, L_n, and L_{de}, for example, 70, 60, and 67 dB(A), respectively. When the statutory limits of the noise indices were exceeded, the implementation of immediate mitigation measures was suggested (e.g., noise barriers). The implementation of esthetic noise barriers with effective acoustic heights up to 4.5 m was proven successful and very well welcomed by the habitants. In order to resolve the issue of the environmental noise exposure on the population exceeding the existing criterion and limit, a full analysis of the implementation of adequate noise barriers was executed for all within the Noise Action Plan 2017 for the Athens Ring Road [11] (**Figure 8**).

The early surveillance of Athens' road traffic made it possible even during the early years of the operation to implement a comprehensive program for noise management and monitoring. As the construction of the motorway is at a level of −14 m below the ground level, very often, Attiki Odos was partially covered to reduce noise emissions and minimize the local residents' noise exposure. Most of the time, it was a good opportunity to introduce sports and social facilities (soccer fields, tennis courts, playgrounds, parks, etc.) and rehabilitate effectively the urban environment (**Figure 9**).

The development of an urban agglomeration is therefore strongly conditioned by the results of the noise monitoring and the implementation of the relevant smart tools ensuring effective keys to the decision-makers introducing appropriate measures. In another scale, the GR medium-sized city of Volos (approximately 120,000 inhabitants), on the east coast of Greece, has set up one of the main elements of its action noise plan. Indeed, the entrance of the city was a source of important road traffic noise because of continuous congestion effects in selected intersections. The NAP proposed the installation of five one-level roundabouts in order to streamline traffic, reduce traffic speeds, and thus reduce the noise emitted by vehicles. In the late 2018, four roundabouts are already constructed, and local studies and monitoring programs have already shown the positive impact of these mitigation measures concerning the environmental noise [9] (**Figure 10**).

Another good example of the use of these smart tools can be presented also in the city of Volos. Indeed, after the 1955 devastating earthquake, the largely destroyed large part of the city was rebuilt by following an orthogonal layout plan where horizontal (toward the seafront) streets manage both main urban and transit traffic and the perpendicular ones the secondary traffic. In this sense, between the two main horizontal road axes of the city center (see **Figure 11**), the municipality

Figure 9.
(Left) Attiki Odos selected partial covers, under construction and in use [12].

Figure 10.
Location of the four roundabouts already in full operation in Volos, Greece [12].

Figure 11.
L_{den} noise action plan maps—impact of the noise mitigation measures (cancel traffic in all perpendicular small streets at Volos city center) (2012) [4].

during the SNM study requested to access the possibility to rehabilitate the acoustic environment between the perpendicular street network by means of full or even semi-pedestrianization. L_{den} and L_{night} contours were predicted resulting in that no impact on noise exposure is to be expected for these mitigation measures with most of the building facades in this internal network to be still exposed at L_{den} levels of 75 dB(A) shown in the figure in blue color.

The smartness of these tools made therefore it possible to evaluate that the noise impact of this small-scale traffic cancellation in the affected inner network would not change the noise exposure of the residential buildings; therefore the noise factor was not a potential evaluation parameter in order to decide such an important measure within the city.

2.4 Smart enough?

The European Directive 2002/49 has established for all Member States a legal and technical framework for managing noise issues in large urban centers and along roads and railways and in the vicinity of airports and industries. The intelligence of these tools lies mainly in the way of measuring and predicting noise and introducing criteria that offer longtime period indices (a whole day/a whole year). These tools have been used for more than 18 years until now and have allowed to have a very precise idea of the environmental conditions in which the inhabitants are exposed to noise. The strategic noise maps are associated with noise action plans accessed by transportation and noise specialists in collaboration with city planners, architects, and policy-makers in order to minimize the impact of environmental noise on the population. The directive gives powerful and intelligent tools to observe the existing situation and its expected development. For example, between 2008 and 2010, Attiki Odos, by monitoring the traffic noise, realized that the noise emissions diminished because the Athenians were reducing the use of their vehicles forced by the economic pressure imposed by governments during the crisis in the country [13].

