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Waste management models and their application to sustainable waste management

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Abstract

The purpose of this paper is to review the types of models that are currently being used in the area of municipal waste management and to highlight some major shortcomings of these models. Most of the municipal waste models identified in the literature are decision support models and for the purposes of this research, are divided into three categories—those based on cost benefit analysis, those based on life cycle assessment and those based on multicriteria decision making. Shortcomings of current waste management models include that they are concerned with refinements of the evaluation steps (e.g. stage four of AHP or the improvement of weight allocations in ELECTRE) rather than addressing the decision making process itself. In addition, while many models recognise that for a waste management model 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.

1. Introduction

The purpose of this paper is to review the models that are being used to support decision making in the area of municipal waste management and to highlight some major shortcomings of these models. A model is representation of an object, system or idea in some form, other than that of reality itself (Qureshi et al., 1999). Many of the models identified are decision support models, using a variety of methods and tools, such as risk assessment, environmental impact assessment, cost benefit analysis, multicriteria decision making and life cycle analysis, as part of the decision making process. Most 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 one of these tools or methods. The type of tool selected also depends on the decision being made and on the decision-makers (Zopounidis and Doumpos, 2002; Guitouni and Martel, 1998; EEA, 2003). Tools such as these are an important part of the waste management models identified, but only a part, as the focus of this research is on models for municipal waste management, and therefore goes beyond the tool used to assist in the decision making process. In some cases, the goal of the model is simple, (to optimise waste collection routes for vehicles), while in others, it is more complex (to evaluate alternative waste management strategies). For the purposes of this research, only the more complex models for municipal waste management decision-making will be considered. Decisions involving industrial, hazardous or liquid waste are also outside the scope of this research.

The remainder of this paper is structured as follows. To put the current research in context, a brief history of the development of municipal waste management models is given in Section 2, with a review of current waste management models outlined in Section 3. Section 4 discusses the shortcomings of the existing models. The conclusions of this review are given in Section 5, along with indications for future research.

2. A brief history of the development of municipal waste management models

Modelling of waste management is not a new idea. A comprehensive summary of the models developed in the

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1970s, 1980s and early 1990s is given by Gottinger (1988), MacDonald (1996a), Berger, Savard et al. (1999) and Tanskanen (2000) and describe among others, the dynamic mixed integer programming model of Baetz and Neebe (1994), a multi-period and multi-regional model developed by Everett and Modak (1996) and the static non-linear programming model, MIMES/WASTE developed by Sundberg et al. (1994). These summary articles are spread over a 12-year period and indicate the changes that has happened in the area of municipal waste management modelling over that time. As Berger, Savard et al. (1999) and Tanskanen (2000) point out, the first solid waste management models were optimisation models and dealt with specific aspects of the problem, for example vehicle routing, Truitt et al. (1969), or transfer station siting, Esmaili (1972). However, according to Berger et al. (1999), the early models suffered from several shortcomings such as having only one time period, recyclables rarely being taken into account, having only one processing option of each type, or having a single generating source. These limitations have the effect of making them unsuitable for long-term planning according to Sudhir et al. (1996). MacDonald (1996a) expands on this, by pointing out that much of the work done in the 1970s "dealt with applying and refining various optimisation and heuristic techniques to provide a more realistic representation of solid waste management practices".

The models developed during the 1980s extended the system boundaries of the earlier models and covered Municipal Solid Waste Management (MSWM) at the system level. This meant that the models looked at the relationships between each factor in the waste management system, rather than looking at each in isolation (MacDonald, 1996b). In addition, the increased computer literacy and availability of the late 1980s provided an opportunity to develop more sophisticated waste management models. The models developed in the 1980s were mainly aimed at minimising the costs of mixed waste management (Gottinger, 1988) and recycling was included in some of them (Englehardt and Lund, 1990). While the main issues of concern of these early models were generally economic, some researchers did acknowledge the social equity issues related to the siting of facilities (Fuertes, 1974). Other researchers, for example, Motameni and Falcone (1990) looked at influencing peoples attitudes, so that they might change their behaviour when it comes to recycling. However, the inclusion of social issues such as these was unusual. Another characteristic of these earlier models is that they were only concerned with dealing with waste once generated, and the models did not include minimisation or prevention aspects. However, Boyle (1989) pointed out that "reducing the amount of wastes ultimately requiring disposal at the point of generation is the most rational and cleanest means of solid waste management". Nevertheless, the concepts of sustainable waste management or integrated waste management were not terms that were used in any waste management model up to this time.

