Journal of Cleaner Production 19 (2011) 1339–1346

Contents lists available at ScienceDirect

Journal of Cleaner Production

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

An occupational chemical priority list for future life cycle assessments

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ARTICLE INFO

Article history:
Received 26 August 2009
Received in revised form
6 December 2010
Accepted 21 March 2011
Available online 30 March 2011

Keywords:
Solvents
Indoor exposure
LCA
Human toxicity

ABSTRACT

A chemical priority list is presented to screen and identify relevant chemicals, for which more detailed and industrial-sector specific quantitative exposure, risk and life-cycle assessments should be completed. A list of 38 solvents were ranked according to the framework of the LCA toxicity model, USEtox, and according to the framework proposed by the UNEP/SETAC working group on Indoor Exposure Assessment in LCA. An additional method, based on a risk assessment (RA) framework, was used to examine the robustness of the priority rank. Under both schemes dichloromethane, ethanol, formaldehyde, hexane and toluene all rank in the top ten positions. These chemicals are currently relevant with regard to health effects on a population level. Some of these chemicals are known as hazardous, while others, such as ethanol, have a low toxicity but were prioritized because of their extensive use and high exposure levels. This study attempts to combine the knowledge and methods of the LCA and occupational hygiene communities in assessing health impacts. It provides a consistent and transparent method for rapid comparative assessments of different chemicals and identifies the chemicals and workplaces that will require more thorough investigations.

1. Introduction

In occupational settings safety measures are in place to protect workers, minimize health risks and ensure overall wellbeing. Engineering measures, personal protective equipment, and regulatory limits are installed to secure airborne concentrations to levels that do not pose a risk to workers. However, for a number of widely used chemicals, lifetime worker exposure at regulatory limits could lead to a significant number of occupational diseases (Alvanja, 1990; Cunningham, 1988; Health Based Exposure Limits Committee, 1995). Furthermore, throughout a chemical's life-cycle, human-health impacts from indoor exposure can be important (Hellweg et al., 2005; Ostertag and Husing, 2008; Kohler et al., 2008) and even greater than those resulting from production or disposal (Hellweg et al., 2005). The importance of incorporating indoor exposures into current LCA studies to avoid problem shifting to human health from process or product optimizations has been demonstrated in previous studies (Hellweg et al., 2005; Meijer et al., 2005a,b; Vernez et al., 2006; Wilson et al., 2007; Nazaroff, 2008; Hellweg et al., 2009) and is currently being addressed by an international expert group working on the integration of indoor and outdoor exposure in LCA (Hellweg et al., 2009), within the UNEP/SETAC Life Cycle Initiative (http://lcinitiative.unep.fr). Indoor occupational exposures is one focus area of this working group (Hellweg et al., 2009).

The identification of relevant chemicals for potential impacts to human health is essential. Classification and labelling systems already exist. These consider hazard information and use symbols, risk and safety numbers for advice on handling and usage (Commision of the European Community, 1967). Such labels can be useful for indoor pollution prevention by identifying hazards. However, a prioritization scheme based on toxicity hazards alone would not cover all determinants of health impacts. Furthermore, it would not allow for quantitative comparisons between chemicals. A prioritization scheme should be a function of a number of relevant parameters, such as a chemical's properties, volume/mass used, toxicity, exposure duration and number of people exposed.

A number of studies have investigated hazards, exposures and risks to chemicals. However, many describe single chemicals or single environments (von Uexkull et al., 2005). Therefore, they do not provide general and extensive data, which is easily accessible and useful for comparative purposes. An exception is

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0959-6526/$ – see front matter
doi:10.1016/j.jclepro.2011.03.011

the study of Koller et al. (2000), which identified safety, health and environmental hazards for 11 effect categories and combined these to assess their importance in early process design (Koller et al., 2000). The 'greenness' of chemicals was also assessed using the above method in combination with two additional assessment schemes considering human health using acute and chronic toxicity indices (Koller et al., 2000; Hellweg et al., 2004). Furthermore, Capello et al. (2007) combined environmental, health and safety (EHS) scores with LCA impacts to provide an environmental assessment of 26 solvents (Capello et al., 2007). In another study, Caldwell et al. (2000) compiled over 350 references of measured or modelled solvent concentrations by solvent, industry and process (Capello et al., 2007). This database provides a broader range of workplace pollutant concentrations and characterizes hazardous workplaces. For instance, by sector highest demonstrated solvent exposures occur in the flooring industry, and significant exposures occur in the fibreglass, paint/coating, construction, shoe, petroleum, marine and leather industries (Caldwell et al., 2000). Moreover, by solvent highest exposures occurred for white spirit and toluene (Caldwell et al., 2000). While these studies provide expanded lists of chemicals, the first three only investigate hazards and the latter is limited to exposure. A combination of the two categories would allow for an improved assessment of possible impacts.

Several chemical priority lists exist, each highlighting relevant parameters for assessing health impacts. In LCA, Meijer et al. (2005a,b) have assessed the effect to human health due to indoor pollutant emissions from building materials. In this study they derive a list of a number of indoor pollutants that have a dominant effect on human health, ranking radon and formaldehyde as the most important (Meijer et al. (2005a,b)). The priority list Process Route Healthiness Index (PRHI), quantifies health hazards along chemical process routes and is intended for use in decision-making in plant and process design (Hassim and Edwards, 2006). A chemical's position within PRHI is estimated by the product of a number of scored factors. These include factors on the assessment of potentially hazardous activities and conditions, on the chemical's inherent toxicity, on the health hazard at each stage of the process route by assigning penalty scores to different processes, and on the exposure concentration relative to occupational limit values (Hassim and Edwards, 2006). This prioritization scheme is very valuable for workplaces for health, safety and process design. However, it currently only assesses six different production routes of a single chemical (Hassim and Edwards, 2006).

The Source Ranking Database (SRD) of the U.S. EPA produces a risk-based ranking. This is based on modelled pollutant concentrations, population size of exposed people, and potential health hazards (U.S. EPA, 2003). The hazard score of a chemical is based on its inherent toxicity and is set based on a review of reference doses (RfD), reference concentrations (RfC), and cancer potencies (U.S. EPA, 2003). It examines 12,000 potential indoor pollutant sources to identify products and materials of highest priority. The rank is obtained through the multiplication of estimated indoor-air concentrations and hazard scores (U.S. EPA, 2003). The environments covered are residences, schools, hospitals, nursing homes, office buildings, public access buildings, hotels/motels, eating/drinking establishments, and vehicles (U.S. EPA, 2003). Although the SRD covers some occupational settings, it does not assess workplaces where extensive chemical use is taking place, such as in industrial and small and medium enterprises (SME).

In this study, the characterization and prioritization of chemicals and the subsequent evaluation and selection of those to be scrutinized in LCA studies and other comparative assessment tools, such as RA, is presented. A priority list as such, attempts to bridge techniques and assessment methods from the occupational hygiene and LCA communities. This could be useful in screening and identifying relevant chemicals for more detailed quantitative exposure, risk or life-cycle assessments, and for directly reducing relevant occupational exposures. Following a similar methodology and assessment framework as toxicity assessment in LCA has the advantage of identifying important chemicals in a consistent framework.

2. Materials and methods

2.1. Ranking methods

The indoor occupational priority list for LCA (OCPL-LCA) was compiled using a method consistent with recent developments in LCA for outdoor impact assessments. This method, hereafter referred to as Method 1 (M1), assesses health impacts in the same fashion as the LCA toxicity model, USEtox (Rosenbaum et al., 2008; Hauschild et al., 2008). The USEtox model was chosen in this study as it is the product of review and consensus amongst seven toxicity characterisation models and their developers (Rosenbaum et al., 2008; Hauschild et al., 2008). The components considered in M1 are the concentration (C) of exposure, the effect factor (EF), the severity (Severity) of the ensuing health effects and the exposed population in a region. A difference between M1 and USEtox is that the former uses the concentration versus the intake fraction (iF) used in USEtox (Rosenbaum et al., 2008). The intake fraction (iF) is the amount of pollutant intake over a specific period of time per unit of pollutant emitted (Bennett et al., 2002). With the use of the concentration in M1 we bypass the step of multiplying the emission from the inventory analysis with iF (part of the impact factor). The second difference is in the population weighting term. Using the number of exposed individuals in workplaces as a weighing factor is consistent with previous studies (Rosenbaum et al., 2008; von Grote et al., 2006) and has been used to weigh workplace and environmental exposures within LCA studies (Hellweg et al., 2005). In USEtox the number of people per compartment is used to weigh spatial scales for the urban, continental and global scales (Rosenbaum et al., 2008). In M1 the normalized value of a single exposed person per chemical ($N_{\text{exposed}}/N_{\text{total}}$) is used (Eq. (1)). Assuming that industrial sectors and employment rates are comparable within industrialized countries, this parameter makes the assessment region independent. To calculate the DALYs for a specific region, the population of the investigated region would have to be multiplied to this parameter to get the absolute number of people exposed.

An additional scheme, Method 2 (M2), was applied to test for sensitivities and differences. Method 2 is consistent with occupational risk assessments. The difference with M1 is the use of occupational risk quotients (RQ). The risk quotient is the ratio of concentration to threshold limit value. The threshold value used here is the occupational exposure limit (OEL) value (OSHA, Occupational Health and Safety Administration., 2007). The OEL already takes into account the toxicity of the compound as well as the severity of the effect. Therefore, in M2 the toxicity and severity of a compound are expressed within the RQ value (Eq. (2)). The risk quotient allows for easy judgments on the degree of safety achieved and for comparisons with other workplaces or databases. However, care must be taken as limit values used can be either regulatory or advisory and are different per country. M2 also conducts a population-based risk assessment. In occupational RA the number of exposed people has previously been used to weigh spatial distributions in exposure (von Grote et al., 2006).

The equations used to rank the solvents are: