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NOISE POLLUTION IN SPAIN: TOWARDS A COMPREHENSIVE ASSESSMENT

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ABSTRACT

This research addresses the lack of a comprehensive view of noise pollution in Spain, which affects both citizens' quality of life and the preservation of terrestrial habitats. Strategic Noise Maps (SNMs), developed under the Environmental Noise Directive (END), currently cover only agglomerations with more than 100,000 inhabitants and major infrastructure (roads, railways, and airports). Consequently, large areas of the territory, smaller municipalities, and other significant sources, such as industry, ports, leisure activities, and events, are ignored, resulting in information gaps. This work highlights the need for an integrated diagnosis of noise produced by all sources, regardless of whether or not they are within the scope of the END, and shows progress in the development of a methodology for an integrated diagnosis of road noise, covering all sources of road traffic noise in Spain. Furthermore, it proposes analyzing the effects of noise pollution on human health and the loss of terrestrial habitat quality, with the goal of generating concise information for society. Through this assessment, the aim is to establish a solid foundation for the implementation of policies and measures to reduce noise levels, thus ensuring effective protection against noise pollution in Spain.

Keywords: *Noise pollution, Strategic Noise Maps, Noise assessment, Spanish strategy against noise*

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1. INTRODUCTION

In Spain, there is no comprehensive understanding of the existing noise pollution issues affecting both the quality of life for citizens and the habitats for terrestrial wildlife [1, 2]. Strategic Noise Maps, prepared by various Competent Authorities, offer insights into the noise situation in urban agglomerations with over 100,000 inhabitants and near major sources (significant noise emitters) as defined by the Environmental Noise Directive (END). This includes roads with more than 3,000,000 vehicles per year, railways with more than 30,000 traffic per year, and airports with more than 50,000 operations per year. However, areas likely impacted by sources that do not meet these thresholds, as well as other types of noise sources, are often not adequately studied [3, 4]. These data may not, therefore, be included in the National Information System on Noise Pollution (SICA) [1] . According to the information available on SICA, Spain only reports to the European Commission strategic noise mapping data for 64 agglomerations with more than 100,000 inhabitants, 21,000 km of major roads, 1,800 km of major railways, and 13 major airports.

This means, studies for 87 cities with populations between 50,000 and 100,000; 613 cities with populations between 10,000 and 50,000; 2,381 cities with populations between 1,000 and 10,000; and 4,986 towns with fewer than 1,000 inhabitants [2] have not been included in the strategic noise mapping.

Furthermore, derived from the consultation of the

[1] https://sicaweb.cedex.es/
[2] https://www.ine.es

transport network cartography of the National Geographic Information Center of Spain [3], excluded from the END scope are 154,000 km of roads, 21,770 km of railways, and 1,136 air facilities, including aerodromes, heliports, and hydro-aerodromes.

Regarding industrial sources, a significant number of 9,067 industrial facilities registered in the Spanish State Registry of Emissions and Polluting Sources (PRTR) [4], and 1,345 wind farms deploying over 22,000 wind turbines are not included in the SICA. Also, according to the Spanish public body Puertos del Estado [5], 49 major state port facilities are also out of the scope of END.

Lastly, local disturbances from sources such as leisure noise, neighborhood activities, urban service noise, recreational events, and construction noise are also overlooked in the SICA, and have an important effect on health [5].

From what has been discussed so far, it can be deduced that the Environmental Noise Directive suffers from "original sin." By determining the study areas based on noise sources, rather than sensitive receptors, it leaves a large part of the human population and sensitive receptors in the natural environment outside its scope.

This lack of a comprehensive perspective on noise pollution has led organizations such as the European Environment Agency (EEA) to attempt to assess noise problems globally [6], using gap-filling statistical methods [7]. However, these estimates can be significantly biased due to the lack of comprehensive data, and they do not address the problem, as they still fail to identify areas affected by noise that require corrective action.

For these reasons, the Spanish Ministry for Ecological Transition and the Demographic Challenge (MITECO) asserts the need for a comprehensive assessment of noise pollution problems. This assessment is crucial for establishing an initial understanding of noise-related issues, analyzing the potential human health impacts of noise pollution, and how it correlates with the degradation of natural terrestrial habitats. Providing synthesized information on noise pollution in Spain could be made publicly accessible through synoptic documents that would support monitoring and evaluating the effectiveness of policies aimed at mitigating noise pollution.