During the 1990s, recycling and other waste management methods were being included in most models developed for the planning of municipal solid waste management (MSWM), such as those developed by Morris (1991), Smith and Baetz (1991), Chang and Wei (1999) and MacDonald (1996a). 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). (ERRA, 1999; Gabola, 1999; Kowalewski et al., 1999; Berger et al., 1999; Clift et al., 2000; EPIC and CSR, 2000). 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 (Barton et al., 1996; Bjorklund et al., 1999; Warmer Bulletin, 2000; Finnveden, 1999; Powell, 2000; McDougall et al., 2001; Harrison et al., 2001; EPIC and CSR, 2000) with the aim of making a comprehensive assessment of the systems environmental impact, including all significant activities during its life cycle. Smith and Baetz's (1991) research also shows that until the 1990s, there was very little literature available detailing costing information on integrated waste management systems.

As described above, most waste management models consider economic and environmental aspects, but 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-Djerf and McDougall (2000), who go on to say, "for a waste management system to be effective, it must be accepted by the population". This point is emphasised by Petts (2000) 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 public's views towards incinerators and landfills [NIMBY, NOTE, LULU and BANANA (see Appendix)] are also factors in determining waste management policy and this is reflected in more recent models. Berger et al. (1999) recognises that a necessary improvement to their optimisation model developed for solid waste management planning, EUGENE, is "the addition of various social and environmental indicators, for eventual use in multicriteria analyses". Hummel's (2000) model aims to help determine what it should cost to meet current recycling targets and establish the optimum level of recycling that could be reached. The difference between this model and other similar ones is that demographics, education and promotion (social factors) are an inherent part of the model in determining the optimum levels.

3. Current waste management models

Rogers (2001) categorises models into two categories: those that use optimising methods and those that use compromising methods. While Rogers's categorisation is centred around engineering project appraisal, it can be applied to waste management models as well. Optimising models assume that the different objectives of the proposal can be expressed in a common denominator or scale of measurement, whereby the loss in one objective can be directly evaluated against a gain in another. Optimisation models include cost benefit analysis and present worth evaluation with the common scale of measurement usually expressed in monetary terms. In contrast, compromising methods assume that the decision-maker may have limited knowledge regarding the decision situation and are based on Simon's Simon (1976) concept of 'bounded rationality'. Guitouni and Martel (1998) also makes the point that the "idea of the optimal solution is abandoned for the notion of the 'satisfaction of the decision maker and that this is the beginning of the development of many MCDA methods." These methods are based on the principle that any viable solution has to reflect a compromise between the various priorities, while the discrepancies between the actual outcomes and aspiration levels are traded off against each other by means of preference weights. Each alternative is judged in relation to multiple priorities, so that the desired alternative is one that performs comparatively well according to these priorities.

A review of current waste management models shows that most can be categorised into one of three categories—those based on cost benefit analysis, those based on life cycle analysis and those based on the use of a multicriteria technique such as AHP or ELECTRE. A brief description of each of these is given in the following paragraphs, followed by a discussion of their shortcomings in Section 4. It is noted that not all models fall into the above categories, for example the models of Chang and Wei (1999), Chang and Li (1997), Berger et al. (1999) and Sudhir et al. (1996). However, as they are more limited and are not of direct relevance to the current research, will not be discussed further.

3.1. Models based on cost benefit analysis

3.1.1. Description

This tool enables decision-makers to assess the positive and negative effects of a set of scenarios by translating all impacts into a common measurement, usually monetary. This means that impacts, which do not have a monetary value, such as environmental impacts, must be estimated in monetary terms. There are several ways to do this, such as estimating the costs of avoiding a negative effect (e.g. the cost of pollution control on an incinerator) or to establish how much individuals are willing to pay for an environmental improvement. Social impacts can also be evaluated in the same way, although social impacts were not included in any of the Irish waste management plans. On completion of the analysis, the scenario with the greatest benefit and least cost, is the preferred scenario.

