Energy from waste: Incorporating the perspective of multiple agents

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Abstract

Energy from waste has been identified as a source of green energy and an effective method to reduce greenhouse gas emissions (GHGE). Nevertheless, energy from waste presents a source of conflict between different levels of government, public and the industry. Opposition may argue that energy from waste plants pose health risk to the public, increase the cost of solid waste management, have negative environmental impacts and encourage NIMBY (not in my backyard) attitude. On the other hand, some social actors may hold opposite views because they perceive them as source of income or as effective methods of maximizing resource utilization from waste. Clearly, selecting an appropriate energy from waste strategy in democratic systems of government involves many layers of decisions and requires the construction of effective dialogue mechanisms among many social agents. This paper demonstrates how life-cycle analysis combined with cost analysis can be integrated with conflict analysis models under conditions of uncertainty to select an appropriate policy for energy from waste production from the combustible fraction of the municipal solid waste of Sydney. The results show that anaerobic digestion combined with recycling is the strategy most likely to achieve highest level of environmental benefits while minimising social conflict.

1. INTRODUCTION

Renewable energies have received much attention as a way of reducing greenhouse emissions (GHGE). Waste is one potential source of renewable energy. Energy from waste (EfW) has been identified as one means of maximizing resource utilization of waste and tackle global warming. Many researchers discussed the benefits of EfW (e.g., Lea, 1995; Porteous, 1998; Murphy and McKeogh, 2004; Skordilis, 2004; Consonni et al, 2005; Finnveden et al., 2005; Porteous, 2005; Eleftheriou, 2007; Emery et al., 2007; Ryu et al, 2007; Giugliano et al, 2008, El Hanandeh and El-Zein, 2009a,b). However, most of the studies focused on the environmental, technical or economic dimensions and rarely considered uncertainty and the social dimension of the problem. Moreover, EfW does not have a 'green image' in the minds of the public and is often met with resistance from the public. As a result, selecting a waste from energy strategy may be opposed because of its health impact, economic cost or merely on the basis of 'not in my backyard' attitude. On the other hand, others may see EfW as an environmentally responsible method of waste management. Therefore, it is obvious that selecting an EfW strategy is a conflict management problem.

Multi-criteria decision aids (MCDA) have been used by many as a tool for analysing problems in solid waste management (e.g. Hokkanen and Salminen, 1997; Lahdelma et al, 2000; Vego, 2008). Nevertheless, including the social dimension has always been a difficult issue to tackle, partly because of the high subjectivity and uncertainty involved and because of the nature of MCDA tools which are often built around a hypothetical single decision maker (Bender and Simonovic, 2000; Proctor and Qureshi, 2005).

The aim of this paper is to illustrate how the perspective of different social agents can be incorporated, at early stages when limited resources are available, to study the effectiveness of different alternatives. The case of utilizing the combustible fraction of municipal solid waste in Sydney as a source of energy is used to demonstrate the method.

2. METHODOLOGY

2.1. Social Multi-criteria Evaluation

Environmental systems are complex systems because they cannot be represented by a single perspective (Funtowicz et al., 1999). Munda (2006) argues that because of this, reductionist approaches (e.g.; carrying capacity, ecological footprint, market-based instruments) are inadequate for sustainability policy making as they require the transformation of incommensurable measurements into a single dimension. Therefore, multi-criteria structuring of the problem can be a very useful tool to create a common language between different agents involved (Munda, 2004). Hence, combining the social and technical issues in a multi-criteria evaluation framework called SMCE is suggested.

The main principles of SMCE is summarised in the following (Munda, 2006; Gamboa and Munda, 2007):

1- The classical schematized relationship decision maker/analyst is embedded in a social framework.

2- The combination of various participatory methods can provide a map of relevant social actors and their desires and preferences. Therefore, it is possible to derive a set of policy options and evaluation criteria.

3- Policy evaluation is an iterative process that allows for continuous incorporation of new knowledge and testing the assumptions made.

4- Mathematical algorithms play important role to assure the consistency of the rankings with the information available and the assumptions used.

In this paper we structure the problem of EfW on the general principles of SMCE. However, we omit the public participatory stage.

2.2. Framework implementation

To implement the framework we need to identify the significant agents involved in the system. A set of alternatives need to be developed and decision criteria, against which the alternatives can be judged, need to be defined. However, the perspective of each agent should be taken into account. Therefore, criteria weights (CW) need to be estimated for each criterion from the perspective of each agent. ELECTRE-SS (El Hanandeh and El-Zein, 2009) in combination with the rough set theory (Pawlak, 1998) are then used to estimate the opinions of each agent about alternatives.

2.3. Ranking strategies according to social agents views

In order to derive the views about each strategy from the agents using the criteria defined, we define U as the non-empty set which contains the agents. We derive a criteria set G_x that captures the relevant concerns of the agent for every agent $x \in U$. Agent x may be in favour of either maximizing or minimizing the value of criterion $g_j \in G_x$.

