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An Analysis of Decision Making Methods in Sustainable Waste Management

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An Analysis of Decision Making Methods in Sustainable Waste Management

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Abstract

The purpose of this study is to review the types of decision making models that are currently being used in the area of waste management. Three main categories of decision making models have been identified with their benefits and limitations in this research. These models are: multi criteria decision analysis, cost-benefit analysis and life cycle analysis. Since the models are representatives of the real world with respect to the scope of study, none of them could encompass all the aspects of the waste management cycle. At this point, for decisions to be effective it is necessary to set a balance between the environmental sustainability, economic viability, technical soundness and the social acceptability of the system.

Keywords: Decision Making Models, Economic Viability, Environmental Sustainability, Social Acceptability, Technical Soundness, Waste Management

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Introduction

This research aims to review the decision making models which are used to support decisions in the area of waste management and to evaluate their merits and drawbacks. Selecting an appropriate modelling tool for decision making is a crucial part of waste management. Also deciding on which modeling tool should be used depends on the aim and scope of the study to be undertaken. In some cases the goal of the model is simple, for example to optimize routes for waste collection vehicles; while in others, it is more complex, for instance, to evaluate alternative strategies for waste management.

The scope of this research includes only the models that are used for municipal waste management decision-making. Therefore decisions involving specific types of wastes i.e. hazardous or healthcare wastes are not taken into account. The remainder of this paper is structured as follows. To put the current research in context, an overview of the decision making process and a brief history of the development of waste management models is given in the following section. The details of different waste management models (multi criteria decision analysis, cost-benefit analysis and life cycle analysis), coupled with their evaluations are outlined in the next three sections. The conclusions of this review along with a discussion of the merits and drawbacks of these models are given in the last section.

A Brief History of the Development of Waste Management Models

In a complex world, decision analysis plays a major role in helping decision makers to gain an understanding of the problems they face (Goodwin and Wright, 2004). The analysis of the way people make decisions (prescriptive theories) or the way people ought to make decisions (normative theories) is as old as the recorded history of mankind according to Triantaphyllou (2000), although not all of these analyses were scientific approaches as those in literature today.

Modelling of waste management started to be a focus of many researchers in the 1960s, when there was an increased attention to efficiency and effectiveness of waste management operations. MacDonald (1996a), Gottinger (1988) and Tanskanen (2000) gave a comprehensive summary of these early waste management models along with their characteristics and a discussion regarding their details. Their review showed that the models developed during the 1960s and 1970s focused on specific elements of waste management, for instance transporting wastes from transfer stations was a focus of the study conducted by Truitt et al. (1969). However, Sudhir et al. (1996) stated that this shortcoming of early models make them unsuitable for long-term planning.

In 1980s, the models had a broader scope with a focus of minimising the costs, for example the study conducted by Kaila (1987) presented costs and benefits involved in municipal solid waste management systems (cited in Hokkanen et al. (1995)). These models also included computational tools by looking at the relationship between components in the system according to MacDonald (1996b). He criticised the models released in the 80s for utilising the capabilities of only one type of software; and expanded on this; “in order for the models to be most useful to city planners, who must take a holistic view of a situation, the application of information technology must address the multi-attribute and geographical nature of waste systems”. Up to the 1990s, the concepts of sustainable waste management or integrated waste management were not used in any waste management model.

In the 1990s, recycling started to be widely included in most municipal solid waste management models including collection and facility options in the context of cost and energy conversion in a more holistic manner. For example, Baetz and Neebe (1994) developed a mixed integer programming model for the recycling of various by-product materials within the overall waste system; Chang and Wei (1999) evaluated the trade-offs between the number of recycling drop-off stations by including the distance travelled by collection vehicles which could be solved by generic algorithms in a geographical information system platform. Furthermore the model developed by Modak and Everett (1996) aimed to determine the volume of the waste landfilled energy content of incinerated wastes and the amount of ashes generated at the incinerators to provide the lowest possible long-term costs for a regional integrated solid waste management system.

Most of the waste management decision support models identified in the literature could be categorised into three groups as stated by Morrissey and Browne (2004): (1) those based on Multi Criteria Decision Analysis, (2) those based on Lifecycle Assessment, and (3) those based on Cost Benefit Analysis. A description of these methods along with a discussion regarding their limitations and benefits is covered in the following sections.

