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Identify stakeholders' understandings of life cycle assessment results on wastewater related issues

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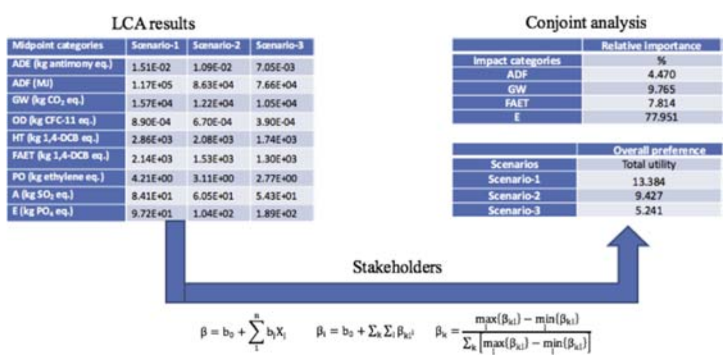
HIGHLIGHTS

- The use of Conjoint Analysis allows for the description of respondents' preferences based on LCA results.
- A case study was conducted to demonstrate how to integrate Conjoint Analysis and LCA.
- Overall preferences for different scenarios of waste management can be calculated from the methodology integration.
- The utilities of attributes represent the relative importance of impact categories perceived by respondents.

GRAPHICAL ABSTRACT



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ABSTRACT

To facilitate decision-making processes in waste management, it is important to not only evaluate environmental impacts, but also to measure how stakeholders form opinions and make choices based one valuation results. Life cycle assessments (LCAs) have been widely used to evaluate environmental impacts; however, LCAs cannot be used to measure how people make judgments based on evaluation results. As such, in this study, we combined LCA with conjoint analysis, an economic method that allows individuals to consider all factors and demonstrate their preferences simultaneously. We used this combined method in a case study on wastewater treatment, and obtained two major types of estimation results: (1) the relative importance of each impact category of LCA, and (2) the overall preferences of respondents for each alternative. This study also highlighted some issues regarding the combination of methodologies, such as the selection of impact categories in LCA, the conversion of impact categories into understandable attributes for conjoint analysis, and weaknesses in conjoint analysis that need to be addressed and corrected in future studies.

1. Introduction

Waste management involves complex activities associated with different ranges of outcomes for society. The major goal of waste management is to promote sustainable development; however, undesirable results may occur as a result of unsustainable management practices. Inadequate forethought for future outcomes is one of the primary factors that lead to unsustainable waste management (Seadon, 2010). For example, consider the legislation of wastewater treatment standards (WTSs). The legislation has enacted policies that focus to removing and reducing various pollutants from the environment; however the policies have not fully taken into account the associated environmental

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burdens such as climate change, limited natural resources, and human health (Wang et al., 2015; Bai et al., 2017).

For environmentally sound waste management practices, the following two factors are crucial for decision-makers: (1) Evaluating and quantifying the environmental impacts of alternative practices for waste management, and (2) taking into consideration how stakeholders from different sectors judge the environmental impacts of alternative practices of waste management.

Life cycle assessment (LCA) is a technique that has been widely employed to evaluate, calculate, and quantify the potential environmental impacts of goods and production processes from "cradle to grave" (Guinee et al., 2011; Hellweg et al., 2014). In terms of waste management, LCA has gained acceptance as a tool for estimating the environmental consequences of waste management (Barton et al., 1996; Ross and Evans, 2002; Ortiz et al., 2007; Remy and Jekel, 2008; Pasqualino et al., 2009; Corominas et al., 2013; Li et al., 2013; Loubet et al., 2016); however, current LCA frameworks fail to include different stakeholders' judgements and opinions on evaluation results. As mentioned above (i.e., the second requirement for environmentally sound waste management practices), understanding the differences in how individuals assess and form judgements from evaluation results would be helpful for decision-makers, and could contribute to adjusting the beneficial allocation of practices across different sectors and different regions. To accomplish this, it is necessary to combine LCA with other methods, which would allow for the ability to determine how individuals make choices concerning different environmental factors and their own personal preferences when using LCA evaluation results.

In previous studies, various economic techniques were used in combination with LCA. For instance, some previous studies used economic techniques (e.g., cost benefit analysis) to determine economic information such as economic benefits and costs (Norris, 2001; Hellweg et al., 2005; Carter and Keeler, 2008; Luo et al., 2009; Jeswani et al., 2010; Bribián et al., 2011). Other studies used economic techniques, such as the market-price method (Ahlroth and Finnveden, 2011) and the contingent-valuation method (Ahlroth and Finnveden, 2011) to weigh LCA methods, with the intention to convert category results from different units into the same monetary units for comparison purposes (Pizzol et al., 2015). However, most of these studies concentrated on providing information to stakeholders, and they did not determine how stakeholders made judgements based on the information provided.