The aforementioned diagnosis is currently in the development phase, with the MITECO team working on global noise models for roads, aeronautical noise, and railways, and advancing evaluation methodologies for the remaining sources (industry, leisure activities, works and other). In this communication, we focus on the global road noise model. It is considered one of the most important because, globally, road traffic has the greatest impact on the acoustic quality of the environment [8].

2. OBJECTIVES

Thus, the objectives of the global analysis of road noise in Spain are as follows:

General Objective: To comprehensively assess road traffic noise pollution across Spain, including areas not covered by the Strategic Noise Maps established under the Environmental Noise Directive (END), in order to provide a complete understanding of the issue, enhance the knowledge base on the health and environmental impacts of noise, and support policy-making through accessible and nationally consistent tools.

Specific Objectives

- To identify and quantify the acoustic impact of road traffic in areas not included in the END, such as municipalities with fewer than 100,000 inhabitants, rural environments, and low-traffic interurban roads.
- To fill the existing data gaps in the National Information System on Noise Pollution (SICA), by incorporating information on road segments, environmental conditions, and population exposure.
- To estimate the number of people potentially exposed to harmful noise levels in areas not currently addressed by strategic noise mapping.
- To evaluate the impact of road traffic noise on the acoustic quality of terrestrial habitats, particularly in protected areas such as the Natura 2000 protected areas network.
- To develop a transparent and reproducible nationwide modeling methodology, integrating open data and open-source technologies.
- To provide a solid technical foundation for the design and implementation of public policies such as the National Noise Strategy, ensuring effective, equitable, and consistent noise protection throughout the Spanish territory.

[3] https://centrodedescargas.cnig.es/CentroDescargas/redes-transporte
[4] https://prtr-es.es
[5] https://www.puertos.es

3. MAIN REFERENCE WORKS

Few studies address noise impact assessment using national-scale models. Countries implementing systemic environmental noise management models typically incorporate advanced statistical methodologies and large-scale data approaches to effectively quantify the impacts of noise pollution [7].

However, several relevant reference works, platforms, and tools have contributed to the development of comprehensive noise assessments at the national and international levels. These resources provide methodological guidance, technical capabilities, and strategic perspectives applicable to the Spanish context.

Notable progress has been made in the Fourth Round of the END implementation in France, where a national database, PlaMADE, was adopted [9]. This database compiles essential data for the development of large-scale noise maps through automated processes using open-source modeling tools [10]. This method not only improves the efficiency of data processing but also provides a more comprehensive national overview of noise pollution, helping competent authorities develop informed noise reduction strategies.

The U.S. National Transportation Noise Map [6], developed by the Volpe National Transportation Systems Center, provides a large-scale visualization of noise exposure from transportation sources across the United States. It serves as a reference for national modeling using open datasets, integrating road, rail, and airborne noise data with demographic information. Similarly, the U.S. National Park Service Noise Map provides large-scale maps of existing acoustic conditions across the country, as well as a map of natural conditions, calculated from long term measurements of sound in national parks as well as urban and rural areas across the country [7].

As for open and collaborative tools, the *Noise Map Tool* [8] is an interactive dashboard that visualizes global noise pollution generated by aircraft and other modes of transportation. It compiles real-time aircraft positions and performs noise simulations to estimate hourly noise exposure near airports. Developed and maintained by Nawar Halabi, it exemplifies the potential of data-driven, web-based noise assessment platforms.

From a computational perspective, some works have highlighted the importance super-computing for noise assessments. For example, the work of Ming Cai et al. [11] presents methodologies for modeling urban traffic noise in complex 3D building environments using high-performance computing, which has implications for model refinement in dense urban areas. Also, the noise maps of major infrastructures in France from the Fourth Phase, previously mentioned, have been produced using supercomputing systems [10].

Together, these references, among others, lay the foundation for the national assessment of road noise pollution in Spain. They highlight the integration of standardized assessment frameworks (CNOSSOS-EU), the use of massive data, environmental considerations, and advanced computing as pillars of modern noise assessments.

