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A proposal for producing calculated noise mapping defining the sound power levels of roads by street stratification

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A Proposal for Producing Calculated Noise Mapping Defining the Sound Power Levels of Roads by Street Stratification

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ABSTRACT

The European Noise Directive proposes using strategic noise maps as tools to assess populations affected by environmental noise. It recommends using computational methods instead of in situ measurements when possible. A sound source's emission power is an important factor in the calculation of noise indicators. For traffic noise, this parameter is usually defined based on vehicle flow considering an emission spectrum that depends on the type of vehicle and its speed. This study analysed the possibility of using the categorisation method to propose an alternative method of defining a sound source's emission power to develop noise maps. This was accomplished using previously published values of the emission power per unit length. Another method is also proposed that estimates traffic flows. To verify their estimation capacity, the results of both methods were compared with the values obtained from in situ measurements. The results demonstrated similar uncertainties in both methods and were in the range of expected average uncertainties compared to the results obtained by calculating a noise map with the measured experimental values. In particular, for the differences between calculations and measurements, in absolute values, the mean uncertainties were approximately 2 dBA in estimating different long-term noise indicators. For the differences, the mean of the uncertainties obtained via the categorisation method did not present significant differences for the null value for all the analysed noise indicators.

Street stratification is a rapid and low-cost approach for road traffic noise mapping without increasing uncertainties.

Keywords: environmental pollution; road traffic noise; categorisation method; noise measurement; health.

1. INTRODUCTION

The World Health Organization (WHO, 2018) highlighted the adverse effects of environmental noise on human health. Although different types of sound sources generate noise pollution, road traffic is commonly the dominant source (EEA, 2014). Some studies demonstrated different impacts of exposure to road traffic noise on human health such as sleep disorders with awakening (Muzet, 2007), learning impairment (Minichilli et al., 2018; Zacarías et al., 2013), hypertension ischaemic heart disease (Auger et al., 2018; Begou et al., 2020; Dzhambov & Dimitrova, 2018), and annoyance (Miedema & Oudshoorn, 2001, Sieber et al., 2018).

The European Noise Directive (END, 2002) introduced strategic noise mapping as a tool for assessing populations affected by environmental noise. Both in situ measurements and computational methods are listed in Annex I, although using calculation methods is recommended (WG-AEN, 2007). Regarding the calculations, diverse standardised models were used (COM, 2015; Harmonoise Project, 2005; NMPB-08, 2009;

NORD2000, 2002). Concerning measurements for noise maps, different strategies were employed to date in research on road traffic noise (Barrigón Morillas et al., 2018; Gómez Escobar & Pérez, 2018; Murphy & King, 2011; Quintero, et al., 2019; Rey Gozalo & Barrigón Morillas, 2016; Shakya, et al., 2019). The grid method was widely used in the scientific literature (Gómez Escobar et al., 2012; Martín et al., 2006; Oiamo et al., 2018). However, some studies indicated that it does not provide an accurate estimation of sound levels (Barrigón Morillas et al., 2011; Rey Gozalo et al., 2012). Based on the functionality concept, Barrigón et al. (2002) proposed the categorisation method. This technique was applied in cities with population sizes between 2,000 and more than 3,000,000 inhabitants. The number of sampling points per city was basically the same in this city size range (Barrigón Morillas et al., 2005; Rey Gozalo et al., 2015; Rey Gozalo et al., 2013). The results showed a significant stratification of sound indicators among the different categories and a high predictive capacity (Barrigón Morillas et al., 2018; Barrigón Morillas et al., 2015; Carmona del Río, et al. 2011; Rey Gozalo et al., 2015). The relationships between sound levels by street category and city size were also ascertained (Barrigón Morillas et al. 2010).

The criterion regarding the microphone's location is fundamental during the process of measuring urban noise (Mateus et al., 2015; Montes González et al., 2015). Several studies investigated the influence of microphone position on the corrections to be applied (Jagniatinskis & Fiks, 2014; Memoli et al., 2008; Montes González et al., 2020; Montes González et al., 2018a; Montes González et al., 2018b). In general, given the complexity of urban environments and the difficulty fulfilling the conditions established in Annex II of ISO 1996-2 (2017), the experimental values of these corrections may be very different from those indicated by this standard (Mateus et al., 2015; Montes González et al. 2015). The presence of different façade elements are also factors that should be carefully considered when comparing the measurements and calculations (Naish et al., 2014; Tang, 2010; Wang et al., 2015). It is important to note that buildings and urban environments are modelled in calculated noise maps by approximating their characteristics and details, so this complexity in real environments tends to be simplified (Arana et al., 2011; Lee et al., 2008; Montes González et al., 2020, Rey Gozalo et al., 2019).

Another important issue in calculating noise maps is defining the sound power (Rey Gozalo et al., 2020). For road traffic noise, this variable is currently defined using the flow of vehicles (Harmonoise Project, 2005; NMPB-08, 2009). In relation to the emission levels, some studies determined that there was a significant difference between the sound powers within a single vehicle category (Brown & Tomerini, 2011; Coensel et al., 2016; Watts, 2012). Brown and Tomerini (2011) found differences between 12 and 20 dBA in 90% of the vehicles in the same category on roads with speeds below 100 km/h. Watts (2012) reported differences of more than 10 dB between vehicles in the same category described using the Harmonoise model (2005). Coensel et al. (2016) concluded that the distribution of vehicle sound power levels affects the estimated levels by up to 4 dB. Thus, there are significant uncertainties in the results obtained using computational methods. The validity of numerical model calculations must be confirmed by conducting in situ measurements. Thus, considering all of the previously mentioned factors, WG-AEN (2007) and others (Bies & Hansen, 2002; Law et al., 2011; Licitra & Memoli, 2008) considered uncertainties of up to 5 dB.

Considering all of these uncertainties, some researchers assessed other alternatives that could reduce the production while maintaining acceptable uncertainty values. Zhao et al. proposed a new model of calculating noise maps based on the sound levels measured through a prior street classification (Zhao et al., 2017). Ausejo et al. (2010) produced a strategic noise map in Buenos Aires (Argentina) in which the daily traffic flow on any categorised road with no data extrapolated from traffic data obtained from major roads. Suárez and Barros (2014) implemented low-cost traffic noise maps in Santiago (Chile) using a street classification according to the official classification.