Conjoint analysis is an economic method that has been widely used in marketing, and allows for the measurement of consumer preferences (Green and Rao, 1971; Green and Srinivasan, 1978; Green and Srinivasan, 1990; Green et al., 2001). For instance, when consumers want to buy a product, they have numerous options concerning brands, prices, and performance. By designing a simulated situation in which respondents can jointly consider all the attributes of a product and rate or rank various predetermined product alternatives, conjoint analysis can be used to measure how respondents evaluate and assign value to different attributes, and how they demonstrate their preferences for different product alternatives (Alriksson and Öberg, 2008). Similar decision situation would occur when stakeholders face with different impact categories and associated LCA results for various environmental alternatives. In this regard, the impact categories of environmental alternatives are equivalent to the attributes of market products. Therefore, it is reasonable to propose the use of conjoint analysis to measure how individuals judge the potential environmental consequences determined by LCA. Specifically, this study proposes to conduct conjoint analysis to determine how stakeholders made decisions when presented with multiple options from different impact categories determined by LCA.

The purpose of this study was to demonstrate how to use conjoint analysis to include respondents' preferences for different waste management alternatives. The novelty of this study is that the combination of conjoint analysis and LCA allows for the description of stakeholders' perception of attributes (impact categories) based on the LCA results and ranking preferences for different policy scenarios. Specifically, we conducted a case study on the combination of conjoint analysis and LCA in terms of the evaluation of three waste treatment standards (WTSs) for a full scale wastewater treatment plant (WWTP). With respect to each WTS, we evaluated the environmental impacts by conducting LCA and calculated the characterization results within a variety of impact categories. Furthermore, to conduct conjoint analysis, we treated the impact categories of LCA as the attributes of conjoint analysis, and treated the characterization results of impact categories as the levels of attributes. Based on the combination of attributes and levels, we generated product alternatives to construct questionnaires. We asked a group of representative stakeholders (experts from field of wastewater treatment) to indicate their preferences by ranking all of the product alternatives based on their own knowledge, conceptions, and ideas. We then applied conjoint analysis models to the preference data that we collected from the questionnaires, and ultimately we obtained the measurement of different impact categories' relative importance and the description of respondents' overall preferences for each WTS.

2. Materials and methods

2.1. Case description

We selected a full-scale WWTP located in northeastern China as a working example for this study. We chose 3 waste treatment standards (WTSs) to be studied and evaluated as 3 different scenarios: scenario-1, scenario-2, and scenario-3. The WTSs we selected were supposed to meet the standards of the tertiary treatment level, the intermediate treatment level, and the basic treatment level, respectively. The treatment level of scenario-1 was the most stringent, followed by scenario-2, with scenario-3 being the least stringent. We conducted LCA on the 3 scenarios to evaluate potential environmental impacts. We then performed conjoint analysis to measure how different respondents (stakeholders) made trade-offs (i.e., decided which environmental impacts were more or less important than others), and determined stakeholders' preferences using LCA results.

2.2. Life cycle assessment

We evaluated environmental impact assessments for each scenario using LCA. We primarily considered the operational stage of WWTP during LCA analysis. The system boundary included electricity production, the manufacture and transportation of chemicals, and waste activated sludge processing. Each functional unit for each scenario produced 10,000 m^3 of wastewater per day at the WWTP.

In the inventory analysis stage of LCA, we considered the input and output flows of the WWTP. Table S1 displays the inventory data. The input flows included elements of electricity, inorganic chemicals, and PAM-acrylonitrile. The output flows included emissions associated with liquid phases (chemical oxygen demands, total nitrogen, and total phosphorus), and solid and air phases (carbon dioxide, nitrous oxide, bio-sludge, tertiary precipitation, phosphorus precipitation, and pre-treatment solid waste).

In the stage of life cycle impact assessment, we utilized the CML method (Guinée, 2001), developed by Leiden University, to obtain the characterization results for each impact category for each scenario. CML has the advantage of covering comprehensive categories for LCA analysis, and is possible to present a general reference for LCA application. The impact categories included eutrophication (E, kg PO_4 eq.), acidification (A, kg SO_2 eq.), freshwater aquatic ecotoxicity (FAET, kg 1,4-DCB eq.), human toxicity (HT, kg 1,4-DCB eq.), ozone depletion (OD, kg CFC-11 eq.), photochemical oxidation (PO, kg ethylene eq.), global warming (GW, kg CO_2 eq.), abiotic depletion of fossil fuels (ADF, MJ), and abiotic depletion of elements (ADE, kg antimony eq.). In order to make a direct comparison between all of the impact