Noise action plans have to be published and publicly discussed between citizen and policy-makers. These important public meetings are delicate because they support environmental and political disputes that often go beyond the scope of the directive. In several cases residents do not fully understand both measurements and simulation in the strategic noise maps and especially noise simulations adjusted on the facade of their building. In general they consider themselves more exposed and therefore more annoyed compared to the relevant strategic noise maps suggest. There are many reasons for that. The environmental noise is predominant in the city, but it is not based on only one distinct potential source of discomfort. Other sources, such as two-wheeled motorcycles and motopeds, heavy vehicles, amplified music emissions, and neighborhood noise, are in several cases far more important. For these cases, the 24-h measurement and prediction of both the L_{den} and L_{night} indexes as average per a year period do not reflect what a given inhabitant experiences in their everyday life. The political dimension is particularly important, and many municipal councils hesitate to communicate any result because they are afraid to generate more complaints after the publication of both SNM and NAP that must be explained, and public discussion might choose in between the various options available that commits public funding.

In many cases and especially in Members States of Southern Europe, the noise action plans are not always considered as an obligation by the policy-makers and the head of the municipalities. From a legal point of view, it is very difficult to depict clearly the responsible if the objectives of the action plan are not achieved, and this is generated by important bureaucratic obstacles and the local legal framework that do not clearly establish the relevant responsibilities among the different branches of the central and regional governments. The municipalities cannot be considered economically responsible for not having met the objectives of the action plan if there is a lack of necessary funding from the central government especially in period of economic crisis as recently in several Member States of the EU. This is especially true for the municipalities, but this is different in the case of private transportation network operators who are responsible for monitoring environmental parameters of their infrastructure by receiving, accessing, and resolving relevant complaints from local residents. By introducing continuous noise monitoring programs and noise mapping in order to verify compliance of the enforced limit values in order to protect inhabitants from noise exposure by implementing appropriate measurement mitigation and operation measures [5, 10].

3. Environmental noise and soundscape action plans as new smart tools for city development

3.1 Necessary evolution and the smart tools associated with the European Directive 2002/49/EC

Not all the EU Member States have followed the same pace in the implementation of the European Directive. Some published their strategic noise maps online, very fast, immediately after the directive enforcement, because it corresponds a clear political will of the decision-makers; some delayed because they needed the directive to be introduced in their respective national legislation. In some countries, several rounds succeeded one another based on the directive's provision to update the data and the relevant results every 5 years (three rounds until now). Whatever the case in which the Member States found themselves, after so many years of operation, many thought that the situation could be improved and achieve a homogenous level of completion.

The primary issue discussed and accessed in the relevant EU committees was to establish a more correct and homogenous methodology for calculating and simulating the propagation of the environmental noise sources introduced by the directive. In fact, the method used until 2018 has often been criticized for not being sufficiently precise as regards the emitted noise of different sources and the effects of soil on propagation. Technical improvements have been proposed and adopted by all users by introducing recently the Commission Directive (EU) 2015/996 of 19 May 2015 establishing common noise assessment methods according to Directive 2002/49/EC of the European Parliament and of the Council, introducing the CNOSSOS-EU methodology, to be enforced obligatorily, by all Members States on 31 December 2018. In particular, within this methodology, two-wheeled noise and a new aircraft database were taken into account in the calculations, simulating noise events that in most urban situations are consisting of an acoustic degradation factor, by themselves [8]. The annual average of the L_{den} and L_{day} indices tends to erase the noisy passage of two wheels or a specific aircraft near a receptor (front of a given building) not only in terms of sound energy received but rather on the impact of the average value to express (or not) an annoyance. In the same way also the other modes of transport as the railway have been also introduced in order to better take into account the specifics of each sound source.