4. METODOLOGY

The methodology outlined in the following sections focuses on the development, calculation, and calibration of a large-scale road traffic noise model in Spain. Much work remains to be done in the evaluation of results for the exposed population and impacts on the natural environment, aspects not addressed in this paper.

4.1 Geographical Scope of Study

The study area is the entire national territory. The calculation area is the entire territory located within 1,500 meters of any road axis (streets, roads, highways, and motorways) mapped in the National Geographic Institute's transport network database and considered capable of supporting road traffic.

Regarding distance calculation, in Stylianos Kephalopoulos et al. (2014) [3], a calculation distance of less than 800 meters is recommended. However, since that publication, the CNOSSOS-EU method has been corrected [12]. The propagation method is based on the ISO 9613-2 standard [13, 14], which does not establish a distance limit. The CEDEX CNOSSOS-EU technical application guide [15] establishes calculation distances greater than 2,000 meters for average daily traffic intensities greater than 300,000 vehicles. Since the propagation method is based on spherical divergence and attenuation and corrections due to atmospheric and environmental conditions, a 1,500 meters source-receiver distance is considered adequate for the purpose of this study.

[6] https://maps.dot.gov/BTS/NationalTransportationNoiseMap/
[7] https://www.nps.gov/subjects/sound/soundmap.htm
[8] https://noise-map.com

4.2 Software and Hardware Tools

NoiseModelling software [16] (NM) is used. *NoiseModelling* is a free and open-source tool designed to calculate noise maps in urban areas, as well as road, railway, and industrial source maps. As stated on its GitHub repository [9], it can be freely used for research, education, or by experts for professional use. NM has been used in various academic and institutional settings [10]. Of note is the creation of the French Government's strategic road noise maps, corresponding to the Fourth Round of END, through the creation of a national database, which feeds the NM software and allows for periodic updates of these maps [10]. The version of *NoiseModelling* used in this study was 4.0.5. According to the developers, this software reasonably complies with the ISO 17534-4:2020 standard checks for the application of the CNOSSOS-EU method.

The noise simulations were carried out using a high-performance workstation equipped with an Intel® Xeon® w9-3475X processor running at 2.21 GHz and 512 GB of installed RAM (fully usable). This equipment was provided to MITECO by the Center for Studies and Experimentation of Public Works (CEDEX) [11], Spain.

4.3 Data Sources for Acoustic Environment Modelling

The following data sources were used to design the acoustic environment, all from the official cartography of the Spanish National Geographic Information Center (CNIG) [12]:

Road transport network mapping, which includes all types of roads with traffic, from residential streets to major thoroughfares.

National Topographic Database (BTN), from which information on buildings, both residential and other types, is extracted.

Digital Terrain Model (DTM), at a scale of 1:25,000, used to obtain the topography.

Digital Building Surface Model (MDSnE2.5 2nd Coverage), used for automatic building height assignment.

[9] https://github.com/Universite-Gustave-Eiffel/NoiseModelling

[10] https://noisemodelling.readthedocs.io/en/latest/Scientific_production.html

[11] https://www.cedex.es

[12] https://centrodedescargas.cnig.es

4.4 Traffic Data and Emission Power Assignment

In CNOSSOS-EU method, the emission power of roads is obtained from their traffic intensity, pavement conditions and vehicle type distribution. The traffic intensity of main roads was obtained from the massive data provided by the Ministry of Transport and Sustainable Mobility [13]. This source offers traffic information for the main national roads and many sections of regional and provincial roads [14].

For the remaining roads for which traffic data are unavailable, the assignment was carried out according to the recommendations of the *Good Practice Guide for Strategic Noise Mapping and the Production of Associated Data on Noise Exposure* [17]. All roads have been assigned the CNOSSOS-EU reference pavement.

4.5 Calculation Process

The simulation process involved dividing the calculation area into 1,058 subdomains, each corresponding to one of the 25,000-scale sheets of the national topographic database. For each subdomain, specific layers were generated, including roads, buildings, a digital terrain model (DTM), and receptors. The calculations were launched by piloting the *NoiseModelling* software using scripts, as indicated in the official documentation [15]. However, it was also necessary to develop additional Python scripts to automatically generate and execute the corresponding software commands for batch processing.