Models Based on Multi Criteria Decision Analysis (MCDA)

The introduction of the term multiple criteria decision making into management science was made at the University of South Carolina in 1972 with the First International Conference on Multiple Criteria Decision Making. In Europe there was a tendency to use “decision analysis”, instead of “decision making” to emphasise the difference between the decision maker and the management scientist (Costa et al., 1997).

Over the past three decades, MCDA has developed as a major discipline. The principle of the MCDA approach is to take several individual and often conflicting criteria into account in a multidimensional way. It is a form of integrated sustainability evaluation (Wang et al., 2009). Morrissey and Browne (2004) stated that any viable solution has to reflect a compromise between the various objectives, while the discrepancies between the outcomes are traded off against each other by means of preference weights. Each alternative (solution option or scenario) is judged in relation to the multiple objectives, so that the desired scenario is the one that performs comparatively well according to the preset scenarios. Mendoza and Martins (2006) defined three dimensions of MCDA, namely: (1) the formal approach, (2) the presence of multiple criteria, and (3) the decisions are made either by individuals or groups of individuals.

The waste management studies applying MCDA, in the literature, generally focus on the selection of facility locations (Erkut et al., 2008; Ersoy and Bulut, 2009; Ulukan and Kop, 2009; Achillas et al., 2010; Banias et al., 2010), evaluation of treatment facilities (Dursun et al., 2011; Rostirolla and Romano, 2011) and the development of the strategy (Su et al., 2007; El Hanandeh and El-Zein, 2010; Su et al., 2010; Ciplak, 2015). The common ground of all these studies is their attempt to provide sustainability for the waste management system under consideration; and one of the requirements of this is the identification of the set of the evaluation criteria.

The criteria identified in the waste management literature mainly focus on these four aspects: technical, economic, environmental and social.

Evaluation of MCDA Techniques

Environmental decision making includes multiple interests and multiple actors with long term implications on a local or global scale. It requires a trade-off between competing interests and values and is an inherent management conflict characterized by ecological, economic and socio-political value judgements of different stakeholders (Munda et al., 1995; Abba et al., 2013).

Dooley et al. (2009) considered MCDA as a useful method in environmental decision making to help trade-off the economic, environmental, and social aspects that need to be considered in making strategic decisions. The methodological framework of MCDA is well suited to the complex nature of environmental decision making; more specifically waste management decision analysis in terms of;

(1) It can deal with mixed sets of data, quantitative and qualitative. This aspect is a distinct advantage especially for developing countries where the data are scarce or include uncertainty (Ciplak and Kaskun, 2015; Mendoza and Prabhu, 2003; Morrissey and Browne, 2004; Garfì et al., 2009; Wang et al., 2009).

(2) It is conveniently structured to enable a collaborative planning and decision making environment. This allows the direct involvement of multiple experts, interest groups and stakeholders. It is transparent to participants and it provides a focus for working through the decision problem by breaking it down (Mendoza and Prabhu, 2003; Goodwin and Wright, 2004; Garfì et al., 2009).

(3) The main benefit is that MCDA provides a better understanding of the decision to be made by the accommodating stimulation of discussion and the sharing of the ideas of others' in a structured way. This benefit is particularly significant for group decisions (Bell et al., 2003; Vego et al., 2008; Dooley et al., 2009).

Models Based on Cost-Benefit Analysis

This method enables decision-makers to examine the performance of a set of scenarios by converting all factors into a common measurement, usually monetary. This means the estimation of monetary values for environmental changes, for example how much individuals are willing to pay for an environmental improvement due to pollution caused by incineration.

Evaluation of Cost-Benefit Analysis

The results and interpretations of the ecologic/environmental studies in the literature point out two important limitations;

(1) Measuring the compensation for the deterioration of the environment in monetary terms is not a sustainable approach in waste management (Morrissey and Browne, 2004); and

(2) Attributing a monetary value to, for example social factors, might not be appropriate or ideal all the time (Simpson and Walker, 1987).