Thus, when Greece and Cyprus start implementing the European Directive 2002/49, the country was inspired by other European similar study cases and had also the capacity to move on several open discussions and innovative approaches. Indeed, from 2012, without interruption, the main urban agglomerations of these SE countries were able to publish their results on SNM and NAP regarding the noise environment: Volos, Larissa, Chania, Heraklion, Agrinio, Corfu, Thessaloniki, Athens, Nicosia, Larnaka, and Lemessos. Especially in Greece the operation started with medium-sized agglomerations in Volos and Larissa in 2012, and it led the authors to propose specific adjustments.

Indeed, starting with the city of Volos in central Greece, we have proposed to proceed a little further than the directive's exact specifications and demands. Firstly, because already extensive measurement monitoring programs were executed [4, 9], it was established that the levels of the directive's noise indices were compatible with the measured ones but relatively low in a general point of view and outside the influence of the main road axes, population is not exposed to high levels as per the national legislation. However, a noise action plan was drafted, including a general plan aiming to preserve the qualities of the sound environment (especially actions to enforce where and when the urban environment is not too noisy). The NAPs are calibrated based on the acoustic monitoring program in the city and have taken also into account a large interview campaign with residents of five selected neighborhoods within the urban agglomeration. The interview campaign, through comprehensive questionnaires performed in local residents, aimed to describe the sounds they hear on a typical week day, to establish the noise sources that they like and those that are uncomfortable, and finally to assess the sources of environmental noise when they perceive them, for example, at home, at work, etc.

3.2 Soundscape issue and inhabitants' perception

Many cities in Europe are undergoing major structural changes and are investing heavily to accommodate more than 70% of the world's population that is projected to be living in urban areas [14] by 2050. Cities are becoming increasingly dense and are forced to implement more and more diversified transport offers. Of course the so-called ecological transport is more numerous, but it is not sure whether they are quieter. Indeed, mass public transport is increasing, solving road traffic problems but not necessarily lowering the noise levels to which people are exposed. At the same time, airplane traffic is exploding and projection gives in this sector. In this context, to create new urban centers and minimize travel, many cities in Europe are trying to build eco-neighborhoods or eco-districts in which all energy dimensions are particularly studied. It is interesting to note that the contribution of the European Directive and its intelligent tools moves from a simple reduction of noise sources to a more qualitative management of the sound environment [15]. The sound dimension is still a dimension of the projects which is not treated as much as that of the energy consumption, but it does not prevent that these questions are now around a global strategy of application of the European Directive. Urban planners, architects, and engineers tried to apply the following principles [16]:

- Remoteness of dwellings and points of interest from major transport noisy infrastructures
- Protection of buildings by noise barriers, mounds, and site topography
- Protection of public spaces and sensitive buildings by using other less sensitive building as a "noise barriers" (parking, commercial spaces, offices, industries)
- Orientation of the buildings according to the strategic noise maps of noise and potential for apartment openings on calm areas
- Maximum reduction of the use of the car in these spaces
- Promotes shared modes of transport and soft and alternative modes
- Promotes the presence of vegetation, loose soil, and "natural" sound sources

But more fundamentally, the Greek experience in the application of the Directive 2002/49/EC has revealed another dimension which has led the authors to propose specific adjustments. In 2012 (relatively late compared to other Member

States and the provisions of the directive), with the experience of applying this directive on the country's main transport infrastructures (roads and airports), the engineering teams, in collaboration with the transportation environmental acoustics and architects, introduced qualitative soundscape analysis tools toward a more efficient assessment and a complete list of recommendations relative to the quality of the sound environment.

They practically note the discrepancy between the values of the relevant noise indices and the common perception of urban sound environments. These elements are all more glaring as the sources of environmental noise are relatively low and much less troublesome. In these medium urban agglomerations, because of their size and their evolution process, residents defend very strongly the identity of their neighborhood, and they describe the sound qualities of these neighborhoods as a very important element in their style of life.