Due to computational capacity constraints, the density of receptors was limited by applying a triangulation with a maximum mesh size of 2,500 m^2, which corresponds to a maximum spacing of 50 m between receptors. This triangulation was performed using the Delaunay algorithm implemented in the *NoiseModelling* software, which enables the refinement of receptor density in acoustically sensitive areas (e.g., near buildings), while reducing density in free-field zones. This approach optimizes the computational load without compromising accuracy in critical regions [18]. The evaluation periods, reflection order, meteorological conditions, and probable propagation conditions are those recommended in the CEDEX CNOSSOS-EU guide [15].

[13] https://www.transportes.gob.es/ministerio/proyectos-singulares/estudios-de-movilidad-con-big-data/opendata-movilidad

[14] https://mapas.fomento.gob.es/VisorHermes

[15] https://noisemodelling.readthedocs.io/en/latest/Get_Started_Script.html

After the simulation, the results were transformed into raster format by applying interpolation over the irregular triangular network, enabling spatial visualization and analysis of the acoustic indicators.

4.6 Calibration Procedure

The Strategic Noise Maps (SNM) of the Fourth Round of the Noise Directive (END) of the official agglomerations of A Coruña, Santander, Bilbao, Pamplona, Salamanca, Roquetas de Mar, Madrid, Barcelonès, Vallès Occidental I and II, Sevilla and Valencia were used for the calibration process.

A total of 8,696,039 point pairs were generated, each representing a spatial match between the simulated noise levels and the official SNM data. These point pairs were used to extract and compare values of the calculated noise levels and the reference data. A linear regression model was then applied to fit the simulated results to the official values. This linear transformation was applied to the raster layers of calculated noise levels.

5. RESULTS

5.1 Calculated Noise Map

Table 1 summarizes the descriptive statistics for the initial calculated road traffic noise simulation (LAEQ data), compared to the reference values (LAEQ_Ref) obtained from those points with values above 30 dB, resulting in a total of 8,696,039 valid records.

Table 1: Descriptive statistics of LAEQ and LAEQ_Ref (only values > 30 dB)

Statistic	LAEQ_Ref (dB)	LAEQ (dB)
Mean	56.17	59.75
Median	57.00	58.98
Std. Dev	10.60	11.85
Min	31.00	30.00
Max	101.00	96.80

As observed, the uncalibrated model tends to overestimate sound levels, with LAEQ values on average 3.6 dB higher than the references. Figure 1a shows the histogram of LAEQ distribution, with a peak between 55 and 60 dB, slightly shifted to the right of the LAEQ_Ref distribution.

The correlation between LAEQ and LAEQ_Ref was 0.575, and the linear regression model yielded the following equation:

$$L_{AEQ} = 23.6350 + 0.6429 \cdot L_{AEQ_{\text{Ref}}}, \quad R^2 = 0.331 \tag{1}$$

This indicates a moderate association, with only 33.1% of the variance explained by the reference values, and a slope significantly less than 1, suggesting a proportional underresponse of the calculated indicator relative to the reference. The weak association also indicates that there is no real linear correlation between the two variables. Noise data depend on a set of highly heterogeneous variables, and small variations in the input data can significantly alter the model's output [19].

5.2 Calibrated Noise Map

To correct the overestimation observed in the initial model, a calibration process was carried out using a linear regression adjustment. This yielded a calibrated indicator, LAEQ_Cal, which was subsequently used to replace the original values.

The calibration reduced the average estimated levels, bringing them closer to the reference values, as shown in Table 2.