3.1.2. Benefits and limitations

- The results are presented in a clear manner, with all impacts summed up into one monetary figure.
- It enables decision-makers to see what scenarios are efficient in their use of resources.
- There is uncertainty involved in estimating the monetary value of several environmental and/or social impacts in monetary terms. This also raises ethical issues.
- The assumptions about prices may change during the lifetime of the waste programme, changing the preferred outcome (e.g. changes in landfill costs may impact on how much waste is recycled).

3.1.3. Applications

The waste management plans drawn up in Ireland are based on cost benefit analysis (e.g. MCCK, 1998). Life cycle analysis data can be used to estimate environmental costs by applying an economic valuation to each environmental impact category. In addition to using CBA analysis to select a waste management scenario, CBA can also be used for specific decisions, e.g. an evaluation of packaging recycling and reuse systems (RDC and PIRA, 2003).

3.2. Models based on life cycle analysis

3.2.1. Description

Life cycle assessment is a tool that studies the environmental aspects and potential impacts throughout a product's life from raw material acquisition through production, use and final disposal (i.e. from cradle to grave) ISO 14040 (1997). 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 Berkhout and Howes (1997). 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.

According to McDougall et al. (2001), LCA offers a system map, that sets the stage for a holistic approach and then by comparing such system maps for different options, whether for different products or waste management systems, environmental improvements can be made. If a holistic approach such as LCA is not applied, concentrating on individual issues, such as euthrophication, may worsen the system as a whole with respect to other environmental issues.

McDougall et al. (2001) link the concepts of Integrated Waste Management with that of Life Cycle Analysis. Integrated Waste Management systems combine waste streams, waste collection, treatment and disposal methods, with the objective of achieving environmental benefits, economic optimisation and social acceptability. The model developed by McDougall et al. (2001) called IWM-2 is based on both the IWM and LCA concepts.

The technique of Life Cycle Assessment consists of four phases each of which is subject to International Standards: ISO 14041(1998) ISO 14042(2000) ISO 14043(2000) for guidelines in their use.

3.2.2. Benefits and limitations

- 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 effects of the product, package or service system. The actual environmental effects of emissions and wastes will depend on when, where and how they are released into the environment. Other tools, such risk assessment, are able to predict the actual environmental effects, but these techniques do not cover all environmental issues in the life cycle. LCA allows the trade-offs associated with each option to be assessed and comparisons made.
- LCA is but one tool in the ''environmental management toolbox'' and should not be used in isolation to decide such issues as which waste management treatment option is to be preferred. (EUROPEN, 1996; Finnveden and Ekvall, 1998).
- A difficulty associated with LCA is establishing where the boundary is and the definition of the functional unit (Ekvall, 1999).
- The results produced by variations of LCAs (e.g. investigating the same product) differ in practice (EEA, 2003).
- LCAs are restricted to looking at environmental impacts only, although both Harrison's et al. (2001) and Craighill and Powell's (1996) models extend the lifecycle assessment methodology to incorporate an economic evaluation of the environmental impacts.

3.2.3. Applications

WISARD is an LCA package that the Environment Agency in England and Wales are using to assist local authorities in waste management. WISARD and a similar application called IWM-2 developed by McDougall et al. (2001) are life cycle inventory models, which take an overall view of a waste management system and ''allow measurement towards the goals of environmental and economic sustainability''. These models can be used in either of two ways, to compare future integrated waste management options or to optimise existing options. While the models only look at the life cycle inventory aspects of the waste management system (i.e. the inputs and outputs of the system), it is recognised in McDougall's et al. (2001) IWM-2 that a methodology for impact assessment for model should be included for completeness. While both the WISARD and IWM-2 models aim to deliver both environmental and economic sustainability, they do not consider social aspects and therefore, cannot be considered truly sustainable waste management models.

Powell (2000) uses the LCI model developed by White et al. (1995) (which is an earlier version of the McDougall et al.'s model described above), to study the factors affecting the utilisation of LCI models. A similar, but more limited model is that developed by EPIC and CSR (2000). This model is also a LCI model for waste management systems, and was designed with input from the City of London, Ontario, Canada and is being used by municipalities throughout Canada. It is more limited, because it does not consider all available waste management processes, or all possible waste management burdens. It is intended to be a guide only and requires the input of a number of other considerations derived from site specific impact studies and economic, social and political factors in order to prescribe the ''best'' system.

A selection of some of the LCA software tools is listed in Table 1.

3.3. Models based on multicriteria decision analysis

3.3.1. Description

A brief history of the origins of multicriteria evaluation methods is given by Bana E Costa et al. (1997). Despite

Table 1
Some of the software tools available for MCDA and LCA

	Applications
MCDA software	
EXPERT CHOICE	For AHP. (Forman, 1998)
ELECTRE TRI Assistant	for ELECTRE TRI (Mousseau et al., 2000)
HIPRE 3+	HIPRE 3+ is a decision support software product integrating AHP and SMART—The Simple Multiattribute Rating Technique. Both methods can run independently or be combined in one model. (http://www.sal.hut.fi/Downloadables/)
HiView	Hiview is a Multi-Criteria Decision Analysis (MCDA) tool that supports decisions regarding mutually exclusive options, using a technique called MACBETH (http://www.catalyze.co.uk/hiview/hiview.html)
LOGICAL DECISIONS	Used with Multi-Attribute Utility Theory. The software provides five different methods for assessing weights, ranging from the "Smarter" method to AHP (http://www.logicaldecisions.com/prod01.htm)
PREFCALC, MINORA, VIG, LBS, CAMOS, M.H.DAS, ADELAIS, MARKEX, UTA+, FINEVA, FINCLAS, MUSTARD	Identified by Siskos (1999) and Jacquet-Lagreze and Siskos (2001) as examples of Third and Fourth generation Multicriteria Decision Support Systems (MCDSSs) and most of which are UTA based
PREFDIS system	Uses the UTADIS method to develop additive utility functions for sorting problems involving two or more groups. (Zopounidis and Doumpos, 2002)
PROMCALC	For the PROMETHEE method.(de Keyser and Peeters, 1996)
RANGU system	Developed by Stam and Ungar which develops discriminant functions for two-group classification. (Zopounidis and Doumpos, 2002)
ROSE system	Developed by Predki and others is based on the rough set method (Zopounidis and Doumpos, 2002)
LCA software	
Boustead model	For life cycle analysis (http://www.boustead-consulting.co.uk/products.htm)
GABI 4	For life cycle analysis http://www.gabi-software.de/
IWMM	Integrated Waste Management Model for life cycle analysis, developed by EPIC/CSR (2000)
IWM2	For Life cycle Analysis (McDougall et al., 2001)
SIMA Pro 5.1	Eco indicator software developed by Pre Consultants. For life cycle analysis (http://www.pre.nl/)
WARM	Waste reduction model, a model to help solid waste planners track greenhouse gas reductions form several different waste management practices. Funded by USEPA http://yosemite.epa.gov/oar/globalwarming.nsf/content/Actions WasteWARM.html
WISARD	For Life cycle analysis and used by the local authorities of England, Scotland and Wales (Clift et al., 2000). Developed by Ecobilan http://www.ecobilan.com/uk_wisard.php

an early insight by Benjamin Franklin into multicriteria formulation of decision problems in 1772, when Franklin used structuring and evaluation to solve problems with conflicting criteria and uncertainty, 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 multicriteria decision analysis (MCDA) are more common 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. The normal approach is to identify several alternatives, (such as different waste management scenarios) which are then evaluated in terms of criteria that are important for the model or circumstances of the model being developed. The result is a ranking of the alternatives. The type of criteria chosen in these model types depends on the objectives of the model, and therefore could include risk assessment or environmental impact assessment.

A detailed description of the various MCDA techniques can be found in Keeney and Raiffa (1976) (MAUT), Roy (1991) (ELECTRE), Brans et al. (1998) (PROMETHEE), Saaty (1980) (AHP), Jacquet-Lagreze and Siskos (1982) (UTA) and Zeleny (1982) (Multi-objective Optimisation). Further details on comparing the main MCDA techniques can be found in Guitouni and Martel (1998), Bana E Costa et al. (1997), Rogers (2001), Salminen et al. (1998), Zopounidis and Doumpos (2002), and van Huylenbroeck (1995).

