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Partial equivalent sound pressure level as an approach to manage irrelevant sounds in environmental noise measurements

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ABSTRACT

Residual sound and unwanted events are known factors affecting the accuracy of environmental noise measurements. ISO 1996-2 provides methods to manage these irrelevant sounds, for example by applying correction factors, but the methods require a degree of knowledge of the irrelevant sounds that is not always practical or possible to obtain when performing long-term measurements with unattended monitoring stations in complex urban soundscapes. While automatic detection of irrelevant sounds provides the required information, it also allows for new approaches not described in ISO 1996-2. In this paper, we discuss a metric called partial equivalent sound pressure level (Partial L_{eq}), calculated after data samples with residual sound and unwanted events are identified automatically and replaced by project-specific values. Our hypothesis is that better estimates of equivalent sound pressure levels (L_{eq}) can be achieved with this metric, compared with the general methods given in ISO 1996-2. Comparisons of results are presented, together with a discussion of applicability of the Partial L_{eq} metric and experiences gathered from its use.

1. INTRODUCTION

Measurement of environmental noise can be a challenging task in complex urban soundscapes, particularly when multiple noise sources are active simultaneously, but the sound pressure level of a single sound source is of interest. This is a common scenario in urban areas where requirements to sound pressure level are given for specific noise sources such as construction sites, landing platforms, and industrial noise, among others. In such scenarios, the contributions from the irrelevant sound sources must be identified and managed – for example, according to the methods described in ISO 1996-2 [1] for handling residual sounds and unwanted events.

The methods described in ISO 1996-2 for the management of residual sounds and unwanted events require knowledge of the irrelevant sound sources: their sound pressure level, and both the time interval and time stamp of the contributions. These characteristics

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can be straightforward to obtain in attended short-term noise measurements, but the analysis is more time consuming, and not always feasible, in long-term measurements with unattended noise monitoring terminals.

Latest advancements in urban noise source identification provide the required information by identifying the direction of arrival of the dominant sound [2] [3] [4] [5] and/or analyzing the spectrum of the signal with artificial intelligence [6] or by other means [3]. However, the degree of knowledge of the irrelevant sound sources that can be achieved allows for approaches that are not described in ISO 1996-2.

In this paper, we discuss a metric called partial equivalent sound pressure level (PL_{eq}), where data samples that are automatically identified as residual sounds and unwanted events are replaced by project-specific values. We compare results provided by this metric with results calculated with the approach described in ISO 1996-2. Our hypothesis is that better estimates of equivalent sound pressure level can be achieved with PL_{eq}.

There are other factors affecting the accuracy of environmental noise measurements, such as weather and ground conditions. These are well described in ISO 1996-2 and outside the scope of this paper. Furthermore, the analysis presented in this paper is restricted to A-weighted single-number quantities. Approaches based on band-limited noise, or which depend on the frequency content of the noise, are not discussed.

2. BACKGROUND

In this section, we present an overview of the methods described in ISO 1996-2 and the current use of the term $L_{eq,T,partial}$.

2.1. Management of irrelevant sounds according to ISO 1996-2

ISO 1996-2 states that all data including unwanted events or with too high residual sound must be removed before evaluating the measurement results, where residual sound is defined as all noise other than the specific sounds under investigation. Furthermore, the standard describes methods to minimize the impact of irrelevant sounds (for example, selection of measurement site, use of directional microphones, blocking unwanted sounds with a screen and selecting quiet intervals for measurements) and/or to manage them (for example, application of correction factors).

According to the standard, the level gap between average residual sound and the onset of a measurement shall be at least 3 dB and preferably more than 5 dB. If the sound pressure level of residual sound is ≤ 3 dB below the measured sound pressure level, no corrections are allowed. The measurement uncertainty is, in such a case, large and the requirements of the test methods are not fulfilled. If the sound pressure level of the residual sound is > 3 dB below the measured sound pressure level, the level is corrected according to:

$$L = 10\log\left(10^{L'/10} - 10^{L_{res}/10}\right)\ \mathrm{dB}, \tag{1}$$

where L is the corrected sound pressure level, L' is the measured sound pressure level and L_{res} is the residual sound pressure level.