In this study, the evaluation of the capacity to estimate the emission power of road traffic lines is proposed using two approximate methods. In the first, a proposal is made to reduce the costs associated with traditional methods. In the second proposal, the objective is to analyse the possibility that the categorisation method can provide an alternative method of defining the sound source's emission power in noise maps using calculations. The results of both methods are compared with in situ measurements to assess their estimation potential.

2. METHODOLOGY

The sound field's behaviour and the source power's definition in noise mapping using calculation methods were produced by traffic flows and standardised (COM, 2015; NMPB-08, 2009). To define the emission power of a sound source, such as road traffic, the computational models use their own characteristics, such as vehicle flow according to the typologies, average speed, type of flow, and type of road surface. However, collecting the necessary data on each of a city's streets to ascertain the flows organised by vehicle categories according to the periods covered in END (2002) is not a simple, rapid, or cost-effective task.

To reduce production costs, this paper demonstrates the possibilities of using two different methods to define the sound source's power.

The first technique, method T (traffic, MT), determines the power in a similar mode to the standard way using traffic flows (WG-AEN, 2007). A simplified method of estimating traffic flows in two steps is proposed to minimise the high costs involved in obtaining noise maps, in which the traffic flow must be measured in each period for each street in a city. In the first step, the necessary data from the sound source (flow, typology, etc.) were recorded during two 15 min in situ measurements over different days and times in streets randomly chosen to study urban noise using the categorisation method. In the second step, the complete vehicle flows in every period (day, evening, and night) were estimated using the data from 20 fixed stations to measure hour-by-hour traffic flows provided by the city council of Cáceres (Spain) as a reference. That is, the city council's fixed stations were used to establish the daily flow at our measurement points proportional to the values obtained at said fixed points. Thus, the vehicle flows recorded in the short-term measurements could be extrapolated to estimate the flows at each street in the city during every time period using this method. Of note, to produce a noise map of an entire city, it is naturally necessary to sample every single one of its streets (WG-AEN, 2007).

In the second technique, method C (categorisation, MC), an alternative is proposed to define the sound source's emission power that was not previously studied with a very low implementation cost. This is based on applying the categorisation method, which allows the satisfactory stratification of urban noise (Barrigón Morillas et al., 2005), and therefore it is expected that the emission power will be successfully stratified in this same size range of cities. Five street categories are defined in this method:

- Type 1: Preferential streets for connection with other towns and interconnection of those preferential streets
- Type 2: Streets that provide access to major distribution nodes in a town or are used as an alternative to type 1 during traffic saturation

- Type 3: Streets that lead to regional roads, streets that provide access from street types 1 and 2 to centres of interest in a town (hospitals, shopping malls, etc.), and streets that clearly allow communication between street types 1 and 2
- Type 4: All of the other streets that clearly allow communication between the three previously defined types and the principal streets in a town's different districts that were not included in the previously defined categories
- Type 5: The rest of a town's streets except traffic-restricted streets

Considering this objective, results previously published by Rey Gozalo et al. (2014) were used. In this previous study, the sound power level per unit length (L_{Aw}) was calculated for each of the categories and each indicators L_d, L_e, L_n, and L_{den} included in END (2002). As a result of the study, a significant stratification of the five categories was obtained for the power corresponding to these indicators. These emission power values are used in the current paper as input data in the calculation model to define the sound source. That is, the second method enables the production of a noise map for all the city's streets while considering only a set of five emission powers for each period during the day. Consequently, the method's costs are focused on obtaining the emission powers via measurements. Once obtained, no more sound levels or traffic flow data are taken. This evaluates the categorisation method's capacity for producing noise maps by calculations.

To assess both methods, 32 new measurement points were selected on different balconies in Cáceres. Figure 1 shows a broad sample of the buildings in which the measurement points were located. The red circle points to the microphone's location. At these points, week-long measurements were conducted following the ISO 1996-2:2017 standard's indications using type I sound level meters such as Brüel & Kjær 2260 and Opera 01dB. Sound indicators L_d, L_e, L_n, and L_{den} used in the strategic noise maps were evaluated based on these measurements. The 32 points covered the five categories established in the categorisation method. This method verified that the noise maps obtained enabled the estimation of the noise levels during each of the periods established for all types of a city's streets from those with the highest traffic flows to neighbourhood streets. Of note, as a result of this control point selection method, a wide variety of situations were considered in the source's characteristics (number of lanes, road speed, type of traffic, traffic volume, etc.), propagation path (U- and L-shaped streets, different distances between the source and receiver, presence or absence of parking lines, etc.), and measuring points (variety of the morphology of facades considered).

Figure 1. (a) to (p) Examples of the façade structure of the buildings where the measurement points were located.

The results of noise indicators L_d, L_e, L_n, and L_{den} from this new long-term measurement campaign were compared with values estimated by computational techniques using the two previously described methods to establish each road's sound power. For the calculations using these methods, a model of Cáceres with 3,020 buildings and 960 roads was produced with CadnaA software v2018 using the NMPB-08 method (2009) and following WG-AEN (2007). The following factors were considered in these calculations: first-order reflection, default values of meteorological conditions (toolkit 17), building height (toolkit 15) of 4 m for the ground floor and 3 m for each additional floor, and vehicle speed (toolkit 3), the maximum allowed for each street. Figure 2a presents the model of Cáceres, and Figure 2b includes the levels calculated in one of the areas studied through measurements.

In this calculation model, the receivers were located at the actual measurement distances. Figure 1 shows significant examples of the usual architectural complexity of the city's building façades. The presence of unevenness in the areas near the microphone locations was associated with different elements and constructive solutions: windows, outgoing balconies, incoming balconies, gaps in the walls, and façade limits near the measurement points. Given the structural complexity of the façades and the prior studies (Naish et al., 2014; Tang, 2010; Wang et al., 2015), the absence of sound reflections was considered at most of the measurement points because there were protrusions, recesses, or unevenness around the microphones higher than the ISO 1996-2:2017 standard's values (see Figure 1). Only in those façades in which these elements or slopes were scarce, small, or far from the measurement points was the presence of reflection on the façade considered.

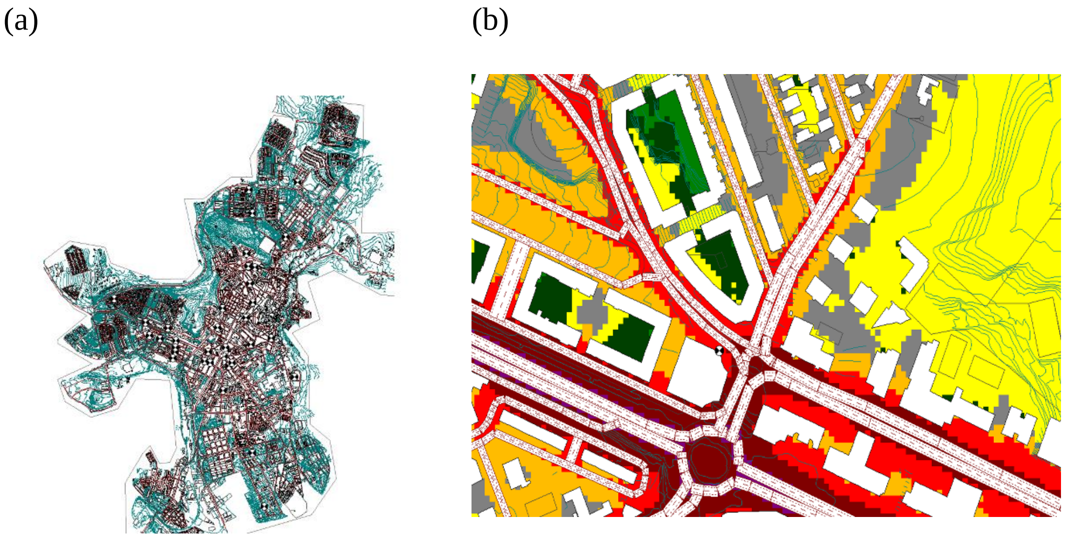
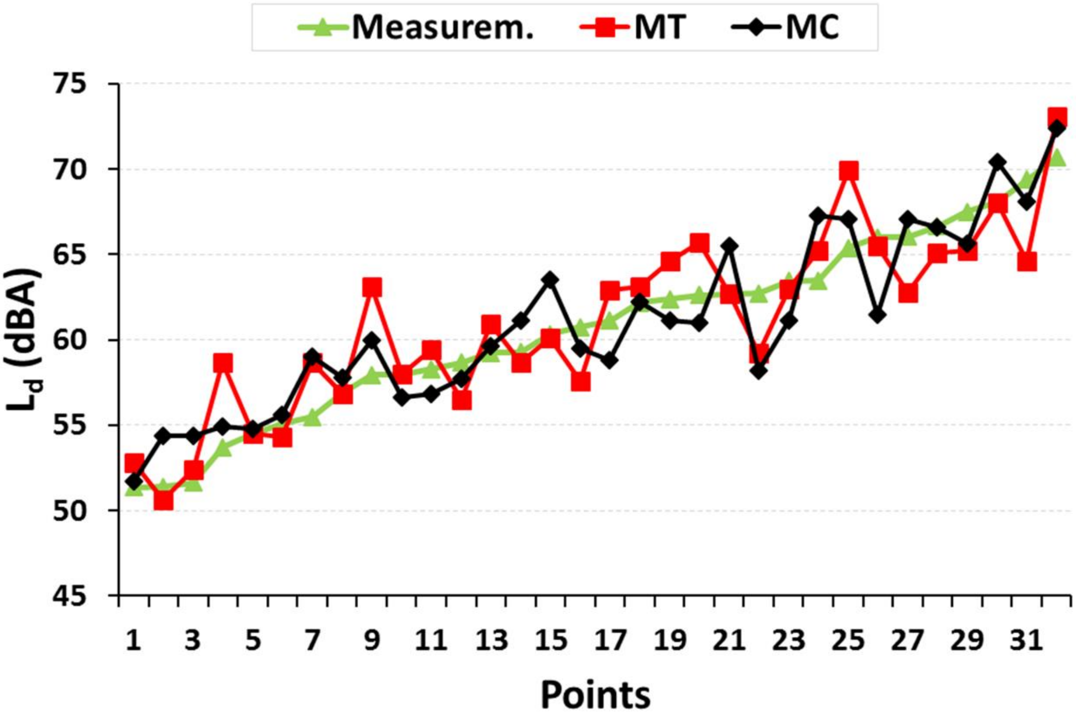


Figure 2. (a) Model of Cáceres. (b) Representation of the noise levels calculated around one of the points studied.

3. RESULTS AND DISCUSSION

To analyse the proposed methods' capacity to define the sound source power introduced in the calculation models of the strategic maps of urban noise originated by road traffic, the results obtained using the two models (MT and MC) were compared with the measurements conducted at the 32 measurement points. Figure 3 shows the noise indicators' values (L_d, L_e, L_n, and L_{den}) obtained at the evaluation points from the measurements and the calculations produced using both methods. To make it easier to visualise and maintain the same point order for all the indicators, the criterion ordered them in increasing value for the L_d levels measured. Naturally, given the criterion used for the representation, the measured values had a more uniform trend than the calculated values. Figure 3 shows that the measured results were generally close to or between those calculated and there was a similar trend in the results obtained through measurements and those obtained using the two calculation methods.

(a)


