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The application of multicriteria decision making techniques in the assessment of waste management strategies

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Abstract

While not a new idea, there has been considerable interest over the years in modelling waste management for decision support. Most current waste models fall into one of two categories: those based on multicriteria decision analysis and those based on life cycle assessment. For a waste management system to be sustainable, it needs to be environmentally effective, economically affordable and socially acceptable and must be accepted by the population affected by the waste management system. It has been identified in the literature that the applications of these models have limitations and none have considered the complete waste management cycle, from the prevention of waste through to final disposal. Most of the models identified assume that all options and decision criteria have already been identified and that the most important stage of the process is the actual evaluation of the alternatives using some form of multicriteria decision making technique or life cycle assessment. While this is important, for a waste management model or strategy to be sustainable, the identification of environmental, economic and social criteria and alternatives is a crucial stage of a successful waste management plan. Many of the waste management systems identified consider economic and environmental aspects, with very few considering social aspects. The outcome of these models also depends on who is making the decisions and on the alternatives and criteria selected. In many cases, the community were not involved in the decision making process and the implementation of these models achieve limited success.

Introduction

While not a new idea, there has been considerable interest over the years in modelling waste management. The way the models are structured and the

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techniques used depends on the specific purpose of the models. Most models are decision support models and there are a variety of techniques available for decision support in the area of waste management, including risk assessment, environmental impact assessment, cost benefit analysis and Life Cycle Analysis Petts [1]. Each of these techniques can become a criteria in the model.

A comprehensive summary of the models developed in the 1970s, 1980s and early 1990s is given by Gottinger [2], MacDonald [3], and Tanskanen [4]. As Tanskanen [4] points out, the first municipal solid waste management (MSWM) models were optimisation models and dealt with specific aspects of the problem, for example vehicle routing, or transfer station siting. The models developed during the 1980s looked at the relationships between each factor in the waste management system, rather than looking at each in isolation MacDonald [5]. In addition, the increased computer literacy and availability in the late 1980's provided an opportunity to develop more sophisticated waste management models. During the 1990s, recycling and other waste management methods were being included in most models developed for the planning of MSWM. Current models also reflect a change in policy where waste planning is being pushed from a reliance on landfill, towards a wider range of waste management techniques based on the principle of Integrated Solid Waste Management (ISWM) Clift, Doig [6] and EPIC and CSR [7] among others. ISWM considers the full range of waste streams to be managed and views the available waste management practices as a menu of options from which to select the preferred option based on site specific environmental and economic considerations. More recent models include the whole life cycle of products Finnveden [8], Powell [9] McDougall, White [10], and EPIC and CSR [7] with the aim of making a comprehensive assessment of the systems environmental impact.

Current waste management models

While it has been identified in the literature that most waste management models consider economic and environmental aspects, very few consider social aspects. For a waste management system to be sustainable, it needs to be environmentally effective, economically affordable and socially acceptable, Nilsson-Derf [11], who goes on to say that "for a waste management system to be effective, it must be accepted by the population". This point is emphasised by Petts [1] who asserts that "The most effective management of MSW has to relate to local environmental, economic and social priorities" and must go beyond the traditional consultative approaches that require the "expert" to draft the solution in advance of public involvement to a much more effective approach by involving the public before key choices have been made.

The next two sections of this paper describes the main characteristics of the waste management models that have been developed since the mid 1990s. Most current waste management models fall into one of two main categories: Multicriteria Evaluation Models and those based on Life Cycle Assessment.

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Multicriteria evaluation models

A brief history of the origins of Multicriteria evaluation methods is given by Bana E Costa, Stewart [12]. Despite an early insight by Benjamin Franklin into these methods in 1772, it was not until 1972 that the term *multiple criteria decision making* (MCDM) was introduced into management science in the United States. In Europe the terms multi criteria decision analysis (MCDA) is a more common term for the same thing. Over the past two decades, MCDA has developed into a discipline in its own right. A common characteristic of all MCDA approaches is that taking several individual and often conflicting criteria into account in a multidimensional way leads to more robust decision making rather than optimising a single dimensional objective function (such as cost benefit analysis). In addition, the multicriteria approach assists decision makers to learn about the problem and the alternative courses of action from several points of view. Many authors including, Hokkanen and Salminen [13] and Guitouni and Martel [14] have classified the different types of multicriteria evaluation models. All authors are in general agreement of the categories of multicriteria decision evaluation models, which are:

- The multiattribute utility theory methods or MAUT (also known as the single synthesizing criterion approach without comparability Keeney and Raiffa [15], Saaty [16],
- The Outranking (synthesizing) methods Roy [17], Brans, Macharis [18]
- Interactive methods with trial-and-error approach.

The Analytical Hierarchy Process (AHP) is sometimes classified separately, although Guitouni and Martel [14] considers this method to be an example of the single synthesizing criterion approach or a special case of MAUT.

An analysis of multicriteria *waste* management models shows that most current models fall into the first two of the above three categories: MAUT and Outranking or Concordance methods. AHP is the application of MAUT most often used in waste management decisions. Similarly, ELECTRE III the most commonly used form of an outranking method used in waste management decisions. This is not to say that none of the other 27 methods identified by Guitouni and Martel [14] could not be applied to waste management problems. However, Salminen, Hollanen [19] compared three multicriteria methods in the context of environmental problems (ELECTRE III, PROMETHEE I and II (outranking methods) and SMART (a simple multiattribute rating technique based on MAUT and concluded that ELECTRE III was the most suitable as the other methods have no superior features when compared to it.

The outcome of the outranking model is a ranking of the options under consideration. The method is particularly useful when a large number of alternatives needs to be short-listed to a smaller number of preferred ones in order to facilitate further detailed discussion. Examples of applications of the ELECTRE methods can be found in Roy, Present [20], Hokkanen and Salminen [13], choosing a solid waste management system in Finland Karagiannidis and Moussiopoulos [21], who did the same in Greece, and Rogers and Bruen [22].

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AHP can also be used in any type of decision making or problem solving that involves evaluation and measurement. For example, AHP can be used to measure the relative impact of numerous influencing factors on the possible outcomes and in so doing forecast outcomes, which can then be used in the evaluation of alternative courses of action. The availability of Expert Choice, a well established PC implementation of the AHP method, allows for a relatively easy way to use the method in decision making.

Life cycle inventory models.

The technique of Life Cycle Assessment is a tool that studies the environmental aspects and potential impacts throughout a product's life (i.e. cradle to grave) from raw material acquisition through production, use and final disposal. While most life cycle studies have been comparative assessments of substitutable products delivering similar functions, (e.g. glass versus plastic for beverage containers), there has been a recent trend towards the use of life cycle approaches in comparing alternative production processes and this includes the use of LCA in comparing waste management strategies. It also provides a general overview of the product system which can then be combined with other assessment tools, such as risk assessment to evaluate the product or service over the entire lifecycle. Use of LCA techniques will not necessarily guarantee that one can choose which option is 'environmentally superior' because it is not able to assess the actual environmental impacts of the product, package or service system. The actual environmental impacts of emissions and wastes will depend on when, where and how they are released into the environment. However, LCA will allow the trade-offs associated with each option to be assessed and comparisons made.

There are many examples of the application of the LCA approach as a decision aid in waste management decisions. The Environment Agency in England and Wales uses an LCA package called WISARD to assist local authorities in strategic planning, while a similar model developed by EPIC and CSR [7], called IWMM is being used by municipalities throughout Canada. Both of these model are similar to IWM-2 developed by McDougall, White [10], and can be used in either of two ways: to compare future integrated waste management options or to optimise existing alternatives. While the model only looks at the life cycle inventory aspects of the waste management system (i.e. the inputs and outputs of the system), it does recognise the need to include a methodology for impact assessment for model completeness. One of the main advantages of this model is that it takes a holistic approach. The model considers all sources and types of waste along with the waste management operations of collection, sorting, recovery of secondary materials, biological treatment of organic materials, thermal treatment and landfill. The model recognises that to handle waste in an environmentally sustainable way, a range of options are required and that there must be a market for the outputs of recycling, composting and waste to energy technologies.

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Shortcomings of current waste management models

Issues relevant to the management of waste are complex and usually involve various stakeholders with conflicting objectives. For the waste management model to be sustainable, there is a need for a systematic approach to evaluate policy options. It has been identified in the literature Qureshi, Harrison [23] that multicriteria analysis is a useful approach that can incorporate a mixture of quantitative and qualitative information and take account of the preferences of the various stakeholder groups. Bana E Costa, Stewart [12] concurs with this and states that the use of formal decision making methods means that it is possible to take into consideration the concerns of groups of decision makers with different priorities. It is also recognized in the literature (Qureshi, Harrison [23]) that environmental management involves consideration of social, political, and physical indicators as well as economic factors. In designing and selecting environmental policies - waste management being one such policy - decision makers should deal with monetary and non-monetary as well as qualitative and quantitative information. Environmental management is essentially an exercise in conflict analysis, evaluation and action characterised by socio-economic, environmental and political value judgements. However, it has been found that many of these methods are according to Guitouni and Martel [14] "merely concerned with refinements of algorithmic steps rather than addressing fundamental aspects of the decision making process." In other words, the most important step to get right is the formulation of the problem in the first place and that these techniques are merely decision aids or a matter of "mathematical or experimental skill". Despite this insight, most of the multicriteria research carried out has focused on the development of different techniques (at least 30 have been identified so far Guitouni and Martel [14], who considers the great number of these methods to be a weakness as it is very difficult to know which one to use in a specific problem situation. Moreover, most of the waste models identified assume that all the options and decision criteria have already been identified and that the most important stage of the process is the actual evaluation of the alternatives or an improved method in allocating weights, for example, Hokkanen and Salminen [13], Rogers and Bruen [22] and Takeda [24].

Similarly, while the LCA models aim to deliver both environmental and economic sustainability, none of those identified consider social aspects and therefore, cannot be considered a truly sustainable waste management model. This latter point is also made by EUROPEN [25], and Finnveden and Ekvall [26] who state that LCA is but one tool in the "environmental management toolbox" and should not be used in isolation. In a similar way to EUROPEN [25], Finnveden and Ekvall [26] outlines the usefulness of the LCA approach but states that LCA alone should not be used to decide which waste management treatment option is to be preferred. Ekvall [27] goes a step further and proposes that the starting point of the environmental assessment should not be the life cycle of the system or product, but the decision itself.

As has been noted elsewhere, both the multicriteria methods and LCA methods are decision aids. Salminen, Hollanen [19], Rogers and Bruen [22] and

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others have shown that the use of MCDA is a suitable method for making decisions in the area of waste management. While multicriteria methods can be applied to any complex decision and can consider criteria such as risk, economics, safety etc, depending on what is considered important, the application of LCA methods, by their very nature, is always in the environmental impacts area. LCA has traditionally not been subject to public involvement, being a specific and highly technocratic environmental loading accounting tool Petts [1], who goes on to say that because LCA is a tool currently incapable of dealing with health effect predictions, it can only have partial relevance to public deliberation. "If too much expert emphasis is put on the output of LCA at the expense of considering other important (from the public perspective) decision criteria, the credibility of the process will be at risk".

Another shortcoming of the LCA approach is that at its current stage of development, LCA cannot easily deal with localised environmental impacts of the type that become a public priority in siting or with effects that cannot be quantified as outputs, for example, the effects on aesthetic quality of a landscape. It requires a risk assessment, an EIA or both, to address these issues in a more detailed way and these additional analyses are not always carried out. Moreover, according to Petts [1] "LCA cannot deal with time dependent impacts of the type relevant to intergenerational considerations." In other words, the use of LCA cannot take into account the long term effects of whatever waste management alternatives are selected.

Further limitations of both the MCDA and LCA approaches are that they are usually complex and very detailed. As a result, the potential users of such models, for example, decision makers such as Local Authorities, "often lack the expertise and the data to use complex mathematical models ... The more complex and confusing.... the environmental data, the more people will look at the financial data". Powell [9]. If this happens, it makes the use of the these approaches a wasted exercise. In addition the use of LCA as a technique has several limitations and does not typically address the economic or social aspects.

It is worth noting one of the main differences between the two multicriteria methods examined in this research. The outranking methods of which the ELECTRE methods are an example, are not concerned with the way criteria or alternatives being examined are selected. The main concern of these methods is how to rank those alternatives that are selected with respect to criteria. The more criteria that are considered, the less alternatives considered and vice versa. Furthermore, if the number of decision makers become large, the number of alternatives and criteria are reduced even less, Hokkanen and Salminen [13] and Karagiannidis and Moussiopoulos [21]. In the same way, while, Saaty [16] makes the point that it is very important to identify the ultimate goals of the problem at the beginning, and that it is possible to consider the way criteria and alternatives are selected within the AHP method, most applications of the AHP method have been concerned with the actual pairwise comparison of the alternatives stage. Rogers and Bruen [22] and Hokkanen and Salminen [13] had difficulty with the pair-wise comparison stage of the AHP method because of the requirement that AHP requires that all options be directly comparable with each

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other, even when such comparisons are questionable because of the lack of suitable data, as well as the concern that they thought that AHP could not deal with a mix of both qualitative and quantitative information.

Forman [28] disagrees with this point of view and argues that one of the strong points of AHP is that it is capable of handling both qualitative and quantitative data. On the other hand, Hokkanen and Salminen [13] were concerned that the pair-wise comparison requirement of the AHP process would be too time consuming for the number and type of decision makers that he was dealing with. As against this, many other authors are of the view that the allocation of weights in the ELECTRE method particularly in the way that Hokkanen and Salminen [13] did, is not a sound basis for making a decision.

Modeling sustainable waste management

The discussion in this paper so far has described the main characteristics of waste management models being used today and the limitations of these models. One of the main limitations identified is that none of the models can be considered to be fully sustainable, as they do not consider the social aspects of waste management, nor do they take intergenerational aspects into account. (The most well known definition of sustainable development is that of World Commission on Environment and Development [29], which stresses the requirement of not jeopardising the needs of future generations by the actions of today). Despite the fact that "it is becoming increasingly evident that a waste management programme and especially a waste treatment technique, which ignores the social aspects is doomed to failure", Joos, Carabias [30], it is only in very recent years that waste management programmes and policies are taking the social aspects into account and indicators for sustainable waste management are being developed. These social aspects include the problems of communication, public acceptance, (NIMBY/social compatibility), public participation in planning and implementation, consumer behaviour, intergenerational factors and changing value systems.

A study by Nilsson-Derf [11], which centred around nine European waste management programmes that were seen as advanced programmes in their countries, concludes that successful waste management programmes have one major factor in common. This common factor is that all programmes considered the issues of public acceptance and communication to be very important. "These programmes all indicate a process of a steady build up of social elements within the organisations including communication" over a long period of time. The same case studies are discussed by McDougall, White [10], who shows that all programmes include recycling and composting, but not all include incineration. The important point to note from this is that it is not the inclusion or otherwise of waste treatment techniques that determines whether a programme is sustainable or not, but whether the programme is accepted by the people who have to use it.

In contrast with these successful waste management strategies is the situation in Ireland. Ireland has one of the lowest municipal waste recycling rates in Europe at 9% DOELG [31] and relies almost totally on landfill for the disposal

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of waste. Most local authorities have produced waste management plans; however, very few of the plans give priority to the waste management strategies of waste prevention, minimisation, reuse and recycling, dismissing all options except for landfilling or incineration O'Sullivan [32]. In addition, there has been little meaningful public involvement or participation in their preparation. As a result, very few of the plans have been implemented and in many places in Ireland, one will see signs saying "no superdump here", or "no toxic incinerator". In the meantime, the management of waste in Ireland is reaching crisis point, with existing landfill sites becoming full or being closed because they do not meet the legislation requirements. Rogers and Grist [33] has also studied the situation in Galway, a county in Ireland, where "the apparently rational formulation of a landfill strategy undertaken by engineers and planners was given precedence over the political and social concerns of elected representatives and community organisations", resulting in a total rejection of the plans by the local community and the local politicians.

Conclusions

The development of MSW management models over the last number of decades has been described in the previous sections. The first solid waste management models were optimisation models and dealt with specific aspects of the problem. More recent models are centred around integrated waste management, with the concept of sustainable waste management becoming central to these models. Two main categories of models have been identified: Multicriteria models and Life Cycle Inventory models. Nevertheless, the models described have limitations and none have considered the complete waste management cycle, from the prevention of waste through to final disposal. Most are only concerned with refining the actual multicriteria technique itself or of comparing the environmental aspects of waste management options (recycling, incineration, disposal). In addition, while many models recognise that for a waste management model or strategy to be sustainable, it must consider environmental, economic and social aspects, no model examined considered all three aspects together in the application of the model.

It was also shown in this paper that successful waste management programmes have one main feature in common – the people affected by the plans were involved in the development of the plans, with communication and participation being central to this. In contrast, the situation in Ireland is at the other extreme, with many of the waste management strategies proposed by the local authorities involving minimal consultation with the stakeholders and as a result are proving to be very controversial.

Finally, future research in this area will bring the two aspects of multicriteria modeling and the concept of sustainable waste management together to develop the most appropriate decision making methodology for sustainable waste management decisions involving all stakeholders. This methodology will look at the development and implementation of a waste management strategy. Successful implementation of the strategy will not just be based on economic

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criteria, or diversion rates from landfill, but also on stakeholder inclusion, intergenerational equity and the satisfaction of social needs.

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