Annex I in ISO 1996-2 describes how to estimate the sound pressure level of residual sound L_{res} by percent exceedance level.

The standard also addresses the management of unwanted discrete sound events, establishing that these shall be verified by correlation with a known event, using previous experience or earlier attended measurements. Non-relevant events shall then be dismissed.

Even though the standard does not provide specific guidance about how to, in practice, dismiss or remove data with too high residual sounds or unwanted events, the methods described for treatment of incomplete or corrupted data can be followed: a) sound level calculations are modified appropriately so that the averaging process is carried out over only those hours for which data is valid or available; or b) only hours with valid data is taken into account.

2.2. Current use of the metric $L_{eq,T,partial}$

Currently, a metric for the equivalent sound pressure level contribution from a sound source called $L_{eq,T,partial}$ is being used in France. The equivalent sound pressure level $L_{eq,T}$, measured for a given time window T and containing the contributions of all sound sources, is referred to as a global metric ($L_{eq,T,global}$):

$$L_{eq,T,global} = 10\log\left(10^{L_{eq,T,partial}/10} + 10^{L_{eq,T,residual}/10}\right)\text{ dB}, \tag{2}$$

where $L_{eq,T,partial}$ is the contribution from a source of interest and $L_{eq,T,residual}$ is the contribution from the irrelevant sources. An example of the use of these metrics can be found in [7]. In this way, one or more $L_{eq,T,partial}$ results can be extracted from $L_{eq,T,global}$ and directly compared to specific requirements that apply for air traffic, railway noise and industrial plants, among others.

While the use described above is intuitive, the term $L_{eq,T,partial}$ is not a standardized metric and the authors are not aware of the term being used outside France. Furthermore, decomposing the global equivalent sound pressure level into partial and residual contributions still requires detailed knowledge of the relevant and/or irrelevant sound sources.

3. THEORY

Our proposed use of the term *partial* $L_{eq,T}$ ($PL_{eq,T}$), is based on knowledge of the relevant and irrelevant sound sources, so that, by managing irrelevant sounds:

$$PL_{eq,T} \approx L_{eq,T,source}, \tag{3}$$

where $L_{eq,T,source}$ is the equivalent sound pressure level of the source of interest.

Knowledge or identification of the sound sources, both relevant and irrelevant, can be achieved in several ways already mentioned in the cited literature. Although our experience with noise monitoring has shown that there are instances where it is not possible to identify components as either relevant or irrelevant with a high degree of plausibility when several sound sources are simultaneously active, it is still possible to divide the residual sound contribution L_{res} into two parts:

$$L_{res} = 10\log\left(10^{L_{irrelevant}/10} + 10^{L_{unknown}/10}\right)\text{ dB}, \tag{4}$$

where $L_{irrelevant}$ gathers components that have been classified as irrelevant with a high degree of plausibility and the components represented by $L_{unknown}$ are both relevant and irrelevant sounds which could not be classified with a satisfactory degree of plausibility.

Equation (4) allows expressing the measured equivalent sound pressure level as:

$$L_{eq,T} = 10\log\left(10^{L_{eq,T,source}/10} + 10^{L_{eq,T,irrelevant}/10} + 10^{L_{eq,T,unknown}/10}\right)\text{ dB.} \quad (5)$$

In the situation where the relevant and irrelevant sound sources are simultaneously active, noise contributions are classified depending on the dominant sound source. Therefore, simply eliminating $L_{eq,T,irrelevant}$ would imply that the sound source of interest was not active in a given time period, resulting in an equivalent sound pressure level that might not be representative of the actual operational conditions. A better approximation could be achieved by giving $L_{eq,T,irrelevant}$ a level that is representative of the sound source of interest when its sound is not dominant in the soundscape. The basis for $PL_{eq,T}$ then resides in selecting an appropriate value for $L_{eq,T,irrelevant}$ so that equation (3) holds and a better approximation of $L_{eq,T,source}$ is obtained. Since $L_{eq,T,unknown}$ contains components emitted by the sound source of interest, together with other sounds, the term should be kept intact for further data analysis. Defining $L'_{eq,T,irrelevant}$ as a term where the irrelevant components are assigned a value that is different from the measured one, the equation for $PL_{eq,T}$ is obtained:

$$PL_{eq,T} = 10\log\left(10^{L_{eq,T,source}/10} + 10^{L'_{eq,T,irrelevant}/10} + 10^{L_{eq,T,unknown}/10}\right)\text{ dB,} \quad (6)$$

In the following, different approaches for establishing an appropriate value for $L'_{eq,T,irrelevant}$ are presented.

3.1 $PL_{eq,T}$ and approaches to establish $L'_{eq,T,irrelevant}$

Different alternatives to establish an appropriate level for $L'_{eq,T,irrelevant}$ have been evaluated:

a) Discarding the term $L'_{eq,T,irrelevant}$. With this approach,

$$PL_{eq,T} = 10\log\left(10^{L_{eq,T,source}/10} + 10^{L_{eq,T,unknown}/10}\right)\text{ dB.} \quad (7)$$

This is equivalent to applying the correction given by equation (1). This approach is considered as the least conservative, since it assumes that that the sound source of interest was not active while the irrelevant sound sources were dominant.

b) Setting $L'_{eq,T,irrelevant} = L_{eq,T,unknown}$. Since $L_{eq,T,unknown}$ may contain components from a variety of dominant sound sources, both relevant and irrelevant, setting $L'_{eq,T,irrelevant} = L_{eq,T,unknown}$ is considered as the most conservative approach provided that a large number of contributions lie within the "unknown" category. Our experience with noise monitoring shows that this is often the case.

c) Setting $L'_{eq,T,irrelevant} = L_{50}$ from computed percentage exceedance levels.

d) Applying corrections from Annex I in ISO 1996-2, where the level of residual sound is based on measurements of L_{50} and L_{90} or L_{95}.

e) Setting $L'_{eq,T,irrelevant}$ to a fixed value which is representative of periods when the source of interest is active, but not dominant. The alternatives tested in this study have been estimating an equivalent sound pressure level based on the average of repeated measurements of $L_{eq,T,unknown}$ over different days; and testing different levels relative to $L_{eq,T,source}$. Other approaches could be to measure the background noise without the source of interest being active, such as ISO 1996-2 recommends, but this is not always feasible and such measurements were not available for our study.

4. METHODS

The proposed use of the PL_{eq} metric was tested with actual measurements. The dataset used and some of the general metrics describing it are presented in this section. PL_{eq} results obtained with values of $L'_{eq,T,irrelevant}$ as described above, are given in the next section.

The actual measurements used were taken from the case study presented in a previous paper [2], in which sources were classified as relevant or irrelevant through their location in 3D space. By using a multi-microphone device and implementing a time-difference of arrival (TDOA) algorithm, the direction of arrival of the dominant sound was automatically identified. In those cases where sound sources could be associated to specific locations in azimuth and elevation with a high degree of plausibility, knowing the direction of arrival allowed for automatic classification of samples in pre-defined sectors describing the contributing sound sources.

An example of classification of incoming sound according to their location in 3D space given in [2] is shown in Table 1. The data shown corresponds to a single measurement location which monitored noise from a construction site. Data samples were associated with different sectors in space, corresponding to road and railway, industry, and construction site. The category “Unknown” gathers components which could not be assigned to a specific sound source with a high degree of plausibility due to a limitation of the method further described in [2].

Table 1: Example from [2], showing measured contributors to a total noise measurement in the 12-hour period of 07 - 19. All sound pressure levels covering a 1-hour are given as $L_{Aeq,N}$ over the N time the sound was dominant. This time is given as a percentage.

Time	**Road and railway ($L_{Aeq,irrelevant1}$)**	**Industry ($L_{Aeq,irrelevant2}$)**	**Construction Site ($L_{Aeq,source}$)**	**Unknown ($L_{Aeq,unknown}$)**
07 – 08	5.6%, 67.2dB	6.4%, 80.7dB	36.8%, 74.3dB	51.1%, 68.1dB
08 – 09	11.1%, 72dB	4.7%, 71.8dB	35.3%, 70.5dB	48.9%, 66.1dB
09 – 10	2.6%, 66.8dB	9.1%, 77.5dB	39.9%, 72.5dB	48.5%, 64.2dB
10 – 11	17.5%, 65.6dB	6.4%, 84.2dB	26.6%, 80.2dB	49.6%, 67.1dB
11 – 12	37.9%, 67dB	3.5%, 72.6dB	8.4%, 66.4dB	50.2%, 62.5dB
12 – 13	36.2%, 66.1dB	2.4%, 70.3dB	10.9%, 72.8dB	50.5%, 67dB
13 – 14	18.8%, 71.5dB	3.7%, 71.7dB	25.9%, 72.7dB	51.6%, 68.9dB
14 – 15	52.5%, 75.8dB	1.7%, 72.9dB	6.3%, 70.4dB	39.4%, 71.1dB
15 – 16	39.8%, 74.7dB	1.4%, 70.3dB	9.2%, 71.7dB	49.6%, 67.2dB
16 – 17	19.5%, 65.7dB	1.7%, 74.4dB	17.1%, 70.7dB	61.6%, 67.8dB
17 – 18	36.9%, 67.6dB	4%, 72.8dB	4.4%, 66.4dB	54.7%, 63.4dB
18 – 19	34.6%, 63.5dB	0.1%, 65.7dB	11.8%, 64.7dB	53.5%, 61.9dB
07 - 19		$\boldsymbol{L_{Aeq,12h} = 71.5}$ **dB**		

Calculated L_{Aeq} values for the time window 07-19, for each sector or sound source, are shown in Table 2. The calculations were done for the time the corresponding sound source was dominant, T, which means that the averaging process was carried out over only those hours for which data was valid. T is equivalent to the sum of N, for each source, in Table 1.

Table 2: Calculated $L_{Aeq,T}$ for the time the sound sources were dominant. T shows the time over which the averaging process was carried out.

	Road and railway ($L_{Aeq,irrelevant1}$)	**Industry ($L_{Aeq,irrelevant2}$)**	**Construction Site ($L_{Aeq,source}$)**	**Unknown ($L_{Aeq,unknown}$)**
$L_{Aeq,T}$	71.5 dB	78.7 dB	74.2 dB	66.9 dB
T	3.1 h	0.5 h	2.3 h	6.1 h

Table 3 shows the calculated levels, per source, when the averaging is done over 12 hours.

Table 3: Calculated $L_{Aeq,12h}$ for each sound source.

	Road and railway ($L_{Aeq,irrelevant1}$)	**Industry ($L_{Aeq,irrelevant2}$)**	**Construction Site ($L_{Aeq,source}$)**	**Unknown ($L_{Aeq,unknown}$)**
$L_{Aeq,12h}$	65.7 dB	64.4 dB	67.0 dB	64.0 dB

For further analysis, the sectors road and railway ($L_{Aeq,irrelevant1}$) and industry ($L_{Aeq,irrelevant2}$) are computed in a single $L_{Aeq,irrelevant}$ term, as shown in Table 4.

Table 4: Calculated $L_{Aeq,12h}$ used in further analysis.

	Road, railway and industry ($L_{Aeq,irrelevant}$)	**Construction Site ($L_{Aeq,source}$)**	**Unknown ($L_{Aeq,unknown}$)**
$L_{Aeq,12h}$	68.1 dB	67.0 dB	64.0 dB

The levels from Table 4 can be directly replaced in equation (5). In this example, the level difference between the measured total equivalent sound pressure level $L_{Aeq,12h} = 71.5$ dB given in Table 1 and irrelevant sounds from Table 4 is > 3 dB.

5. RESULTS

In this section, we present the results obtained for the different approaches described in 3.1. Not listed is the alternative of setting $L'_{Aeq,12h,irrelevant} = L_{Aeq,12,irrelevant}$, resulting in $PL_{Aeq,12h} = L_{Aeq,12h} = 71.5$ dB

5.1 Discarding $L'_{Aeq,12h,irrelevant}$

Computing $PL_{Aeq,T}$ as given in equation (7) yields $PL_{Aeq,12h} = 68.8$ dB for the example above. This is, however, not a conservative approach as it assumes that the sound source of interest was not active during 3.6 hours of the measurement time (see Table 2), in which road, railway and industry were dominant with much higher sound pressure levels than the construction site.

5.2 Setting $L'_{Aeq,12h,irrelevant} = L_{Aeq,12h,unknown}$

Letting $L'_{Aeq,12h,irrelevant} = L_{Aeq,12h,unknown}$ yields $PL_{Aeq,12h} = 70.0$ dB for the example presented. This approach can be considered conservative since $L_{Aeq,12h,unknown} = 64.0$ dB may contain not only dominant components from irrelevant sources, but also from the sound source of interest.

5.3 Setting $L'_{Aeq,12h,irrelevant} = L_{50}$

Percentage exceedance levels were computed for the data from the presented example and are given in Table 5.

Table 5: Percentage exceedance levels computed for measured data shown in Table 1.

Percentile	**Level (dB)**
L_5	75.7
L_{10}	71.6
L_{50}	63.7
L_{90}	60.0
L_{95}	59.1

By setting the level of $L'_{Aeq,12h,irrelevant} = L_{50}$, the partial equivalent sound pressure level becomes $PL_{Aeq,12h} = 69.9$ dB.

5.4 Corrections from Annex I in ISO 1996-2

Annex I in ISO 1996-2 introduces two equations to calculate the level of residual sound based on measurements of L_{50} and L_{90} or L_{95}.

Equation I.1 in the standard utilizes the level difference between L_{50} and L_{90}, while Equation I.2 does so with L_{50} and L_{95}. For the example described in this paper, the calculated levels are significantly different, as Table 6 shows.

Table 6: Residual sound levels calculated according to equations I.1 and I.2 in ISO 1996-2.

Equation	Residual sound level (dB)
Eq. I.1	64.7
Eq. I.2	60.0

For the purposes of the analysis, the level given by equation I.2 is used forward. By letting of $L'_{Aeq,12h,irrelevant} = 60$ dB, the partial equivalent sound pressure level becomes $PL_{Aeq,12h} = 69.3$ dB.

5.5 $L'_{Aeq,12h,irrelevant}$ is set to a fixed value

Figure 1 shows the resulting $PL_{Aeq,12h}$ for levels of $L'_{Aeq,12h,irrelevant}$ ranging from $L'_{Aeq,12h,irrelevant} = (L_{Aeq,12h,source} - 1\text{ dB})$ to $L'_{Aeq,12h,irrelevant} = (L_{Aeq,12h,source} - 15\text{ dB})$.

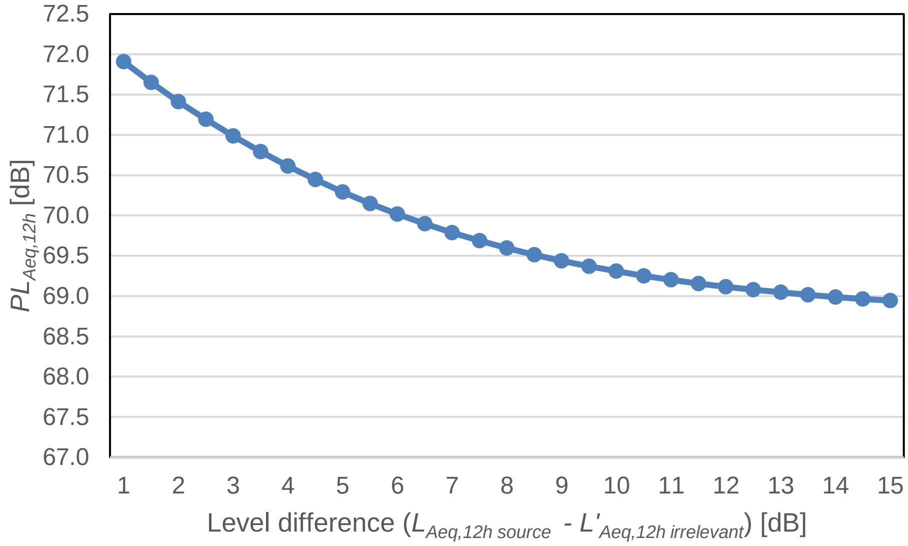

Figure 1: $PL_{Aeq,12h}$ as a function of the level difference between $L_{Aeq,12h,source}$ and $L'_{Aeq,12h,irrelevant}$.

As Figure 1 shows, choosing a too conservative level for $L'_{Aeq,T,irrelevant}$ can result in a $PL_{Aeq,T}$ that is higher than the measured equivalent sound pressure level, a situation that must be avoided. As a general rule, $L'_{Aeq,T,irrelevant} \leq L_{Aeq,T,irrelevant}$

$L'_{Aeq,T,irrelevant}$ could be set to a level which is representative of background noise in an urban soundscape, but this level is not always feasible or practical to measure. Therefore, 5 repeated measurements of $L_{Aeq,12h}$ were analyzed. The measurements were conducted on the following days of May 2022: 12th (data is shown in Table 1), 13th, 18th, 19th and 20th. The results are presented in Table 7.

In order to establish a fixed value for $L'_{Aeq,12h,irrelevant}$, the arithmetic average of the measurements categorized as "Unknown" was computed, yielding $L'_{Aeq,12h,irrelevant} = 62.7$ dB and $PL_{Aeq,12h} = 67.7$ dB. Note that the arithmetic average is lower than the energy averaged sound pressure level.

Table 7: Repeated measurements of $L_{Aeq,12h}$, per source, performed over 5 days.

Dato	$L_{Aeq,12h}$			
	Road and railway	**Industry**	**Construction Site**	**Unknown**
2022-05-12	65.7	64.4	67.0	64.0
2022-05-13	69.1	56.5	61.3	59.3
2022-05-18	62.6	58.0	68.0	63.4
2022-05-19	66.7	62.3	69.6	65.9
2022-05-20	61.0	61.7	65.4	60.8

6. DISCUSSION

A summary of the alternatives presented above is shown in Table 8, where the alternative values of $L'_{Aeq,12h,irrelevant}$ and the resulting $PL_{Aeq,12h}$ values are listed. In all cases, $L_{Aeq,12h,unknown}$ was kept as measured.

Table 8: Alternative values of $L'_{Aeq,12h,irrelevant}$ and the resulting $PL_{Aeq,12h}$.

	# 5.1	# 5.2	# 5.3	#5.4	#5.5
$L'_{Aeq,12h,irrelevant}$	-	64.0 dB	63.7 dB	60.0 dB	62.7 dB
$PL_{Aeq,12h}$	68.8 dB	70.0 dB	69.9 dB	69.3 dB	69.7 dB

The resulting $PL_{Aeq,12h}$ takes values from 1.5 dB to 2.7 dB below the measured $L_{Aeq,12h}$. While alternatives #5.1 and #5.2 can be considered as the extremes of the scale, either too little conservative or too conservative, a more balanced result seems to be achieved with the other alternatives.

It could be argued that a level difference of 1.5 dB to 2.7 dB between measured $L_{Aeq,12h}$ and $PL_{Aeq,12h}$ is not necessarily significant when the measurement uncertainty, which can be large, is taken into account. However, many national regulations do not include guidance to handle the measurement uncertainty when evaluating measurement results by comparison with specific requirements. This means that a level difference of 1 dB or less can determine whether a noise regulation requirement is evaluated to be fulfilled or not, with the associated social and economic consequences.

The hypothesis of this work was that the use of a project-based value for $L'_{eq,T,irrelevant}$ could result in better estimates of the equivalent sound pressure level of a source of interest. Since the differences are small, no general conclusion can be reached as to whether the project-based value approach should be preferred over other approaches such as using L_{50} or the corrections from Annex I in ISO 1996-2. However, for the example presented in this paper, the arithmetic average of $L_{Aeq,12h,unknown}$ measured over several days seems to be a balanced trade-off value for $L'_{Aeq,12h,irrelevant}$ and a valid approach.

7. MEASUREMENT UNCERTAINTY

ISO 1996-2 has extensive explanations and examples of uncertainty calculations for environmental noise measurements and will not be repeated here. In general terms, an uncertainty contribution can be obtained by multiplying a standard uncertainty u_i with the corresponding sensitivity coefficient c_i. For the terms in equation (1), the level difference between for L' and L_{res} determines the size of the sensitivity coefficients used when calculating the uncertainty contributions for L' and L_{res}, see the formulae given in the cited standard.

Given that L' > (L_{res}+3 dB) and that the u_i calculated from repeated measurements is below 2 dB, representative uncertainty contributions c_iu_i for L_{res} are shown in Figure 2.

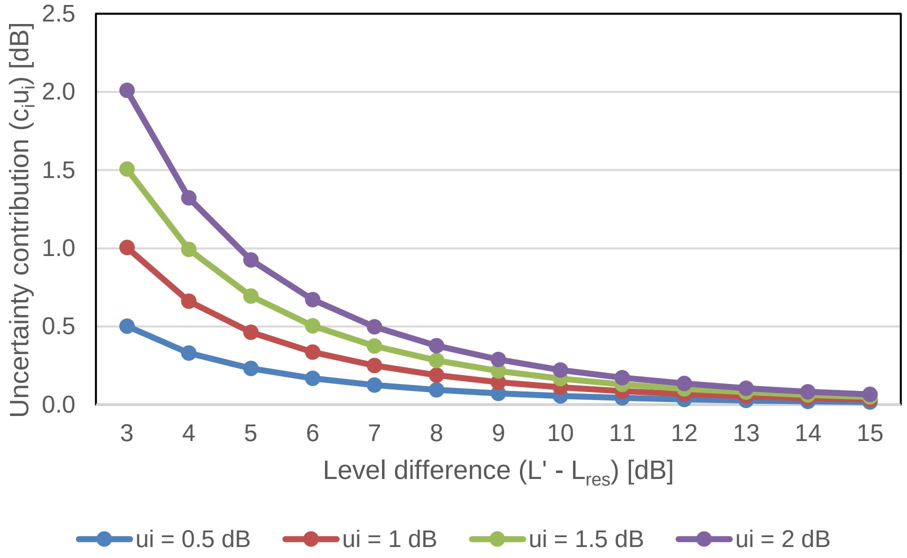

Figure 2: Representative uncertainty contributions c_iu_i for L_{res} in equation (1), depending on standard uncertainty u_i obtained from repeated measurements.

If the level difference between L' and L_{res} is large, the uncertainty contribution for L_{res} becomes small. Typically, the uncertainty contribution due to meteorological conditions is then the dominant term in the uncertainty budgets for environmental noise measurements.

In the region 3 dB < L' - L_{res} < 5 dB, given that u_i is large, lower levels of L_{res} can affect the size of the uncertainty contribution. However, there will also be uncertainty components associated with the correction applied to L_{res}. This suggests that the model of the measurement function should be analyzed, and possibly modified, to allow for the use of $PL_{eq,T}$ in those cases where c_iu_i is large. Exploring the modification of the model of the measurement function remains as further work.

8. CONCLUSION

The measurand $PL_{eq,T}$ has been introduced, where automatically identified irrelevant sounds are replaced with project-specific values represented by $L'_{eq,T,irrelevant}$. A comparison of different values that $L'_{eq,T,irrelevant}$ can be assigned has been performed with actual measurements. The results suggest that the obtained differences are relatively small, and no conclusion can be reached regarding which approach should be preferred. However, the use of $PL_{eq,T}$ can still make a difference when a measurement result is compared to a regulatory requirement. As further work, the model of the measurement function should be analyzed and, possibly, modified to account for new uncertainty components introduced by $PL_{eq,T}$.

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