Next, we build an information system S'_x such that $S'_x = (G_x, A)$ where A is the non-empty set of strategies. Following Pawlak (1998) model; $a \in A$ is a map $a : G_x \to V_a$. V_a is the domain of *a* and $a(g_j(x))$ is the evaluation of criteria g_j according to the preferences of agent *x* for the performance of strategy *a*. The domain V_a is restricted to the set {-1, 0, 1}. The value -1 means that the strategy will cause a change in the value of criteria g_j in opposite direction to the agent's preference, 0 the change is insignificant and +1 means that the change is in the direction of the agent's preference. To evaluate the direction of change we benchmark the values to an agreed reference such as the business as usual (BAU) case. To determine if the change is significant, we define a threshold value q. Assuming that criterion g_j is to be maximized, we can then define

$$a(g_j(x)) = \begin{cases} 1 & g_j(x) > g_j(R) + q \\ 0 & \left| g_j(x) - g_j(R) \right| \le q \\ -1 & g_j(x) < g_j(R) + q \end{cases}$$

Next, multi-criteria aid (MCDA) is used to evaluate the alternatives from the perspective of each agent.

3. CASE STUDY

3.1. Background

The combustible fraction (food waste, green waste, plastic and paper) constitute 80% of the municipal solid waste in Sydney. It amounts to more than a million Mg a year. Bio-degradable material makes up most of the combustibles. Therefore, it is a good source for renewable energy because the CO_2 emissions from this operation are considered biotic. There are several methods which can be used to harvest the energy from waste such as incineration, bio-digestion, landfilling with gas collection and energy recovery.

Once the agents are identified, the problem can be structured in a multi-criteria framework. A set of alternatives need to be generated and a set of criteria is developed to judge the alternatives against them.

3.2. Generating the alternatives

To generate the alternatives we construct combinations of the available methods; incineration, traditional landfilling with energy recovery, bio-reactor landfill with energy recovery and bio-digestion. The alternatives are presented in a matrix format in table 1.

[Table 1]

Alternative Alt1 represents the business as usual. We use Alt1 as a reference to compare the performance of other alternatives against it. Alternatives Alt2, Alt3 and Alt4 test the feasibility of diverting all combustible waste to one treatment method/facility. This will allow the system to take advantage of the economies of scale. Alt5 is designed to maximize the bio-gas production for electricity generation.

3.3. Social agents

In this study we consider the social agents who are directly involved or affected by the waste management system. We have identified the following agents who are immediately affected by the decision making process: public, waste management industry, local government, state government and federal government. Table 2 summarises the role of each agent in the system.

[Table 2]

In 2006, the NSW parliament called an inquiry into municipal solid waste management practices in NSW. Referring to the submissions to the inquiry and reviewing various surveys conducted by various agencies as well as studying historic documents we are able to construct an overview of different stakeholders' opinions regarding municipal solid waste management systems. These views are presented in table 3.

[Table 3]

3.4. Developing the criteria set

In this section we develop the criteria set which we use in our analysis. We do this by analysing published literature and documents available in the public domain. The submissions made to the parliamentary inquiry into municipal solid waste conducted in 2006 are very useful source in the case of Sydney. Table 4 summarises the criteria and the level of concern of each agent regarding each criterion.

3.4.1. Estimating criteria weights

To estimate the criteria weights we map the linguistic descriptors to ranges on a scale [0,100] using the fuzzy set definition to account for the vagueness in the definition of the upper and lower bounds of each range. Ranges are defined in table 5. To calculate the overlap, we define a threshold value of 20% following the recommendations of Rogers and Bruen (1998) who suggested that preference thresholds in environmental criteria be set at around 20%.

[Table 4]

[Table 5]

3.4.2. Estimating the criteria performance values for each alternative

SIWMS, an integrated waste management model that applies a life-cycle approach with consideration of uncertainty in the system (El Hanandeh and El-Zein, 2009), is used to evaluate the health risk, GHGE, landfilled waste reduction, green electricity generation potential and the system cost. SIWMS is run 10,000 times to obtain the average and standard deviation of each of the impact parameters mentioned earlier. Table 6 shows the expected emissions from each alternative.

[Table 6]

Quantifying the rest of the criteria is more subjective. We use expert judgment to estimate the direction of change compared to the BAU case.

Alternatives based on a single technology are clearly less operationally complex than those based on multiple technologies. Traditional landfilling and incineration are well established methods whose operations are well understood. Alt2, Alt3 and Alt4 do not require sorting or special pre-treatment of the waste which reduces their operational complexity.

Bio-reactor landfills are now used in large scale operations in several cities around the world including Sydney. They require recirculation of leachate to enhance the biomass retention time which leads to accelerated decomposition of organic waste and faster release of biogas. A downside to this is the instability of waste and higher potential of groundwater contamination due to the increase of leachate volume. Bio-reactor landfills act as un-optimised anaerobic digestion process. They are more technically and operationally complex than traditional landfills. Anaerobic digestion of municipal solid waste is an emerging technology. There are several patented processes on the market. However, due to the high sensitivity of the anaerobic digestion process, they require more attention to keep their operation at optimal conditions.