Measurem.
MT
MC
75
70
65
60
55
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45
L_d (dBA)
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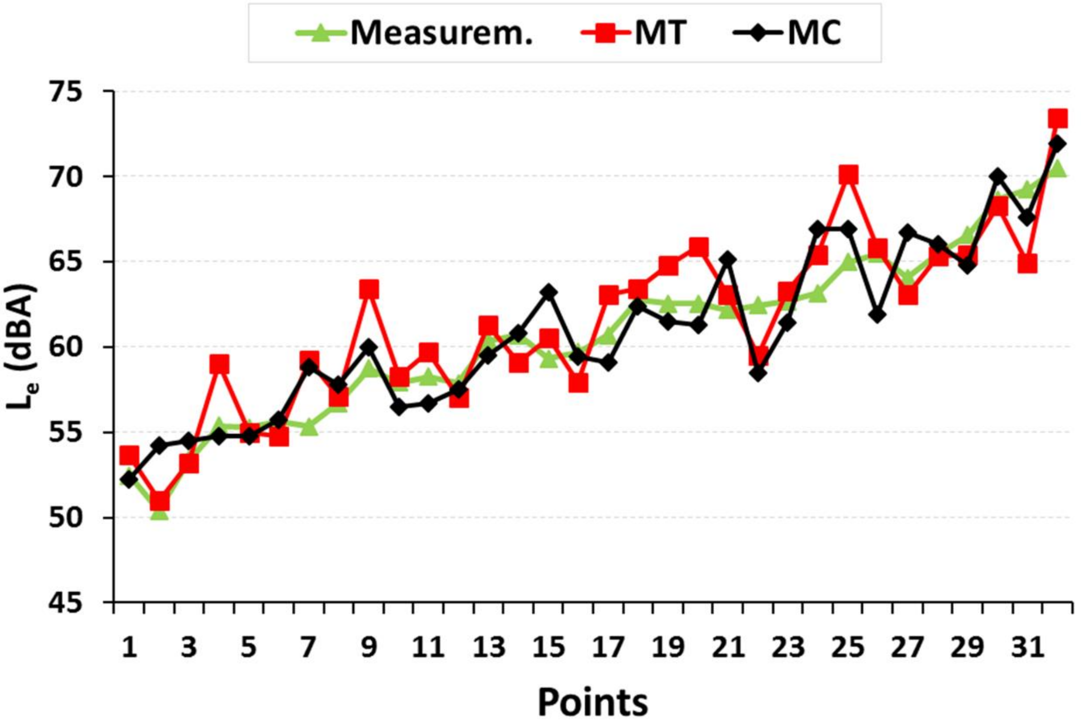
31
Points

(b)


Measurem.
MT
MC
L$_e$ (dBA)
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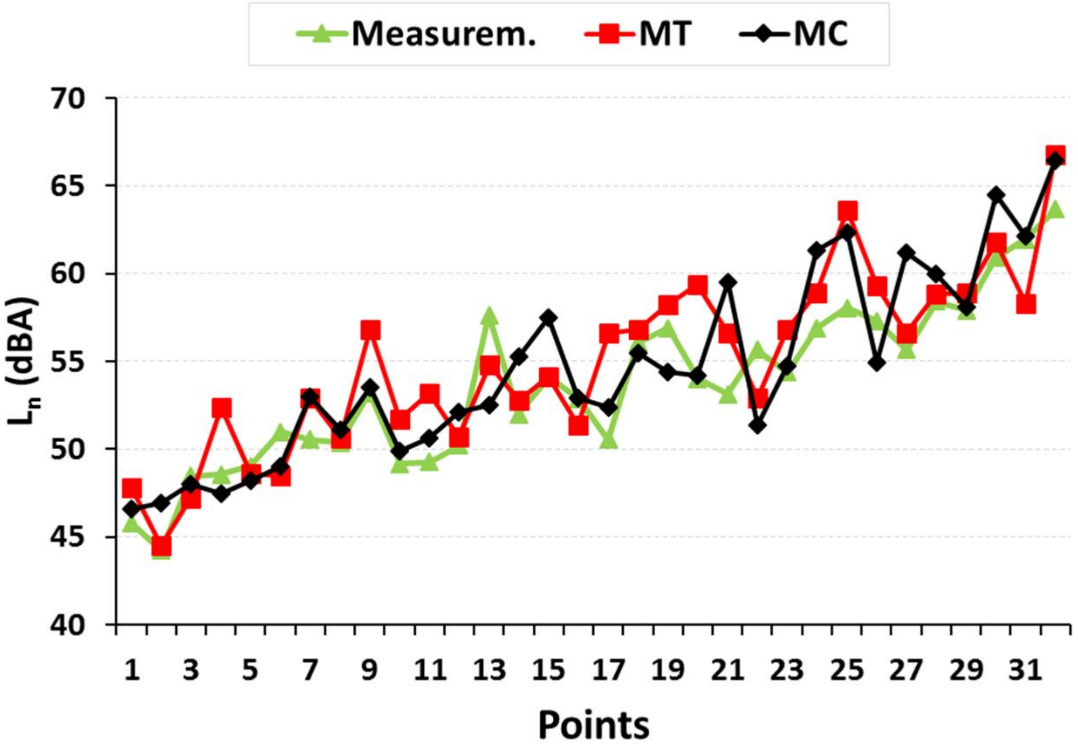
(c)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L$_n$ (dBA)
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(d)

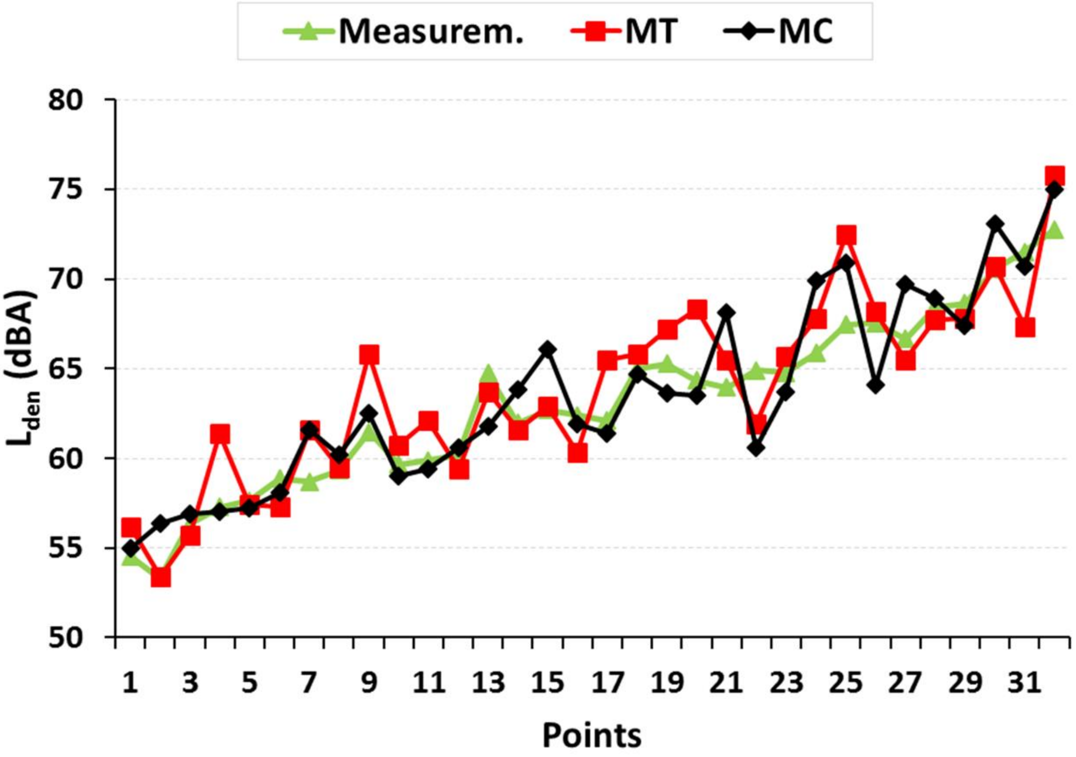


Figure 3. Sound indicators obtained at each measurement point using measurements and both simulations. (a) L_d, (b) L_e, (c) L_n, and (d) L_{den}.

To analyse the goodness of the results obtained using both methods, a comparison of the differences' means of the sound level indicators L_d, L_e, L_n, and L_{den} simulated with the values obtained from the long-term measurements was made. First, to analyse if there was a tendency in the calculated values, Table 1 shows the mean values of the difference and standard deviation in which the sign of the differences was considered. The results are presented for all the streets (global) and groups (main or neighbourhood streets).

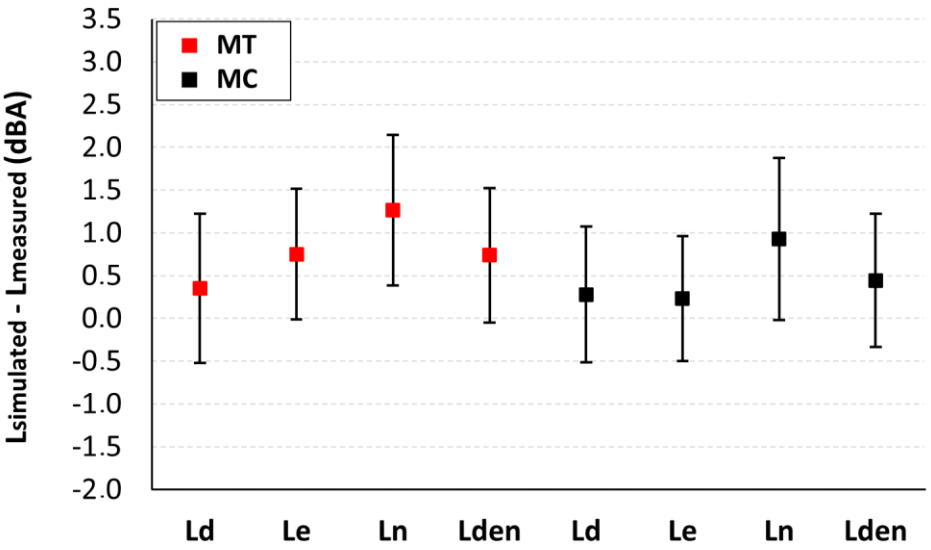
Table 1. Average differences in the sound indicators between the values calculated by both simulation methods and measurements

		$\Delta L_d \pm \sigma$ (dBA)	$\Delta L_e \pm \sigma$ (dBA)	$\Delta L_n \pm \sigma$ (dBA)	$\Delta L_{den} \pm \sigma$ (dBA)
MT	**Global**	0.3 ± 2.4	0.7 ± 2.1	1.3 ± 2.4	0.7 ± 2.2
	Main streets	0.4 ± 2.3	0.4 ± 2.4	1.4 ± 2.4	0.5 ± 2.2
	Neighbourhood streets	1.2 ± 2.4	1.2 ± 2.2	1.1 ± 2.5	1.1 ± 2.2
MC	**Global**	0.3 ± 2.2	0.2 ± 2.0	0.9 ± 2.6	0.3 ± 2.2
	Main streets	0.3 ± 2.5	0.0 ± 2.4	1.3 ± 2.9	0.4 ± 2.5
	Neighbourhood streets	1.0 ± 1.6	0.5 ± 1.6	0.5 ± 1.6	0.6 ± 1.7

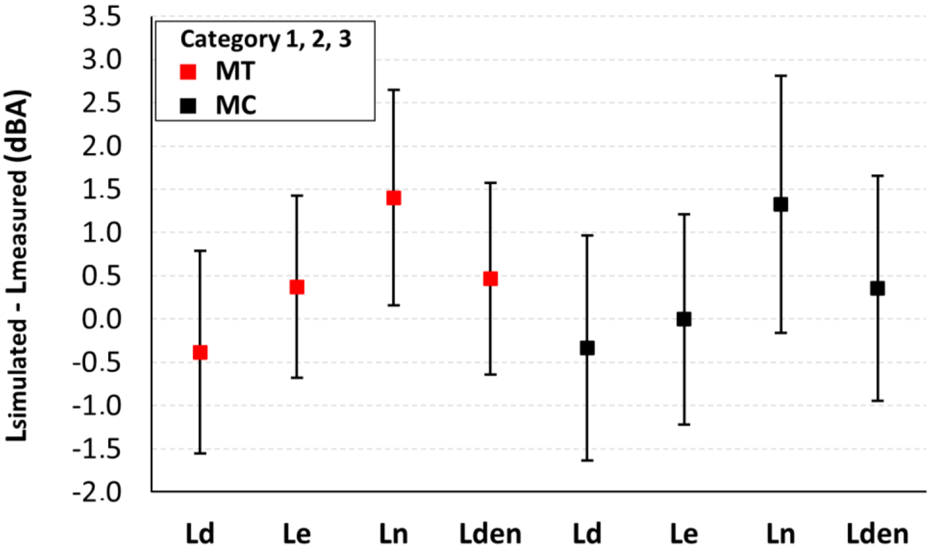
The mean indicator and group values obtained were positive using both methods. This may indicate that both methods of defining the source power predicted levels that were far from the measurements in both directions but with slightly higher calculated values than those measured (Bastián-Monarca et al., 2016). However, when both methods were compared, method C (in which the source powers were obtained from the categories proposed using the categorisation method) had mean results closer to zero. This may have occurred because the sound source's emission power associated with traffic, when defined by flow only, produced a variable that influenced the power in an important way: for speed in the models, the road's limit value was usually used, while for the power defined from the average powers per category, this effect disappeared. When the results were analysed by grouping the streets into main and neighbourhood streets using both methods and all the indicators, except for L_d, the main streets were those in which the differences with respect to zero were the smallest and the group corresponding to the neighbourhood streets was the farthest from this value. Of note, the null value was in the standard deviation's variability range in all the cases.