In practice, the decision problem is further complicated by several uncertainties and there are always some objectives which cannot simply be traded off against each other by means of monetary units according to Loken (2007). Using a single dimensional objective method for this type of problem would probably lead to a deadlock as it imposes conditions too rigid to reach a compromise between stakeholders (Haastrup et al., 1998). Nijkamp and Delft (1977) supported the opinions against this method by stating "When making decisions, decision makers always try to choose the optimal solution. Unfortunately, a true optimal solution only exists if you are considering a single criterion. In most real decision situations, basing on decision solely on one criterion is insufficient."

It is known that environmental decisions usually involve conflicting objectives, various types of information and several individuals. Therefore environmental decision making using a multi-dimensional way leads to more rational decision-making than the optimisation of a single dimensional function (Vego et al., 2008). For this reason, Weng and Fujiwara (2011) argued that the cost-benefit analysis is not a suitable method for this kind of process unless it is coupled with a workable integrated framework.

Models Based on Life Cycle Assessment

A life cycle assessment (LCA) is a quantitative methodology consisting of the compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle -"cradle to grave" (ISO 14044, 2006). In the definition of LCA, the term 'product' not only refers to analysing material products, but also includes service systems such as waste management. It allows decision makers to analyse the direct impacts (such as emissions to air, water or soil) and indirect outcomes (such as consumption of resources or the emissions generated to make available the energy or the infrastructure needed by the production process) of these systems. The technique of LCA consists of four phases each of which is subject to the International Standards (ISO 14044, 2006): (1) definition of the goal and scope (definition), (2) compiling an inventory of relevant inputs and outputs of a system (inventory analysis), (3) evaluating the potential impacts of those inputs and outputs (impact assessment), (4) interpreting the results (interpretation) in relation to the objectives of the study.

Environmental LCAs developed rapidly during the 1990s and had reached a certain level of harmonisation and standardisation (Finnveden, 1999). They have been commonly undertaken in the governmental, non-governmental, industrial and consulting sectors in the waste management field. LCA applications in the literature are generally in one of two groups in terms of their scope; the first (A) are those which have a particular focus on one of the waste management system elements (such as the selection of an appropriate recycling scheme or deciding on which ash treatment system would be appropriate for the incineration in place); and secondly (B) the ones considering different waste management strategies ranging from local planning to strategic decision making at national and international levels. They aim to determine the optimal scenario from an environmental point of view by making a comparison of several alternatives. The examples of these two groups along with their details are provided in Table 1.

Table 1. *Group A and B Applications in the Literature*

A		
Focus	**Study Area**	**Reference**
Waste Treatment Facilities	Pudong-Shangai, China	Hong et al. (2006)
	Indonesia	Aye and Widjaya (2006)
	Iran	Rajaeifara et al. (2015)
Incineration Ash Treatment Systems	Sao Paulo City, Brazil	Mendes et al. (2004)
Waste to Energy Plants	Hypothetical Italian Cities with population of 200,000-1.2 million	Consonni et al. (2005)
Waste Collection Methods	Rural communities in two districts in the province of Salzburg, Austria	Beigl and Salhofer (2004)

B	
Study Area	**Reference**
Hangzhou City, China	Yan et al. (2009)
Umbria Region, Italy	Di Maria and Fantozzi (2004)
Ankara City, Turkey	Ozeler et al. (2006)
Sweden	Finnveden et al. (2005)
Bologna District, Italy	Buttol et al. (2007)

Evaluation of LCA

The benefits and limitations of this technique have been identified by various researchers in the LCA literature. McDougall et al. (2001) emphasised that LCA takes a holistic approach as it provides a system map and attempts to address a broad range of environmental issues. Cherubini et al. (2009) stated that a broader perspective of the LCA allowed users to take into account significant environmental benefits that could be obtained through different waste management processes, for instance, waste incineration with energy recovery reduced the need for other energy sources. Likewise Ekvall et al. (2007) emphasised that LCA helps expand the perspective beyond the waste management system since it covers not only the direct impacts but also the indirect impacts of the system. They found this important since the indirect environmental impacts caused by surrounding systems, such as energy production, often override the direct impact of the waste management system itself.