Table 2: Descriptive statistics of LAEQ_Cal and LAEQ_Ref (only values > 30 dB)

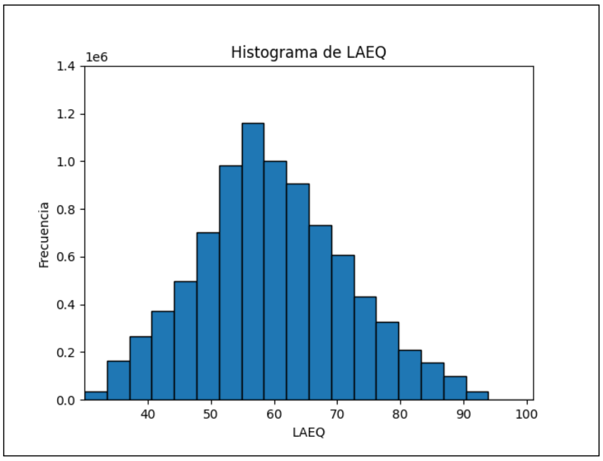
Statistic	LAEQ_Ref (dB)	LAEQ_Cal (dB)
Mean	56.17	54.22
Median	57.00	53.51
Std. Dev	10.60	10.41
Min	31.00	30.00
Max	101.00	86.68

Although LAEQ_Cal tends to slightly underestimate the reference values, the bias has been significantly reduced. The histogram in Figure 1b illustrates a shift of the distribution toward lower values compared to the original LAEQ.

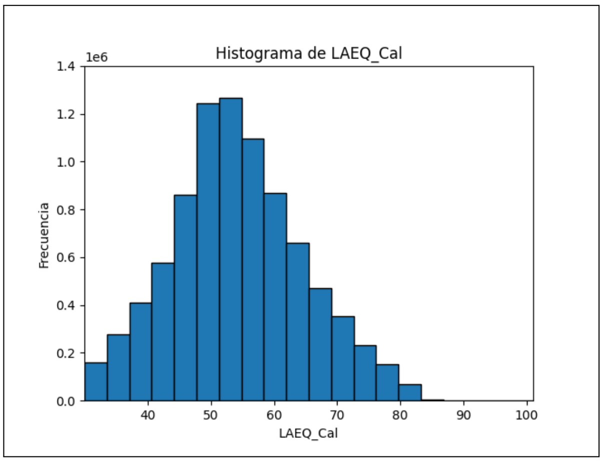
The adjusted regression model is:

$$L_{AEQ_{\text{Cal}}} = 22.0235 + 0.5732 \cdot L_{AEQ_{\text{Ref}}}, \quad R^2 = 0.340 \tag{2}$$

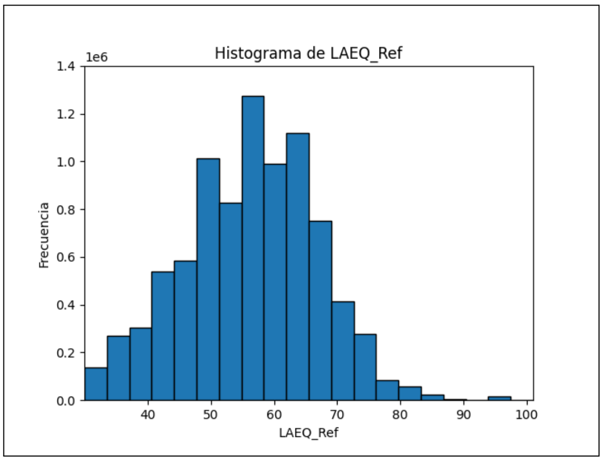
With a slightly improved R^2 and points correlation (from 0.575 to 0.583), the calibration enhances the consistency between calculated and reference values.



(a) Histogram of LAEQ (original calculated values).



(b) Histogram of LAEQ_Cal (after calibration).



(c) Histogram of LAEQ_Ref (reference values).

Figure 1: Comparison of LAEQ distributions before and after calibration, and reference values.

6. DISCUSSION

In the creation of a road noise map for Spain, significant differences were observed when compared to official strategic noise maps. Understanding these discrepancies is important for interpreting the data accurately and grasping the wider implications associated with noise pollution assessment and management.

One of the primary factors contributing to the difference between the calculated noise map from this work and the reference maps is the use of lower-precision source cartography, particularly regarding the digital terrain model employed. The DTM used in this study was less precise as a consequence of attempting to cover a larger calculation area within computational limitations. This inaccuracy inevitably leads to an underrepresentation of terrain-induced attenuation effects that are integral to interpreting noise propagation. According to Renterghem et al. [5], inaccuracies in urban noise mapping frequently stem from adjustments made to reflect the topographic characteristics of the area under consideration. The lack of rigorous terrain models can result in an inadequate reflection of real-world conditions, which is essential for properly modeling the effects of topography.

