Science of the Total Environment 468-469 (2014) 280–291

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Characterisation factors for life cycle impact assessment of sound emissions

S. Cucurachi *, R. Heijungs

Institute of Environmental Sciences (CML), Leiden University, P.O. Box 9518, 2300 RA Leiden, The Netherlands

HIGHLIGHTS

- Characterisation factors for the impact of sound emissions on humans are proposed.
- Different levels of specification are available (i.e. spatial, temporal, physical).
- The factors are applicable to any sound emitting source located in Europe.
- Archetypal situations of emission are modelled (e.g. urban location, day, 8000 Hz).
- The factors are ready to be implemented in LCA databases and case studies.

ARTICLE INFO

Article history:
Received 21 March 2013
Received in revised form 19 June 2013
Accepted 23 July 2013
Available online 10 September 2013

Editor: P. Kassomenos

Keywords:
Noise
Noise impacts
Life cycle
LCIA
LCA
Annoyance

ABSTRACT

Noise is a serious stressor affecting the health of millions of citizens. It has been suggested that disturbance by noise is responsible for a substantial part of the damage to human health. However, no recommended approach to address noise impacts was proposed by the handbook for life cycle assessment (LCA) of the European Commission, nor are characterisation factors (CFs) and appropriate inventory data available in commonly used databases. This contribution provides CFs to allow for the quantification of noise impacts on human health in the LCA framework. Noise propagation standards and international reports on acoustics and noise impacts were used to define the model parameters. Spatial data was used to calculate spatially-defined CFs in the form of 10-by-10-km maps. The results of this analysis were combined with data from the literature to select input data for representative archetypal situations of emission (e.g. urban day with a frequency of 63 Hz, rural night at 8000 Hz, etc.). A total of 32 spatial and 216 archetypal CFs were produced to evaluate noise impacts at a European level (i.e. EU27). The possibility of a user-defined characterisation factor was added to support the possibility of portraying the situation of full availability of information, as well as a highly-localised impact analysis. A Monte Carlo-based quantitative global sensitivity analysis method was applied to evaluate the importance of the input factors in determining the variance of the output. The factors produced are ready to be implemented in the available LCA databases and software. The spatial approach and archetypal approach may be combined and selected according to the amount of information available and the life cycle under study. The framework proposed and used for calculations is flexible enough to be expanded to account for impacts on target subjects other than humans and to continents other than Europe.

1. Introduction

1.1. Scope

Life cycle assessment (LCA; ISO 14042, ISO, 2000) aims at quantifying in a holistic and integrated way how each phase of the life cycle of a product contributes to impacts such as climate change, eutrophication, and resource depletion among others (Rebitzer et al., 2004; Pennington et al., 2004). The necessity of quantifying the impact of noise emissions from any life cycle has been stressed since the first days of the formalisation of the methodology (Heijungs et al., 1992).

Noise has for long been recognised as a stressor. Scientific studies have shown that the impacts of noise are not limited to psychological effects, such as annoyance, but also to physiological effects, such as cardiovascular diseases (WHO, 2011; Babisch, 2006). As a result of traffic noise, one in three individuals in Europe is affected by environmental noise during the daytime, and one in five at night (WHO, 2011). It has been quantified that disturbance by noise is responsible for a substantial part of the damage to human health, when measured in disability-adjusted life years (DALY; Müller-Wenk, 2004).

Abbreviations: i, frequency index; c, time index; f, location index; CF, Characterisation factor [number of people-Pa/W]; D, Directivity [dB]; EF, Effect factor [number of people]; FF, Fate factor [Pa/W]; Lw, Background sound power level [decibel]; Nf, Number of exposed subjects; AC, archetypal context; SC, Spatial context.

* Corresponding author. Tel.: +31 71 527 1478.
E-mail address: cucurachi@cml.leidenuniv.nl (S. Cucurachi).

0048-9697/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.scitotenv.2013.07.080

The LCA handbook of the European Commission (ILCD, 2010) included noise as one of the impact categories with high priority for methodological development, because no recommended approach to address noise impacts could be proposed by the handbook. To date all practical applications of LCA (case studies, databases, software) do not include noise as an impact category. To a large extent this is due to a lack of a good method and to a limited investigation of the relevant literature in acoustics and impact assessment of sound. Cucurachi et al. (2012), after an analysis of epidemiological data and a study of the LCA literature on noise, proposed a new theoretical framework. It aimed at presenting a rigorous formal way of characterisation of noise impacts, which is in line with the characterisation model and the overall theoretical structure used for other impact categories in LCA.

1.2. Problem definition

Sound and noise are two categories of the same physical phenomenon. However, sound emissions are not necessarily determining noise. Noise is the result of unwanted or intolerable sound, to which one is not voluntarily exposed. From a physical point of view, sound emissions are associated with a momentary compression and decompression of sound waves through a medium, which lead to a change of pressure and a shifting of molecules in the medium. Thus, sound emissions are temporary and expire in a limited amount of time. Sound propagates and dissipates while it travels through air (i.e. the only medium considered by this contribution).

Several factors (e.g. meteorological conditions) intervene in and attenuate sound emissions, while other factors (e.g., directivity) orientate them. In the work of Cucurachi et al. (2012), such factors were included in the theoretical framework indicated for the calculation of the fate of and the effect factor for noise impacts. However, the framework provided only a theoretical model, with model parameters to be filled in. The aim of this new contribution is to operationalise the model, implement these factors and use them for the calculation of characterisation factors for noise impacts.

The environmental mechanisms involved in the propagation and attenuation of sound emission, and the relative noise impact are complex, non-linear and highly dependent upon local circumstances. The acoustic phenomena and parameters which are relevant in the proposed framework are, in fact, strictly related to a particular topography and to specific local conditions. To reach greater accuracy, propagation of sound is usually calculated by either taking a fully empirical approach, or assuming specific conditions of propagation (e.g. a flat area with short grass). In an ideal world, LCA should be able to portray any possible context of (sound) emission and to account for the effects of those emissions on the target subjects. In practice, sound levels need to be predicted for different heights above ground, various types of foliage (e.g. tree belts), walls, houses, etc. For a fully-empirical local noise assessment, this can be done. In LCA, however, a life cycle typically spans thousands of locations, so a site-specific assessment is not feasible. This constrains the modeller to face a situation in which one has to choose between the use of highly-specific spatially-defined data, or a situation in which it is necessary to assume representative conditions for the archetypal compartments of emission. Even though the level of accuracy may be greater when location-specific data is considered, spatially-defined variables are not uncertainty-free, nor is the amount of information available to practitioners sufficient to use it to describe the specific life cycle under consideration.

1.3. Research focus

The method described in the following sections is based on the established standards of propagation of sound from static or moving sources, such as ISO 9613-1, ISO 9613-2 (ISO, 1993; ISO, 1996), as well as on the recommended approach for the calculation of sound emission and propagation at a European level (European Commission, 2012). Data was processed and scaled to allow for the calculation of characterisation factors for noise, both in the form of ready-to-be-used maps at a European scale, and in the form of archetypal dimensions of emissions. The special case of indoor “occupational” sound emissions was defined only as an archetypal situation of emission. It was decided to use spatially-defined parameters (i.e. GIS map or raster data) to compile characterisation factors in the form of maps in a spatially-defined context. The outcome of this process was used to define archetypal situations of emissions, which used central nominal values for calculations. The use of spatially-defined CFs allowed for the selection of central values in the most appropriate range.

This contribution fills the gap of the absence of noise as an impact category in LCA and presents CFs for noise impacts at a European level (i.e. EU27), which can be used by practitioners, provided the inventory (i.e., sound emission) data are available. The factors produced are, in fact, ready to be implemented in the available LCIA databases and software. The framework proposed and used for calculations is flexible enough to be expanded to account for impacts on target subjects other than humans and to continents other than Europe.

In the following section, the model is described in detail. The results of the modelling decisions are shown in Section 3 and discussed in Section 4. The Supplementary material of this contribution provides a detailed description of the equations and modelling choices (Supplementary material 1), and their results (Supplementary materials 2, 3 and 4).

2. The noise impact assessment model: elaboration of the framework

2.1. The background model and the life cycle inventory phase

Most sounds emitted by a source are complex and fluctuate in amplitude and frequency. The relationships between sound energy level and frequency are required for the meaningful analysis of a sound spectrum. Cucurachi et al. (2012) propose to analyse the sound emitted by a source according to the one-third octave bands centre frequencies in which its spectrum can be split into. The distinction among frequencies allows not only depicting and following the ability of our hearing system to perceive the frequency composition of a sound, but also allows accommodating any context of emission. If certain centre-frequency bands are dominant for a specific source, or limited information is available, selected centre-frequency bands may be chosen instead of others (e.g. 63 to 500 Hz, instead of 2000 to 8000 Hz). Similarly, if the model had to be expanded for the consideration of impacts on target systems other than humans, the centre-frequency ranges of interest may be differently chosen. No differentiation among sources (e.g. static or moving) was proposed in Cucurachi et al. (2012), but it recommended the differentiation of emissions at the inventory level according to the frequency of emission (e.g. 63 Hz), the location (e.g. rural and urban), and the time of the day (i.e. day, evening, and night. The characterisation of the frequency, the time, and the location of the sound emission is also crucial in the later impact assessment of the relative noise perceived by the target subjects.

In Cucurachi et al. (2012), 8 centre-octave frequency bands are considered in line with the ISO 9613-2 (1996) standard on the attenuation of sound during propagation outdoors. As for the location of emission, they were defined by analysing the result of the spatial analysis described in Section 2.2, and in accordance with the literature on the determination of archetypal situations of emission (Jolliet et al., 2005; Curran, 2012). Time specifications refer to the common practice of distinguishing between day, evening, and night time of sound emissions that are commonly used to allow for a different perception of sound by humans according to the time of the exposure. The case of the undefined compartment of emission (e.g., time or otherwise) was introduced in all cases to account for limited information in the hand of the practitioner who would have to use the CFs.