3.3 Toward a smarter tool for urban development: soundscape mapping

The European Directive on noise environment has introduced the possibility for all Member States to develop a specific methodology in order to preserve and protect quite areas. The directive gives several recommendations, and many cities in Europe develop their own guidelines to identify them and protect them. Climate conditions and social behaviors are however quite different between, for example, London and Thessaloniki, so, once again, the smart thing to do was not to decide what it could be good as a max noise level for all involved in a so diverse European Union. Quantitative criteria (L_{den}, L_{night}, $L_{evening}$, L_{day}) had to be completed with more qualitative criteria, and the notion of soundscapes was useful for that: "a soundscape is the acoustic environment as perceived by humans, in context" popularized by Schafer [17] who describes how people like to listen to the sounds and the noises of their environment when they are not annoyed and when they describe qualities of their neighborhood.

In this context, NAPs were completed with soundscape action plans based on the analysis of the relevant quantitative mapping. Many times, specific areas are selected because they are representative of noise and soundscape issues in link with urban development. Several strategies are defined for the protection, the management, and the creation on soundscapes in these areas.

The identification of these zones allows its protection and restoration of those responsible for the development of the agglomeration's urban space (municipalities, architects, urban planners) within the physical city development. Consequently, this quantitative measure does not translate itself all the quality parameters of the acoustic environment of the area. For these reasons we consider it interesting to grow along with the "quantitative" mapping and a "qualitative" mapping of the acoustic environment. To ensure the appropriate assessment tools to city authorities in order for them to act on upgrading the sound identity of the subregion proposed below, the following mapping investigations have been realized.

The city center of Thessaloniki where we applied this methodology is described hereafter based on the following series of diverse layers of mapping [18]:

- Urban typology map: This map describes mainly the propagation space of sounds and noise and shows on 2D drawings the section of the streets, road, boulevard, and avenues of the studied area (U- or L-shaped roads or open road). This map makes it possible to evaluate the qualities of the urban spaces in which sounds and noise spread (sound space more or less closed, even reverberant or open space) (**Figure 12**).

Figure 12.
L_{den} strategic noise map for Thessaloniki city center (left) and the relevant urban typology map of the center area (right).

- Spatio-acoustic typology map: This map presents the potential acoustic effect that can be created by the urban forms: filers, reverberation, silence islet, cutting effect, etc.) (**Figure 13**).
- Map of predominant uses of the public spaces: This map shows the most prevalent uses of public spaces (traffic, shops and shopping areas, services, pedestrians, services, etc.)
- Map of predominant uses of building uses: This map presents the main uses of the buildings of the area studied: residential building, point of interests, shops and shopping areas, services, industrials, crafting, etc. (**Figure 14**).
- Map of sound markers and sound signals of identity's characteristics: This map shows the sounds that characterize a place and that are often quoted by residents (**Figure 15**).
- Soundscape maps: This map is a drawing of different areas where the soundscape that one can experiment is remarkable and has been described by the majority of people interviewed. It describes the main sound and noise sources heard on site, their relation in intensity and in time, and the way they are interpreted by the residents. This map actually regroups the results of the previous analysis (**Figure 16**).

The creation of these mapping databases in correlation with the quantitative noise measurements allows in-depth analysis of the acoustic qualities and noise characteristics of a given neighborhood while they are not only clarifying the reasons for acoustic quality existence at the neighborhood scale but also annoyance problems. All the previous maps are fully correlated with the relevant noise action plan map of the area produced as per the European Directive guidelines (**Figure 17**).

At the same time, they facilitate the decision-making in relation to the urban agglomeration planning (sources, propagation conditions, ground coverings, social

Figure 13.
Spatio-acoustic typology map for Thessaloniki city center (right) urban typology map.

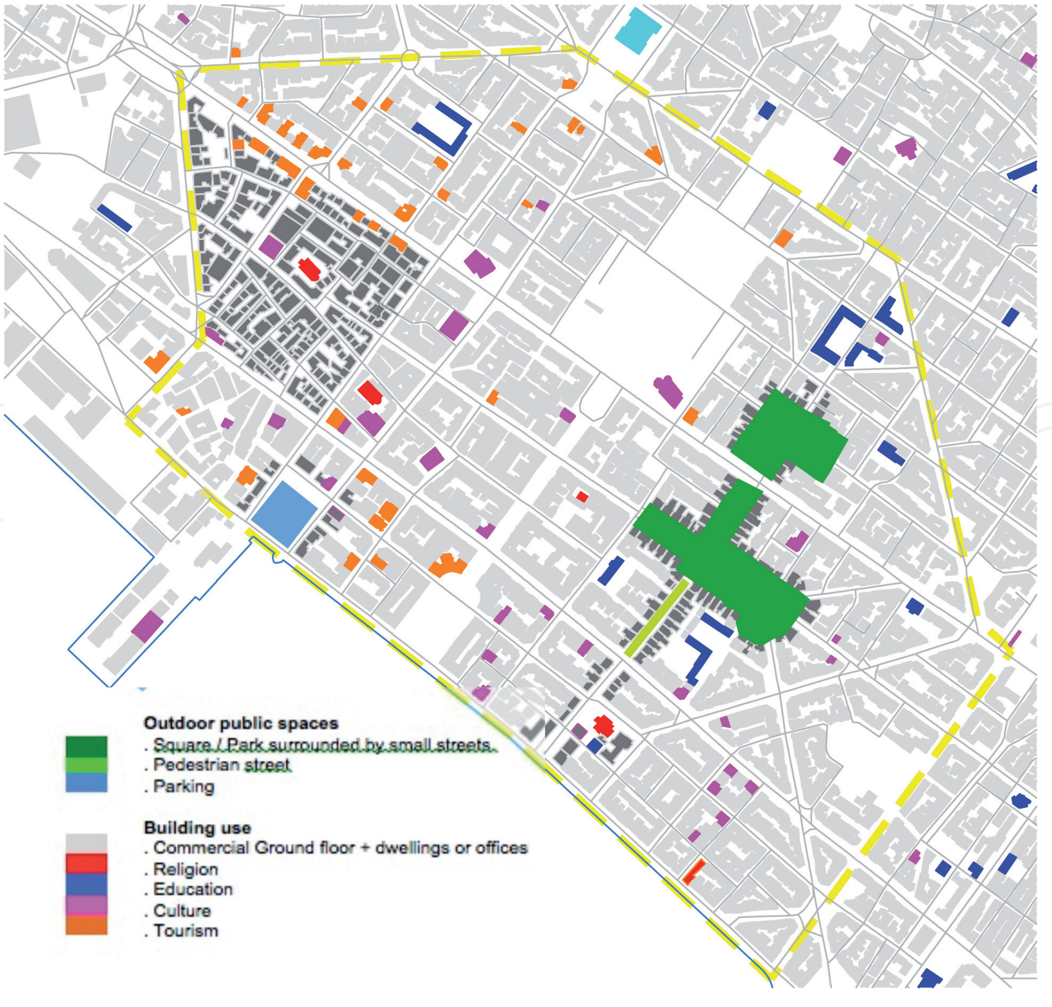


Figure 14.
Map of predominant uses of the public spaces and building in Thessaloniki city center.

Figure 15.
Map of sound markers and sound signals of identity's characteristics of Thessaloniki city center.