Recently there have been a number of LCA software tools developed by researchers. The initial aim of developing LCA computer models was defined by Winkler and Bilitewski (2007) that made sure that the results of LCAs which are conducted by different researchers are within an acceptable range and didn't lead to different or contradictory conclusions. These models, some of which are shown below, have recently extended beyond the scientific world to a widespread practical application.

EPIC/CSR (Integrated Waste Management Model / Canada)

DST (Decision Support Tool / United States EPA)

IWM2 (Life Cycle Inventory Model for Integrated Waste Management / UK)

WRATE (Waste and Resources Assessment Tool for the Environment/ UK Environment Agency)

ORWARE (Organic Waste Research Model / Sweden)

EASEWASTE (Environment Assessment of Solid Waste System and Technologies / Denmark)

Some of these tools, for example IWM-2 and WRATE, are based on integrated waste management and aim to deliver both environmental and economic sustainability. In order for the LCA technique to be improved further the scope and the level of detail needed at the life cycle inventory stage should always be reviewed in the light of the practical results obtained according to Barton et al. (1996). Winkler and Bilitewski (2007) believed that this improvement can only be achieved by sharing more of the data and modeling methodology.

LCA has also been used in conjunction with other environmental information and assessment tools. Harrison et al. (2001), Craighill and Powell (1996) extended the lifecycle assessment methodology to incorporate an economic evaluation of the environmental impacts in their studies. Additionally Reich (2005) conducted an economic analysis (namely life cycle costing –LCC-) including the same system boundaries as his LCA. However he reported some theoretical discrepancies which stemmed from different perspectives in dealing with the timing of effects.

Regarding the LCA method there are some issues needed to be considered by strategic decision makers. Firstly LCA does not predict the actual impacts or assess risks, or whether thresholds are exceeded (McDougall et al., 2001). The actual environmental effects of emissions and wastes will depend on when, where and how they are released into the environment (McDougall et al., 2001). Secondly, LCA, itself does not typically address the economic or social aspects within the system. However these aspects are essential in sustainable waste management decision making which has a combinatorial nature with multiple objectives. LCA requires risk assessment, environmental impact assessment or both, to address these issues according to Morrissey and Browne (2004).

Petts (2000) mentioned that LCA has traditionally not been subject to public involvement, being a specific and highly technocratic environmental loading accounting tool. She further commented that at its current stage of development LCA is incapable of dealing with health effect predictions; it can only have partial relevance to public deliberation. For all these reasons, it is highlighted in the literature that (1) decision making on the basis of the LCA results should be made by open public debate as part of the democratic process (McDougall et al., 2001); and (2) LCA should only be used for identifying opportunities for improvement and not used as the sole basis for a final decision on a waste strategy (Emery et al., 2007).

In conclusion, while LCA can be a powerful tool for estimating cradle to grave environmental impacts, these outputs still need to be weighed against the socio-economic factors. Thus LCA is one of the best pre-assessment tools to generate inputs for decision tools such as MCDA.

Conclusions

Waste management decision making in developing countries has moved towards being more pragmatic, transparent, sustainable and comprehensive. On the other side it has been recognised that a fully quantitative approach in decision making is difficult to apply in the context of developing countries due to the lack of information and variety of data. Likewise, the comprehensiveness of the method to be adopted is also restricted by the nature of local specific environmental and social issues.

Recently the MCDA has become a more widely used technique in decision making. A broad range of decision analysts emphasised that the most important advantage of MCDA over other methods is its capability of dealing with the social criteria which is a necessity for sustainability. In this sense it does not only cover technical aspects but also includes the environmental and social sustainability domains (Zurbrügg et al., 2014). Petts (2000) encouraged MCDA techniques to be used by concluding that “Such approaches incorporating multi criteria analysis are more consistent with the objectives of resolving problems as they force values and problem framing to be made transparent".

In this study three main categories of decision making models have been identified with their benefits and limitations: multi criteria decision models, cost-benefit analysis models and life cycle analysis models. Since the models are the representatives of the real world with respect to the scope of this study, none of them could encompass all the aspects of the waste management cycle. At this point, it is crucial that for decisions to be effective it is necessary to set a balance between the environmental sustainability, economically viability, technical soundness and the social acceptability of the system.

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