For a more detailed analysis of the mean values and their variability range, Figure 4 shows the mean differences' values with their 95% confidence intervals. In general, in both the global values and those corresponding to the main and neighbourhood street groups, the presented confidence intervals included the null value in its variability range. However, this did not occur for indicator L_n in some cases, in particular for the overall values and those of the main streets group using the T and C methods for the neighbourhood streets group.

(a)



(b)



(c)

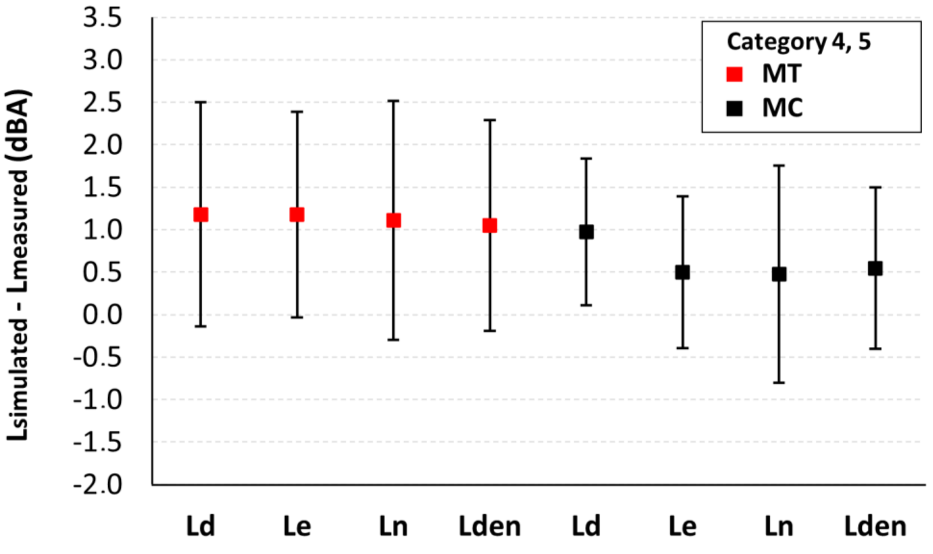


Figure 4. Values of the sound indicators' mean differences calculated using both the simulation methods and measurements with their 95% confidence intervals for (a) all the streets, (b) main street group, and (c) neighbourhood street group.

The t-test was used to accept or reject the hypothesis that the averages differed from the null value. The results shown in Table 2 indicate that, for method T for the global streets, the L_e and L_n indicators did indeed have mean values other than zero (p value < 0.05). In contrast, for method C, there were no significant differences between the mean values found and the null value (p value > 0.05). This indicated that method C better defined the emission power. In particular, the indicators related to the population's rest schedule and therefore those most related to the nuisance L_e and L_n were better estimated from the power of the source obtained using the categorisation method (method C) than from the estimation of the traffic flows (method T).

Table 2. P values of the differences with respect to the null of the mean values of the differences. Comparisons include the measurements of the different sound indicators calculated using both methods.

		***P* value** ΔL_d	***P* value** ΔL_e	***P* value** ΔL_n	***P* value** ΔL_{den}
MT	**Global**	0.422$^{n.s.}$	0.049*	0.006**	0.065$^{n.s.}$
	Main streets	0.498$^{n.s.}$	0.465$^{n.s.}$	0.030*	0.388$^{n.s.}$
	Neighbourhood streets	0.076$^{n.s.}$	0.056$^{n.s.}$	0.113$^{n.s.}$	0.092$^{n.s.}$
MC	**Global**	0.482$^{n.s.}$	0.525$^{n.s.}$	0.055$^{n.s.}$	0.254$^{n.s.}$
	Main streets	0.591$^{n.s.}$	0.994$^{n.s.}$	0.077$^{n.s.}$	0.574$^{n.s.}$
	Neighbourhood streets	0.299$^{n.s.}$	0.252$^{n.s.}$	0.438$^{n.s.}$	0.239$^{n.s.}$

However, for noise maps, it is preferable to know the absolute differences between predictions and measurements. Thus, the rest of this section is dedicated to thoroughly analysing the goodness of the results obtained in absolute values. Table 3 shows a comparison of the means of the differences of the sound indicators L_d, L_e, L_n, and L_{den} simulated using both methods with the values obtained from the long-term measurements

(L_M) in which the absolute value was considered. The results are presented for all the streets (global) and groups (main or neighbourhood streets).

An analysis of the absolute values demonstrated that the mean values were approximately 2 dBA for both methods and all the indicators, while the deviations were close to 1.5 dBA. The L_e and L_{den} indicators had the smallest mean differences, while L_n had the largest. This may have been due to the sources' high variability at night (Brown & Tomerini, 2011; Watts, 2012). The highest standard deviation was recorded during this period. A comparison of the two methods of defining the power of the sound source from the results given in Table 3 shows that, systematically, the means of the absolute values of the differences were somewhat lower using method C than method T. When the average of the differences between the sound levels were compared using the t-test, no significant differences were found between the two methods for all the sound indicators and groups analysed.

Table 3. Average differences in the sound indicators between the values calculated using both simulation methods and measurement

		$\Delta L_d \pm \sigma$ (dBA)	**$\Delta L_e \pm \sigma$ (dBA)**	**$\Delta L_n \pm \sigma$ (dBA)**	**$\Delta L_{den} \pm \sigma$ (dBA)**
MT	**Global**	1.9 ± 1.6	1.7 ± 1.4	2.2 ± 1.6	1.8 ± 1.4
	Main streets	1.8 ± 1.4	1.6 ± 1.2	2.2 ± 1.7	1.7 ± 1.3
	Neighbourhood streets	1.9 ± 1.8	1.8 ± 1.7	2.2 ± 1.5	1.8 ± 1.6
MC	**Global**	1.8 ± 1.2	1.6 ± 1.2	2.1 ± 1.8	1.7 ± 1.3
	Main streets	2.1 ± 1.3	1.9 ± 1.2	2.5 ± 1.9	2.0 ± 1.5
	Neighbourhood streets	1.5 ± 1.0	1.2 ± 1.1	1.7 ± 1.5	1.4 ± 1.2

To fully understand the way the absolute differences between the calculated and measured values were distributed in the set of control points used in this study and to better understand the potential of the methods proposed for defining the emission power of traffic lines, their distribution is presented in class intervals of 1 dBA. This made it possible to analyse in more detail the global results found whose mean values are provided in Table 3. Figure 5 shows the statistical distribution, and Figure 6 presents the cumulative distribution using a class interval of 1 dBA. The errors in the intervals between 0–1 dBA and 1–2 dB were basically in the range of 20% to 45%. This implies that, in the cumulative distribution (Figure 5), the 0–2 dBA interval was basically in the range of 60% to 75%. The 2–3 dBA interval had values generally ranging from 10% to 25%. This means that the cumulative distribution between 0 and 3 dB had proportions that, for all indicators and both calculation procedures, were higher than 70% and reached values above 80% for indicator L_e in both methods and indicator L_d for method C. For the remaining class intervals, Figure 5 shows that, in general, they were in a range of 0% to 15% using both methods and all the indicators, and the 3–4 dBA class interval had the highest values, ranging between 10% and almost 20%. As a result (Figure 6), the cumulative distribution led to values of approximately 90% using both methods and the majority of the indicators. In any case, method C for indicator L_n reached a cumulative value of approximately 80%, while for indicator L_e, this range already represented 100% of the values. This better result of method C can also be observed in the cumulative range of 0–5 dBA. Thus, method C presented a better estimate of almost all the noise indicators so that the differences between the calculated and measured values did not differ by more than 5 dB in 100% of the cases, except for the night indicator, in which both methods reached more than 90%.

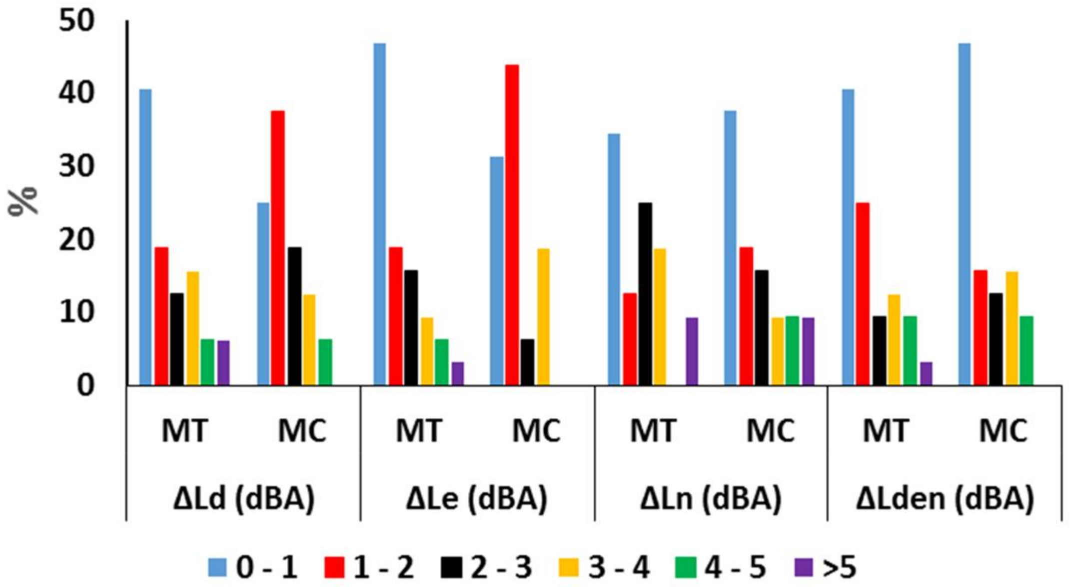


Figure 5. Statistical distribution of the absolute values of the differences between the values calculated using the two methods and the measurement results in class intervals of 1 dB.

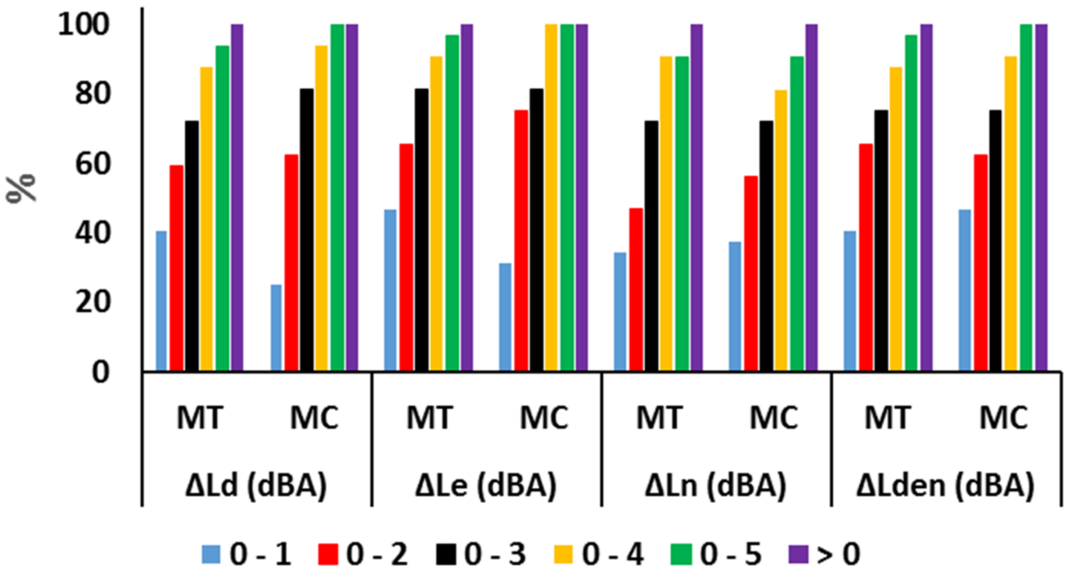


Figure 6. Cumulative distribution of the absolute values of the differences between the values calculated using both methods and the measurement results with a class interval of 1 dB.