Noise can result from the collection of waste and from operating equipments and other processes at the plant. The most obvious to the public will be from the collection operation. Although this may be a small change in the ambient environment, its effects can be amplified by other inconveniences, such as the frequent need to put the bins out for collection, the need for separating waste streams, odour and temporary storage space requirements.

Temporary storage is of special concern in inner city dwellings where space is restricted. Current practices require residents to separate waste into 2 or three streams, depending on the municipality. Therefore, we assume that if an alternative requires providing more than 3 temporary storage bins, it will cause a negative impact. Alternatives that require only one bin are considered to be a positive change.

Collection frequency has a significant impact on the overall cost of the system. Trucks used in collection will also release emissions which will add to the overall inventory of the emissions from the system. Separate collection of waste streams usually translates in longer routes in order to fill the truck and increase the number of trucks travelling partially full to the disposal/processing facilities. Therefore, alternatives that require lesser collection frequencies and increase the waste stream volume collected at once would usually be more economical. On the other hand, alternatives that require more collection frequencies and multiple collection trucks will result in higher employment in the sector and will usually be preferred by the collection industry as it creates more financial opportunities.

Alternatives that require more handling of waste streams may result in an increase of employment opportunity, especially in the collection and processing industry.

Table 7 summarizes the performance of alternatives compared to the business as usual case (Alt1).

[Table 7]

4. RESULTS AND DISCUSSION

ELECTRE-SS is run with each set of weights to obtain the ranking of alternatives from the perspective of each agent. A summary of the ranking is presented in fig. 1. Based on the ranking of each alternative and its ranking index, table 8 is constructed to describe the performance of each alternative. The alternative is assigned a value of +1 to indicate that it is likely to be supported by the agent. The value of -1 is assigned to alternatives that obtained poor ranking from the perspective of the agent. The value (0) is assigned to alternatives that are ranked in the middle range by the agent. These alternatives, although not supported by the agent; are not strongly opposed either.

[Fig 1]

Alt5 is the most favoured alternative with all agents supporting it. Alt2 comes second, as it is supported by the local government and the industry and is not strongly opposed by any of the other agents. Therefore, these alternatives are good candidates for further development and are likely to be the conflict minimizing alternatives.

Murphy and McKeogh (2004) compared alternatives for generating electricity from waste from technical, economic and environmental perspective and El Hanandeh and El-Zein (2009) analysed various alternatives to manage the degradable fraction of the municipal solid waste considering economic, health and environmental criteria under conditions of uncertainty. Both studies concluded that anaerobic digestion is likely to outperform incineration when no market for thermal products exists. Our findings here suggest that this notion holds true in multiple social agent scenarios.

The incineration-based alternative (Alt4) achieved low overall rank in multiple social agents settings. This is in line with the findings of other researchers who compared incineration to other waste management alternatives and found that incineration does not necessarily minimize the 'social cost' of the waste management system. On the contrary, it may even result in higher total 'social cost' than landfilling (Dijkgraaf and Vollebergh, 2004; Rabl et al., 2008).

Recycling is commonly viewed as an environmentally responsible practice. Our results confirm that recycling is an effective waste management alternative from a social perspective, even when considering the high levels of uncertainty associated with the process.

As this is only meant to be a preliminary analysis of potential strategies the result should be viewed as a guideline and be used to enhance the design of alternatives before presenting them to the public. Further and more detailed study, including stakeholder participation, should be carried out before the final selection of a strategy for EfW.

5. CONCLUSION

In this paper we presented and applied a novel approach to incorporate the social perspective in the decision analysis process of selecting an appropriate strategy for energy from municipal waste. The results illustrated the effectiveness of anaerobic digestion of bio-degradable waste as a method for retrieving the energy capacity of waste. Moreover, the results suggested that recycling of plastics is a more socially effective solution than incineration.

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Tables and figures

Table 1

Alternatives to harvest energy from waste*

Alternative	Waste fraction			
	Plastic waste	Food waste	Green waste	Paper
Alt1	REC	LDF	COMP	REC
Alt2	LDF	LDF	LDF	LDF
Alt3	B/LDF	B/LDF	B/LDF	B/LDF
Alt4	INC	INC	INC	INC
Alt5	REC	AD	AD	AD

* REC: Recycling, LDF: landfill, COMP: composting, B/LDF: bio-reactor landfill, AD: anaerobic digestion.

Table 2

Role of different agents in the municipal solid waste management system in Sydney

Agent	Role
Public	It plays the role of 'client'. It is directly affected by the system and its co-operation and acceptance is essential for the success of the system.
Local government	In Australia, the local government is in charge of administering municipal solid waste management systems. In most cases, this is done by contracting the collection, processing and disposal to commercial companies. It is also in charge of setting the rules, regulations and strategies in its own local jurisdiction.
State government	The state government is involved in the decision-making process by setting the rules, regulations and directions. At the moment, the state government of New South Wales (NSW) adopts a target-based approach to municipal solid waste government.
Federal government	The federal government is in charge of setting rules and regulations at a national level. