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Research article

Aiding alternatives assessment with an uncertainty-tolerant hazard scoring method

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ABSTRACT

This research developed a single-score system to simplify and clarify decision-making in chemical alternatives assessment, accounting for uncertainty. Today, assessing alternatives to hazardous constituent chemicals is a difficult task—rather than comparing alternatives by a single definitive score, many independent toxicological variables must be considered at once, and data gaps are rampant. Thus, most hazard assessments are only comprehensible to toxicologists, but business leaders and politicians need simple scores to make decisions. In addition, they must balance hazard against other considerations, such as product functionality, and they must be aware of the high degrees of uncertainty in chemical hazard data. This research proposes a transparent, reproducible method to translate eighteen hazard endpoints into a simple numeric score with quantified uncertainty, alongside a similar product functionality score, to aid decisions between alternative products. The scoring method uses Clean Production Action's GreenScreen as a guide, but with a different method of score aggregation. It provides finer differentiation between scores than GreenScreen's four-point scale, and it displays uncertainty quantitatively in the final score. Displaying uncertainty also illustrates which alternatives are early in product development versus well-defined commercial products. This paper tested the proposed assessment method through a case study in the building industry, assessing alternatives to spray polyurethane foam insulation containing methylene diphenyl diisocyanate (MDI). The new hazard scoring method successfully identified trade-offs between different alternatives, showing finer resolution than GreenScreen Benchmarking. Sensitivity analysis showed that different weighting schemes in hazard scores had almost no effect on alternatives ranking, compared to uncertainty from data gaps.

1. Introduction

Existing tools for hazard assessment, including GreenScreen (GreenScreen, 2013) and Design for the Environment (Lavoie et al., 2010), are excellent credible tools for tabulating toxins. However, critics question their usefulness in deciding between alternatives, because they provide few levels of differentiation, focus exclusively on hazard, and require extensive data to score (Gauthier et al., 2015; Koch and Ashford, 2006). This paper proposes a scoring system to ease alternatives assessment by presenting decision-makers with high-resolution yet easy-to-understand scores while capturing the large uncertainties and potential trade-offs in a transparent fashion. The proposed evaluation framework, Weighted Average Functional Assessment, includes both product function and health hazards in order to balance industry and regulator concerns. The output of the assessment is a pair of numeric scores, each of which has a range of values to incorporate data gaps and differing hazard levels among chemical compounds.

Many commercial products contain chemicals of concern targeted for replacement by regulators (ChemSec, 2014; DTSC, 2013; Schwarzman and Wilson, 2009, 2008; Wilson and Schwarzman, 2009). The process to replace them is usually long, complicated, and risks regrettable substitutions—hazard shifting and/or compromising product quality (National Research Council, 2014).

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Searching for alternatives works best when a wide range of technologies are evaluated, based on functional substitution that examines direct chemical replacements, material substitution, and design solutions (Tickner et al., 2014). The proposed method does replace complete hazard assessments. It is based on GreenScreen, and it aims to support steps 5, 6, 7, 9.2, 9.3, 10, and 11 of the National Academy of Sciences (NAS) alternatives assessment method (National Research Council, 2014). It does not include life cycle assessment or other measures of environmental impact, which are important for global sustainability assessments. Rather, the proposed scoring method summarizes toxicity in a high-resolution score that includes uncertainty, and provides a similar score for functionality, to aid decision-making.

2. Methods

The scoring method consists of two components: hazard and functionality. Assessing chemical hazards of product alternatives is necessary to prevent regrettable substitutions and health effects. Assessing product functionality is necessary for alternatives to be adopted in the marketplace. Product functional requirements will be specific to the product being replaced, and will require an expert from that industry to define them. This paper solely describes the hazard assessment method.

2.1. Hazard evaluation method

The proposed hazard scoring method deconstructs each product alternative into its composite chemicals and assigns scores to each chemical of every alternative product for eighteen different hazard endpoint categories, adapted from GreenScreen (GreenScreen, 2013). These endpoint scores are then grouped into six hazard category scores, slightly differing from GreenScreen's groups, and scored differently: Rather than GreenScreen benchmarking's worst-case heuristic, our method's hazard category scores contain a worst-case and best-case score to include hazard range and uncertainty. Finally, the overall score for each product alternative is a weighted average of the six hazard category scores, giving different weights to different hazard categories.