3.3.2. Benefits and limitations

- Allows a systematic approach to evaluate policy options and helps understanding of the problem.
- A mixture of quantitative and qualitative information can be incorporated. MCDA goes beyond the evaluation of purely economic consequences and allows non-economic criteria to be assessed on an equal basis.
- Account can be taken of the preferences of the various stakeholder groups with conflicting objectives (Bana E Costa et al., 1997, Qureshi et al., 1999).
- Multicriteria techniques offer a level of flexibility and inclusiveness that purely economic based models tend to lack.
- These methods do not produce the ''best'' solution, but a set of preferred solutions or a general ranking of all solutions. Solving such a multicriteria problem is therefore, a compromise and depends on the circumstances in which the decision aiding process is taking place.
- There is a need for personal judgement and experience in making the decisions
- Some of the multicriteria techniques are very cumbersome and unwieldy (Beynon et al., 2000).
- The allocation of weights to each criterion is subjective. Changing the weights could lead to a different result.
- When this category of model is used to consider waste management options, the models identified in the literature take into account waste once generated only. Waste prevention, waste minimisation, or product design for the environment, which would eliminate the production of materials which cannot be reused, recycled or naturally biodegraded are generally not considered.

3.3.3. Applications

An analysis of multicriteria waste management models shows that ELECTRE III is found to be the most commonly used method for waste management decisions in the literature, e.g. Hokkanen and Salminen (1997) Courcelle et al. (1998) and Karagiannidis and Moussiopoulos (1998b). The AHP method is also used in some applications e.g. MacDonald (1996b), or a variation of the AHP Takeda (2001) and Haastrup et al. (1998). This is not to say that none of the other methods identified by Guitouni and Martel (1998) could not be applied to waste management problems. Indeed, as van Huylenbroeck (1995) points out, both the PROMETHEE and ORESTE methods could be applied to waste management. However, Salminen et al. (1998) 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 the utility theory of Keeney and Raiffa, 1976) and concluded that ELECTRE III was the most suitable as the other methods have no superior features when compared with it.

While there is a well-established PC implementation of the AHP method called Expert Choice, the AHP method is not widely used in waste management problems. Indeed, MacDonald's (1996b) model is the only one found and even in this model, the use of the AHP method is only the final stage of a seven stage process (which also uses a geographical interface system, databases and spreadsheets). In addition, Rogers and Bruen (1998a) suggests using outranking methods in preference to the AHP method because the AHP method requires that all options be directly comparable with each other, even when such comparisons are questionable because of the lack of suitable data. Rogers and Bruen (1998a) also considered the outranking methods more capable than the AHP method of dealing with the mix of both quantitative and qualitative information and this was one of the main factors in their choice of the outranking approach. However, other authors, such as Lai et al. (2002) and Carlsson and Walden (1995), disagree with this point of view and also show that the AHP method has been successfully used in group decision making. The availability or otherwise of software tools to assist in MCDA can be a reason for selecting a particular MCDA method (Guitouni and Martel, 1998). Table 1 shows a selection of such software.

4. Shortcomings of existing models

Three points should be made at this stage to put the discussion of waste management models in context. The first point relates to decision making and decision support in general. How decisions are made, the cognitive tasks undertaken by the decision-maker and the type of decisions that can be made are not the focus of the current research. Secondly, as has been noted elsewhere, CBA, multicriteria methods and LCA methods are decision aids. Salminen et al. (1998), Miettinen and Salminen (1999), Rogers (2001) and 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 area. Finally, the focus of this research is on the applicability of the methods and tools to sustainable waste management only. A more thorough analysis these methods can be found in a recent study by the European Environment Agency (EEA, 2003).

The shortcomings of each of the three approaches are discussed in the following sections.

4.1. Cost benefit analysis

As is often the case, particularly in Ireland, waste management scenarios are evaluated on the narrow framework of cost benefit analysis. Environmental decision making usually involves competing interest groups, conflicting objectives and different types of information and CBA is not a suitable decision aid for such a decision (Carbone et al., 2000). In addition, the CBA approach allows improvements in one problem dimension (e.g. costs), to compensate for a deterioration in another (e.g. emissions), which is not a sustainable approach to waste management. Finally, the maximisation of economic efficiency is usually the overriding factor in a cost benefit analysis at the expense of environmental and social criteria, which once again, is not a sustainable approach to waste management.

4.2. Life cycle analysis

LCA has traditionally not been subject to public involvement, being a specific and highly technocratic environmental loading accounting tool according to Petts (2000), 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". However, it is proposed by some authors (McDougall et al., 2001) that decision making on the basis of the impact assessment results should be done by open public debate as part of the democratic process.

In addressing several environmental issues and human health impacts, LCA cannot predict or measure actual effects. It is a comparative tool that reduces data to mass loading based on simplifying assumptions and subjective judgements and hence it can add independent effects into an overall hazard score on a system wide basis. At the 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 environmental impact assessment or both, to address these issues in a more detailed way. "Significantly, LCA cannot deal with time dependent impacts of the type relevant to intergenerational considerations" Petts (2000).

Models that consider the full life cycle of products in deciding on a waste management strategy are complex and very detailed. As a result, the potential users of such a model, 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, 2000). If this happens, it makes the use of the LCA approach 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 (ISO 14040). Craighill and Powell (1996), however, extends the LCA technique to include economic and social factors by developing the technique of Lifecycle Evaluation (LCE). It should be pointed out that these models only consider the life cycle inventory phase of the life cycle assessment framework. The availability of a methodology for the assessment stage of LCA (ISO 14042), should mean that the newer LCA models will include both impact and assessment analyses. There are many advocates of the LCA approach including EUROPEN (1996), McDougall, White et al. (2001), Daskalopoulos et al. (1998), Finnveden (1999), EPIC and CSR (2000) and Ayalon et al. (2000).

4.3. Multicriteria decision analysis

While the applications of ELECTRE are well covered in the literature, many authors have identified the allocation of weights as a major shortcoming of the method. As a result, there have been several attempts to improve on this shortcoming, such as those of Rogers and Bruen (1998a,b) and Takeda (2001). Rogers's contribution is in an improved method of weight and threshold selection to be used in the ELECTRE methods. Takeda introduced the idea of combining the outranking methods with those of AHP. However, Takeda only looked at Stage 4 of the AHP process, i.e. the pairwise comparison stage, and did not consider the complete AHP method.

This last point also highlights one of the main differences between the AHP and ELECTRE methods. 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. Furthermore, if the number of decision-makers become large, the number of alternatives and criteria are reduced. With the exception of the ELECTRE TRI software package, there does not appear to be any commercial application of the ELECTRE methods available. In contrast, the starting point of the AHP methods is the objective or goal of the decision. Arising out of this are the criteria that relate to the goal and possible alternatives. With the availability of Expert Choice, the number of criteria and/or alternatives that can be considered is very large.

Despite this, some authors Rogers and Bruen (1998a) and Hokkanen and Salminen (1997) for example, decided against using the AHP process in their research, while others including Beynon et al. (2000) used a modified version of AHP using the Dempster–Shafer Theory (DST) to reduce the number of alternatives to a manageable level. In essence, what Hokkanen and Rogers had difficulty with was Stage 4 of the AHP process, i.e. the pair-wise comparison stage. Rogers and Bruen (1998a) was concerned with the requirement that AHP requires that all options be directly comparable with each 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 (1998) 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 (1997) and Beynon et al. (2000) 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 they were dealing with.

In contrast with this, many other authors are of the view that the allocation of weights in the ELECTRE method is not a sound basis for making a decision. Nevertheless, according to the authors, Hokkanen and Salminen (1997) successfully applied the ELECTRE method in Finland, as did Karagiannidis and Moussiopoulos (1997) in Greece, while there are fewer applications of the AHP methods to waste management.

The weighting problem in the outranking methods is one of its major shortcomings. In a similar way, weighting is also a problem for the LCIA stage of LCA. The development of this phase of the LCA process is becoming established. Many researchers, including Hertwich and Hammitt (2001), Seppala et al. (2002), Geldermann et al. (2000) among others, are recommending applying the concepts of multicriteia decision making to LCIA. Equally, it could be argued that LCA data are an essential part of any MCDA approach to waste management, as LCA data are used as the environmental criteria, e.g. carbon dioxide emissions over the life cycle of the different waste management techniques.

An aspect of the use of the models that is not considered in detail in any of the models identified, is the issue of whether the techniques can be used by disparate groups of decision makers. Both Hokkanen and Salminen (1997) and Karagiannidis and Moussiopoulos (1997) applications did involve groups of decision-makers, but while Hokkanen and Salminen (1997) identifies the decision-makers as the municipal councils and the associated environmental and technical committees, Karagiannidis and Moussiopoulos (1997) does not identify who the decision-makers are. Similarly, the decision-makers in any of the LCA models identified are also the local authorities or government officials and as stated by Petts (2000) above, LCA is not a suitable tool for public involvement. It is the assertion of this research, that the non-involvement of the people who generate the waste, (i.e. the general public) in a meaningful way in the decision making process is a major shortcoming of these models. None of the models identified consider the social aspects of waste management or intergenerational aspects and as a result, it is contended that none of the models can be considered to be fully sustainable. (The most well known definition of sustainable development is that of World Commission on Environment and Development (1987), 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 et al. (1999), 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-Djerf (1999), 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 et al. (2001), who shows that while all programmes include recycling and composting, not all include incineration. The important point to note from this is that it is not just 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 13% EPA (2003) and relies almost totally on landfill for the disposal 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 (2001). In addition, there has been little meaningful public involvement or participation in their preparation. 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 (2001) 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.

Finally, most of the waste management models identified are concerned with refinements of the evaluation steps (e.g. stage four of AHP or the improvement of weight allocations in ELECTRE) rather than addressing the decision-making process itself and how the participation of all relevant stakeholders in the decision-making process may be improved. In other words, the most important step to get right is the formulation of the problem in the first place, but most models identified gloss over this aspect, concentrating on the actual MCDA technique itself.

5. 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 compromising models, focused around integrated waste management, with the concept of sustainable waste management becoming central to these models. Three main categories of models have been identified: cost benefit analysis models, life cycle inventory models and multicriteria 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, and 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 and none considered the intergenerational effects of the strategies proposed. It is the assertion of this research, that the non involvement of the people who generate the waste, (i.e. the general public) in a meaningful way in the decision making process is a major shortcoming of these models and as a result, it is contended that none of the models can be considered to be fully sustainable. Another identified weakness of the current models, is that no model identified considers the involvement of all relevant stakeholders, namely the government, the local authorities, the technical experts and the community.

As a result of these shortcomings, future research in this area will bring the two aspects of multicriteria modelling and the concept of sustainable waste management together to develop a suitable decision making methodology for sustainable waste management decisions involving all stakeholders in a community. This methodology will look at the development, evaluation and implementation of a waste management strategy. Successful implementation of the strategy will not just be based on economic criteria, or diversion rates from landfill, but also on stakeholder inclusion, intergenerational equity and the satisfaction of social needs. It has been identified in this paper that two important steps in decision making in the area of municipal waste management are the formulation of the problem and the involvement of all relevant stakeholders in the decision-making process. These aspects will be included in the methodology developed along with the use of an appropriate decision aid.

Appendix. Definitions and abbreviations

AHP	Analytic Hierarchy Process
ASSURRE	Association for the Sustainable Use and Recovery of Resources in Europe
BANANA	Build absolutely nothing anywhere near anything
BPEO	Best Practicable Environmental Option
CBA	Cost Benefit Analysis
EIA	Environmental Impact Assessment
EEWC	European Energy from waste coalition
ELECTRE	Elimination and Choice Translating Reality (multicriteria method)
EPA	Environmental Protection Agency
ERRA	European Recovery and Recycling Association
EUROPEN	European Organisation for Packaging and the Environment

INCPEN	Industry Council for Packaging and the Environment
IWM	Integrated Waste Management
LCA	Life Cycle Analysis
LCIA	Life Cycle Impact Assessment
LULU	Locally unacceptable Land Use
MAUT	Multi Attribute Utility Theory
MCDA	Multicriteria Decision Analysis
MCDM	Multicriteria Decision Making
MSWM	Municipal solid waste models
NIMBY	Not in my backyard
NOTE	Not over there either
PROMETHEE	Preference Ranking Organisation METHod for Enrichment Evaluations
SETAC	Society of Environmental Toxicology and Chemistry
SPOLD	Society for the Promotion of Life Cycle Assessment
UTA	Utility Additive (multicriteria method)

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