Furthermore, the absence of noise barriers in the calculated map remains another significant area leading to discrepancies. Noise barriers have a significant impact on reducing the levels of road traffic noise in adjacent areas, and their omission results in an overestimation of noise levels in shielded zones. Studies show that effective noise barriers can yield a reduction of up to 10 dB in sound pressure levels, indicating their importance in comprehensive noise assessments, as highlighted by Morley et al. [20]. Without these barriers, the calculated map fails to capture the corrective measures already implemented, leading to an overestimation of noise in some areas.

The varying mesh sizes utilized in the calculations create another layer of complexity affecting the outcomes. The calculated map's larger receiver mesh size leads to interpolation of results derived from the reference maps. When mapping noise on a larger scale, finer resolutions can capture localized variations that a coarser grid may overlook, thus leading to different noise exposure estimations. Differences in mesh size can substantially affect estimations, particularly when significant noise barriers or other mitigating factors spatially coalesce, as discussed by Hauge et al. [21].

Traffic data constitute another relevant difference. The current approach relies on data derived from sources other than official reference maps and, in some cases, applies generic traffic volume assignments based on road characterization. Reference maps are expected to employ more rigorous methodologies, likely integrating real-world traffic data that reflect precise traffic conditions. Consequently, this variation can lead to misalignment in the noise levels associated with particular roads, as variations in traffic flow and speed contribute significantly to the overall noise profile [19]. Moreover, the software implementing the CNOSSOS-EU standard demonstrates a substantial influence on the results obtained from the noise mapping procedure. Different software tools designed to comply with CNOSSOS-EU may yield variations in results, with discrepancies noted to exceed 5 dB in some studies, as indicated by Khan et al. [22].

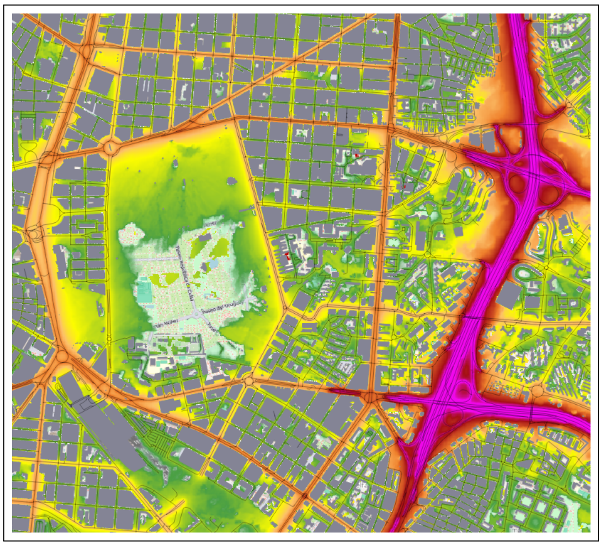


Figure 2: Overview of calculated road noise map for Spain.

The variability found is due to the accuracy of the traffic data, the precision of the design of the propagation environment, the use of different software, the availability of information such as noise barriers, etc. The multiple factors that influence the results of the noise assessment, in this case traffic noise, and the need to standardize methodologies are highlighted.

7. CONCLUSIONS

Despite the observed disparities, it is considered that the main objective of generating a noise map that encompasses all road traffic sources in Spain, regardless of whether they fall within the scope of the END, has been achieved. The objective was to provide a large-scale assessment, and it is generally considered acceptable within the limitations of the approaches adopted. The analysis performed presents significant, but at the same time reasonable and acceptable, discrepancies compared to the reference strategic noise maps.

8. FUTURE STEPS

Looking ahead, much work remains to be done to achieve a comprehensive view of noise pollution in Spain. Some of the most significant work already underway relates to large-scale studies of aeronautical, railway, and industrial noise. In addition, the methodology for studying other sources outside the scope of END and CNOSSOS-EU is currently being designed, such as noise from leisure activities, neighborhood activities, and events, which often cause significant disturbance to the population. The work already underway toward a comprehensive noise assessment in Spain is exciting.

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