The scoring process is summarized in Fig. 1, along with its evolution from GreenScreen. Abbreviations are as follows: C = carcinogenicity, M = mutagenicity, R = reproductive toxicity, D = developmental toxicity, E = endocrine activity, AT = acute mammalian toxicity, SnR = respiratory sensitization, IrS = skin irritation, IrE = eye irritation, AA = acute aquatic toxicity, ST = systemic toxicity, N = neurotoxicity, SnS = skin sensitization, CA = chronic aquatic toxicity, P = persistence, B = bioaccumulation, Rx = reactivity, F = flammability.

Fig. 1 illustrates how GreenScreen endpoints are regrouped: the five “Group I Human” endpoints become two categories, “Carcinogens/Mutagens” (“C/M”) and “Reproductive/Developmental/Endocrine” (“R/D/E”), to separate the risks presented to pregnant women and children at low levels of exposure. GreenScreen's nine “Group II and II* Human” endpoints are regrouped to distinguish health effects between acute (single) and chronic (repeated) exposures. Our “Acute” category consists of Group II acute toxicity/systemic toxicity/neurotoxicity/irritation for single exposures (“Acute ST/N/Ir”) and our “Chronic” category consists of Group II* chronic systemic toxicity/neurotoxicity/skin and respiratory sensitization for repeated exposures (“Chronic ST/N/Sn”). Our “Aquatic Toxicity” and “Fate” are equivalent to GreenScreen's “Ecotoxicity” and “Fate” groups. For the current analysis, we did not consider GreenScreen's physical hazards (flammability and reactivity), as our focus was toxicity.

The proposed method's hazard endpoint scores derive from GreenScreen v.1.2 and the Globally Harmonized System (GHS) of Classifying and Labelling of Chemicals (GreenScreen, 2013). Scores range from 1 (high hazard) to 4 (safe or minimal hazard). If a chemical's results are uncertain or conflicting, its hazard endpoint score may be a range, such as “1 – 2” or “2 – 3”. Where data is unavailable, the data gap is denoted “UNK” for “unknown.” Chemical constituents that cannot be identified (common in early-stage product alternatives) should be denoted with dash marks (“-”) and treated as unknown. For our testing of the scoring system, GreenScreen hazard endpoint scores for each chemical compound were obtained from Healthy Building Network's Pharos Chemical and Material Library, screening against 60 authoritative lists (Lent, 2014). When chemicals were not included in authoritative lists, we searched additional sources for hazard information, including: European Chemical Agency (ECHA)'s Registered Substances Database (ECHA, 2014), US National Library of Medicine (NLM)'s Hazardous Substances Data Bank (HSDB) (NLM, 2013a), US NLM's ChemID*plus* (NLM, 2013b), the International Programme on Chemical Safety (IPCS)'s INCHEM (IPCS, 2014), and fourteen corporate Material Safety Data Sheets (MSDS).

Grouping hazard endpoints into hazard category scores should combine data for all chemical compounds, as this compensates for data gaps. The hazard category score for each product lists the best-

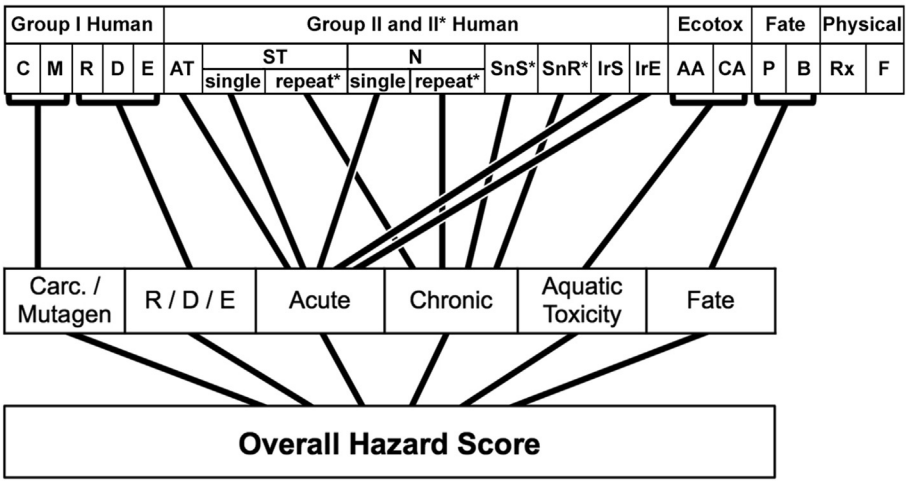

Fig. 1. The process of bundling GreenScreen categories into our scoring tool's categories.