Figure 16.
Soundscape maps of Thessaloniki city center (each color represents an area where pass by people experiment some remarkable soundscapes).

organization of the city, etc.). All these overlapping maps consist for the authors a significant improvement of the available tools provided by the directive. These tools make it possible to articulate a complete quantitative and quantitative approach to the urban space and introduce, as well as the physical acoustic one, the results of interviews and all in situ observations. In this way, these tools compile users' points

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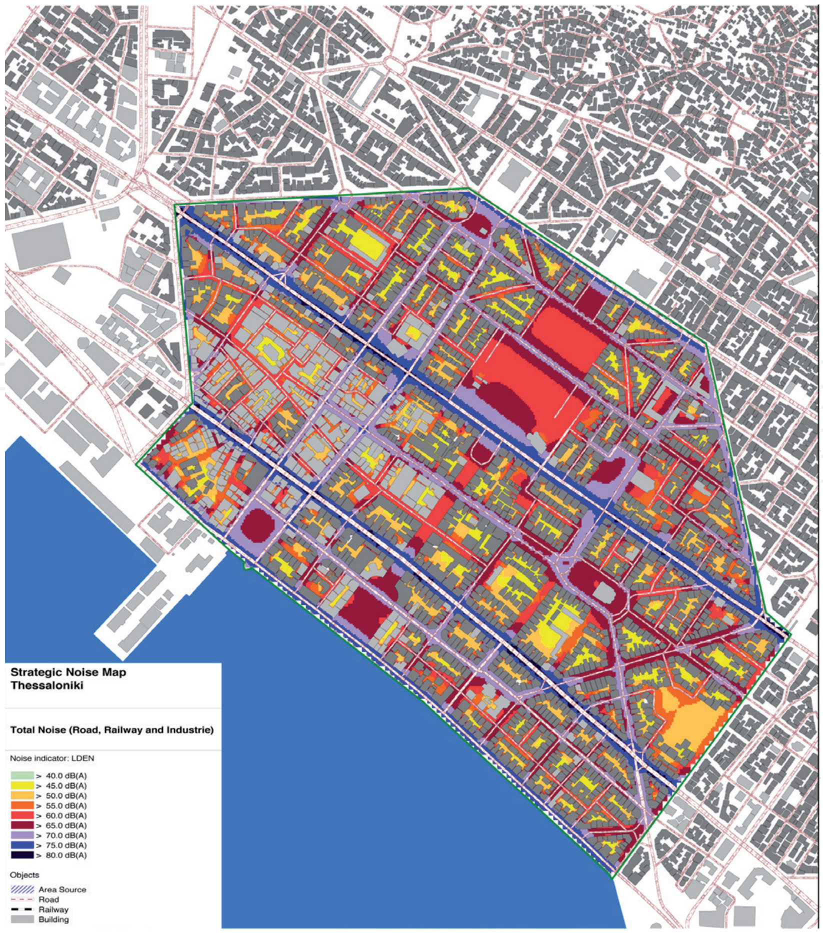

Figure 17.
Noise action plan maps for Thessaloniki city center.

Figure 18.
(From left to right) Stock Exchange District, Freedom Square, and Agia Sophia Achiropiitou axis localization in Thessaloniki center.

of view and produce a more general vision of how the sound environment of a neighborhood is perceived by the inhabitants. He accumulates the opinions and the points of view and allows to evaluate the factors that shape the originality of these places. It does not reduce the potential noise problems that managers have to deal with but, on the contrary, emphasizes their magnitude and characteristics by drafting a noise action plan for the soundscape as well. These plans aim also to reduce the areas exposed to high noise levels, thus not only reducing the noise exposure of residents but also preserving, managing, or even creating new soundscapes.

In the example, the historic center of Thessaloniki, which is the subject of numerous renovation projects, the specifics of the action plans can be summarized as follows (**Figure 18**):

Thessaloniki will be equipped shortly with a very modern subway whose main objective will of course be to decongest the urban arteries from the excessive road traffic of today. In this sense, a lot of public space has been the subject of international architectural competitions aiming at their rehabilitation and renovation. In this sense, NAPs, completed by a relevant soundscape action plan (SAP), will allow to introduce a series of development for the city and its neighborhoods:

- The rehabilitation principle (especially in Stock Exchange District) will have a positive impact on noise exposure. By reducing in general the use of the private car in such environment, the impact will be important because the buildings themselves by their masses and their heights will protect the area from main surrounding circulation axes. By limiting car traffic (streets becoming pedestrian and semi-pedestrian), it will ensure higher importance to the sounds characterizing the recreational and touristic activities' sound signatures (coffee and food places, taverns, bars, clubs, live music, shopping).

- On the north-south axes of Saint Sophia and Achiropiitou (east side of city center), the architectural project selected defends the idea to introduce more (sounds) of nature along the street: water fountains and surfaces, pedestrian areas, benches, etc. will give the opportunity to residents, consumers, and tourists to enjoy the location during the whole week. The light slope from north to south (until the sea level) with relevant urban interventions will help to disconnect the square from the noise traffic impact from Egnatia Avenue, one of the most busy road axes of Thessaloniki. In this case, noise reduction within soundscape creations is expected to manage the main sound ambiances for this district and for the next years.

- Regarding finally Freedom Square, the challenge was to radically change its architectural image. From the visual aspects, the architectural competition selected a project that will highlight the square. From the acoustic point of view, the challenge is much harder because actually the square is only used by road traffic, parking, and also bus and taxi stations. The natural parameter is highlighted by planting more trees, deciduous and evergreen, and by using on the ground a combination of soil and aged blocks. The project increase also the spaces dedicated to pedestrians by closing the south part of a street. These actions will change the sonic identity of the place if they are fully implemented and then properly maintained (especially regarding the vegetation introduced in the area). It will not be expected to achieve important reduction of the noise exposure from road traffic especially in the sea front, but it will change the space propagation properties and the inhabitant perception. The foreseen interventions is expected to offer several new ways to use this area in an enhanced sound environment, implementing adequate seating possibilities and meeting points, coffee shops, cultural exhibition areas, and with the parking area to be relocated.

4. Conclusions

The tools presented in this chapter can be considered as quite intelligent because they can handle a large amount of data related to environmental noise and the urban soundscape. The mapping features representing these data and their relevant analysis, coupled with the use of detailed geographic information systems, allow to reveal a number of strategies to reduce residents' noise exposure and negative reactions and, above all, to ensure a quality sound environment (soundscape) that characterizes their neighborhood and their city.

Environmental Noise Directives 2002/49/EC and 2015/996/EC need to be implemented along with soundscape analysis in order to propose a more extended and complete noise action plan that considers the urban environment as a whole and not only specific noise sources. In case studies where the environmental noise is very important (as for example, in proximity of major international airports) such study give guidelines to follow for several scenarios and of course including also severe operation measures and even relocation if needed. By embracing a broader framework, acoustic and transportation consultants along with the municipality's officials may develop efficient tools and comprehensive noise action plans that go beyond the simplified issue of noise and offer an expanded view of the situation. The question is therefore not only to specify the tools to develop the city without noise but especially the use of intelligent tools that allow a city to evolve with all its sonorities and soundscapes, toward the noise abatement which is undoubtedly the first preoccupation of the Member States managing adequately all environmental noise dimensions and introducing the proper solutions. An action guide for environmental noise and the soundscape is therefore a powerful intelligent tool that seeks to manage an environmental problem while keeping what makes the identity (sound) of neighborhoods, all over urban agglomerations in Europe.

The main criticism that can be formulated about this approach lies in the forms of consultation of residents and citizens. Until now, it is often more practical to conduct in situ interviews with the residents of the area. The duration of studies, constrained for economic reasons, does not allow time to "hear the opinion" of everyone. Although the survey techniques used show recurrences in the opinions of interviewees, one could imagine that a system of automatic soundscape perception could be more effective than the method used. Citizen participation through mobile phones for the measuring and the qualification of noise sources and soundscapes has been developed in the recent years and might be used in this purpose. Noise-Capture is described as the scientific tool for environmental noise assessment [19]. The project gives the opportunity to any Android mobile phone to participate in the creation of a strategic noise map. The tool offers the capacity to share the measurement and display maps created by all the users, for example, at Vieux Port area in Marseilles [20] (**Figures 19** and **20**).

On both figures above, and at different scales, these tools present a new approach of strategic noise mapping, by indicating noise value and noise source characteristics recorded (noises, soundscapes, etc.). This map created by various independent users depending on the hour of the day, the duration of the measurement, allows an interesting representation of the sound environment as experimented by the residents.

These new tools are complementary to the European Directives' provisions and methodological tools, but indeed they are somehow smarter in their ability to massively aggregate noise measurements, predictions, and comments of residents. Therefore the environmental mapping will introduce new ways of representing complex and dynamic sound phenomena in an urban area ensuring deeper analysis in

Figure 19.
Noise map visualization at Vieux Port of Marseilles (NoiseCapture application) [19, 20].

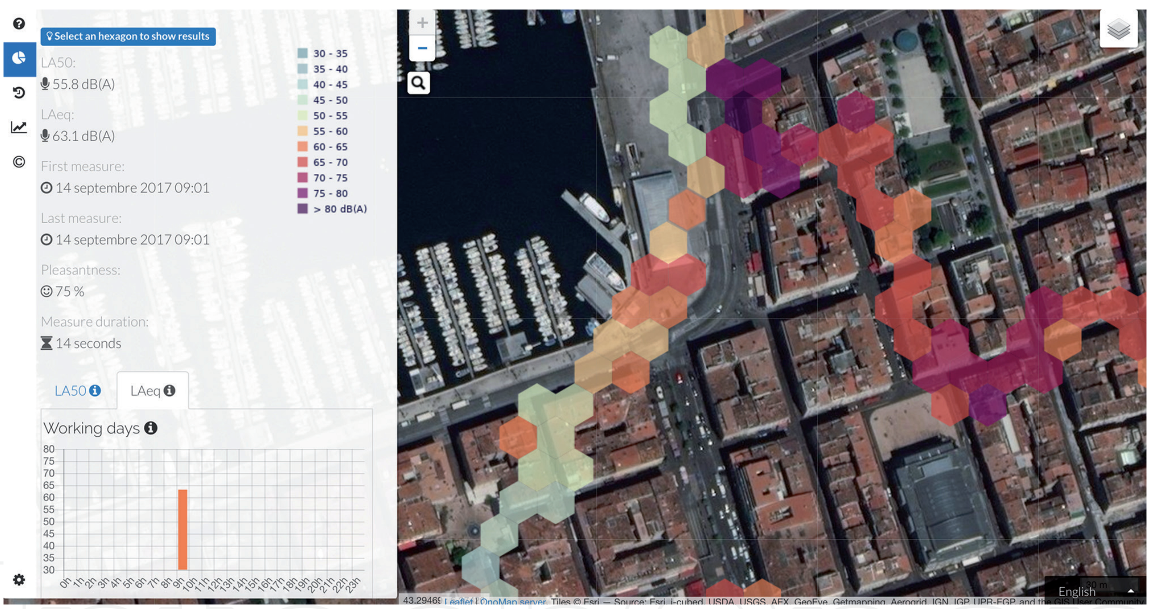

Figure 20.
Zoomed in view of Vieux Port of Marseilles (NoiseCapture application) [19, 20].

order to understand and fully access all elements of the soundscape contributing in the formation of the sound identity of neighborhoods and cities. Enriched with all these approaches, there is no doubt that the city will be better equipped by many intelligent tools to proceed in its development by ensuring a sustainable sound environment.

Conflict of interest

Both authors, Prof. Konstantin Vogiatzis and Associate Prof. Nicolas Rémy, declare no conflict of interest.

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