Considering the different sources of uncertainty analysed in the literature, the statistical and cumulative distribution of the differences between the results of the calculation models and measurements shown in Figures 4 and 5 were within the expected values. These values were similar to those in other studies that found differences of up to 5 dB between measured and calculated sound levels (Bies & Hansen, 2002; Licitra & Memoli, 2008). A series of factors inherent in noise mapping and measurement can contribute to this range of uncertainty. WG-AEN (2007), analysing the uncertainty of evaluation data, indicated differences in environmental noise measurements within 5 dBA at the same site on different days. WG-AEN (2007) also indicated an accuracy of 4 dB when official traffic flow data were used for typical road types. Arana et al. (2011) suggested that uncertainties associated with terrain models can lead to errors up to 3 dB. Other factors, such as the presence of parking lanes in an urban environment not considered in noise mapping, may cause uncertainties even greater than 4 dB (Montes González et al., 2020). Similarly, other researchers reported uncertainties associated with the presence of building elements on façades not considered in models when evaluating the sound level measured by a microphone (Naish et al., 2014; Tang, 2010; Wang et al., 2015). Coensel et al. (2016) found uncertainties affecting the power of the sound source of up to 4 dB concerning model variables, such as driving style, vehicle speeds, or traffic flow. Naturally, if a combined uncertainty associated with all these calculation models' uncertainties is considered in the way that, for example, the ISO 1996-2:2017 standard is used to calculate the measurement uncertainty, the value obtained would be higher than the maximum independent values presented. This suggests that calculation uncertainties have the same order as measurement uncertainties, that is, with values exceeding 5 dBA.

Furthermore, the slightly worse behaviour of the two methods at night was neither surprising nor a problem in the quality of the results. Previous studies also indicated a greater dispersion of results in this time range (Licitra & Memoli, 2008). Of note, it is difficult to maintain the same degree of precision in night-time methods as in daytime methods, mainly because of the significant decrease in traffic flow during the night. If it is added to low traffic flows, the variations in the emission power of the different types of vehicles can result in very important variations in sound levels. As previously discussed in the introduction, Brown and Tomerini (2011) found differences between 12 and 20 dBA in 90% of the vehicles in the same category on roads with speeds below 100 km/h, and Watts (2012) reported differences of more than 10 dB between vehicles in the same category that were described in the Harmonoise model (2005).

Therefore, taking into account the results and the bibliographical discussion, the proposed methods present uncertainties in the range of those expected. Moreover, they represent a good alternative for assessing noise maps, especially in cases where there is a lack of economic, technical, or human means of carefully applying WG-AEN's recommendations (2007).

Although both methods provide acceptable and comparable results, it is important to analyse their differences, the novelty they represent in methodological terms, and their advantages in terms of resource requirements. With respect to the results, method C behaved somewhat better than method T. Regarding novelty, method T has the same foundations as those currently applied, while method C represents a basic novelty by defining the power of the sound source from the strata proposed by the categorisation method based on the usefulness of the streets as a communication system. Finally, with respect to resources, in method T, it is still necessary to sample all the streets of a city to produce a noise map. However, in method C, once a relatively small set of streets has been sampled, it is possible to define an emission power for all the streets of the city.

Furthermore, in the range of cities studied using the categorisation method, the number of streets sampled is independent of a city’s size.

Owing to these reasons, the results showed that method C, based on the estimation of noise indicators from the sound power obtained using the categorisation method, can be considered an interesting alternative for defining the sound power of traffic lines in noise maps. Of note, this proposal, with similar uncertainties to those of methods based on traffic flows, implies a significant reduction in resources necessary for noise mapping, which are greater in larger cities. In addition, as this method is based on emission power by street categories, it allows predictions of noise levels in cases in which the authorities modify the functionality of streets, establish new traffic regulations, or propose new urban development.

4. CONCLUSIONS

Two methods were proposed and studied to define the power of the noise source associated with urban traffic in noise mapping. The first method, based on flow, reduced costs by proposing a system for estimating traffic flow. The second method, based on the categorisation method, was used to define the source’s emission power from a limited sample of a city's streets.

The results demonstrated similar uncertainties for both methods. Considering the consulted literature, the values were in the range of the expected uncertainties when comparing the results obtained by calculating a noise map with the measured experimental values. In particular:

- In the differences, in absolute values, between the results of the measurements and those calculated:

    - Both methods had average uncertainties of approximately 2 dBA in estimating the different sound indicators.
    - No significant statistical differences were found between the results obtained using both methods.
- In the differences, considering the sign, between the results of the measurements and those calculated:
    - With both methods, the calculated values obtained were somewhat higher than those measured, and those obtained using method T were higher.
    - For indicators L_e and L_n, method T demonstrated significant differences from the null value, while method C showed no significant differences from the null value in any of the indicators.

Therefore, the proposals studied can represent an alternative for the assessment of noise maps. Above all, their application can be of considerable interest when:

- A rapid and low-cost approach for assessing a noise map is preferable without increasing the results' uncertainty and to understand a city's noise pollution.
- Producing noise maps in towns that are not required to do so, but the authorities are interested in understanding the noise pollution with uncertainties similar to those of other traditional methods.

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Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

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Juan Miguel Barrigón Morillas: Conceptualization; Data curation; Formal analysis; Funding acquisition; Investigation; Methodology; Project administration; Resources; Supervision; Validation; Visualization; Roles/Writing - original draft; Writing - review &editing. **David Montes González:** Conceptualization; Formal analysis; Funding acquisition; Investigation; Methodology; Supervision; Validation; Visualization; Writing - original draft; Writing - review &editing. **Valentín Gómez Escobar**: Data curation; Formal analysis; Investigation; Methodology; Software; Validation; Writing - review &editing. **Guillermo Rey Gozalo**: Conceptualization; Formal analysis; Funding acquisition; Investigation; Methodology; Validation; Visualization; Writing - review &editing. **Rosendo Vílchez Gómez**: Formal analysis; Investigation; Methodology; Validation; Visualization; Writing - review &editing.