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A fuzzy decision aid model for environmental performance assessment in waste recycling

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Abstract

This study introduces a methodological framework for environmental performance assessment of waste recycling programs. We develop two categories of indicators: the efficiency indicators that compare the environmental achievements of a program with the required expenditures (benefits per unit cost), and the effectiveness indicators that compare the environmental benefits of a program with the amount of generated wastes (benefits per unit waste). Aggregation of these indicators, in relation with their associated criticalities, will give us a number of environmental performance indices to represent the status of the environmental performance. This score-based assessment has two major advantages: it takes complex scientific information and synthesizes it in a way that makes it easily understandable for non-experts while in comparison with other environmental performance assessment methods it is not computationally intensive. In this aggregation, the importance values (criticalities) are often expert based uncertain judgments, which are defined according to the objective of performance assessment. Therefore, a fuzzy multiple attribute analysis can be employed to express these judgments by fuzzy sets and to formulate the weighted aggregation process. For case study, we have investigated the environmental performance of the provincial beverage container recycling programs in Canada, which illustrates the applicability of the proposed methodology.

Keywords: Recycling; Performance assessment; Multiple attribute analysis; Fuzzy sets; Decision support systems

1. Introduction

Waste management activities consist of two major different levels of activities in terms of targets and technologies involved, waste minimization and waste disposal. Waste minimization refers to actions that target the reduction in the quantity of waste managed through disposal. This level of activities includes waste prevention, recycling and waste combustion with energy recovery (Stutz, 2002). Waste disposal takes place when there is not a feasible way to minimize the waste. The disposal is accomplished via burning (without energy recovery) and land filling (waste dumps) (Lehr et al., 2002).

Disposal of wastes has been the main waste management strategy over many decades. Today, this legacy of the past is a major environmental problem. Waste material may migrate into the surface water or groundwater resources, where it can be ingested and harm the human body and other living organisms. It may enter the food chain via uptake by plants and consequently by human, with possible long lasting impacts on human health. The gradual decomposition of waste materials generates organic toxic gases, methane and carbon dioxide, which are categorized as air pollutants. Moreover, from a land use perspective, especially in urban areas, space for landfill is either limited or unavailable. On the other hand, open burning and inefficient combustion of waste materials produce air pollution and toxic residues. In addition, the clean-up and remediation technologies applied to eliminate or to reduce the environmental consequences of waste disposal are very expensive and slow to implement due to technological complexities involved (Rubin, 2001).

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Considering the above-mentioned challenges, in recent years, the waste minimization technologies have been used in many waste management practices (Lehr et al., 2002). Besides the implementation of waste prevention strategies in product design, manufacturing and packaging and improvement of product reuse opportunities, waste recycling technologies have been applied to recover a wide range of materials from the waste flow. For example, in the United States, recycling rate for municipal solid waste (including paper, plastics, glass, metals, foods, woods, etc.) has reached about 22% and some states have designed a target diversion rate of 50% (Kreith and Tchobanoglous, 2002).

Despite the many advantages obtainable from developing an effective recycling process, experience has shown that there are several obstacles, which hinder the development of effective recycling markets. From a consumer point of view, there is not enough awareness about the recycled products and enough confidence in the quality of recycled material. From a technological point of view, recovery of certain types of recyclable materials such as plastics and oil is difficult and costly, and more technological improvements are still required. Finally, from an environmental perspective, recycling activities (collection, processing and marketing) have certain types of cross-media environmental impacts. Therefore, to ensure that the recycling programs, in terms of design and operation, are economically and environmentally responsible, and to keep track of the environmental achievements obtained through these programs, environmental performance measurement indices have been developed for waste recycling programs.

An environmental performance index (EPI) is a score value derived from certain economical and environmental parameters and indicators, which represent the state of a program in comparison with the others or a predetermined target or standard. It is similar to the UV (Ultra Violet) index we check before spending the day in the sun. This index takes complex scientific information and synthesizes it in a way that makes it easily understandable. It can help to translate a wide variety of environmental indicators into a simple system that can be easily communicated. This index provides a decision-making tool for the governments in design, implementation and control of environmental policies. The last but not the least, it can provide easy-to-understand information to citizens in order to help them comply with regulations (like no-burn days and air quality index) or make personal lifestyle choices that will benefit the environment.

Measurement of environmental performance using an EPI has been studied in various domains (Tyteca, 1996, 1997; Courcelle et al., 1998; Ethridge, 1998; Jung et al., 2001; Lippke et al., 2004; Färe et al., 2004). In practice, in corporate level, Nortel was the first company in North America to develop an EPI in 1993 to study the environmental impact of the company operations (Poltorzycki, 1996). In national level, the Environmental Protection Agency (EPA) launched the national environmental performance track in 2000, a voluntary partnership program to recognize and reward the annual improvements in a set of core performance indices (EPA, 2003). Later, World Economic Forum organization introduced the first serious attempt to measure environmental performance on a global scale via one summary index by compounding 22 environmental indicators (Easty and Cornelius, 2002).

Although, using the environmental performance indices has many beneficial aspects (as previously mentioned), the uncertainties involved in index making process may result in misleading outputs. To define an EPI, several parameters and indicators are required to be aggregated in relation to their relative weights. Therefore, this index making process relies on the experts' judgments in selecting the appropriate parameters, and in assigning the appropriate aggregation weights. The situation becomes more complex when we encounter several performance measurement scenarios (such as corporate level scenarios, regional scenarios, etc.). Moreover, there are uncertainties involved in measurement of performance parameters because of incomplete and imprecise data or measurement errors.

Fuzzy sets theory (Zadeh, 1965) as an advanced method capable of accounting for imprecise information offers a way to deal with decision-making and assessment uncertainties (Fila et al., 2006; Keramitsoglou et al., 2006; Koutroumanidis et al., 2006; Visser and de Nijs, 2006; Yong et al., 2006; Fleming et al., 2007; Schlüter and Rüger, 2007). In performance assessment studies using fuzzy sets theory, emphasis has been placed on two directions of fuzzy rule-based modeling (FRM) (Plantamura et al., 2003; Sadiq et al., 2004) and fuzzy data envelopment analysis (FDEA) (Triantis and Girod, 1998; Tsou et al., 2004). In fuzzy rule-based modeling, a set of fuzzy logic *if–then* rules are used to build a model for the prediction of environmental performance in form of linguistic assessments. Fuzzy data envelopment analysis is a nonparametric estimation methodology based on linear programming, which measures the relative performance of a collection of decision-making units (alternatives) by doing an input–output analysis. Although, both FRM and FDEA methodologies are capable of dealing with the uncertainties embedded in the environmental performance assessment problems, there have been some complexities, rather than fuzziness of data, involved in both methodologies. Design of a fuzzy logic-based rule becomes complex if the number of decision parameters increases. Reaching a decision becomes cumbersome when we encounter a large number of rules, especially, when there are overlaps between them. Even using reduction techniques such as decision tables, rough approximations, etc. (Pawlak, 1991; Mafakheri et al., in press), to get rid of superfluous attributes and/or rules, makes the decision-making process more complex. In FDEA, on the other hand, a performance assessment study is computationally intensive. This method works based on the repeated application of linear programming. Moreover, several iterations are required to solve each LP model.

To avoid the above-mentioned complexities, in this study, we propose a fuzzy multiple attribute analysis (FMAA) approach for the environmental performance assessment of waste recycling programs. This methodology calculates an environmental performance index, which has the previously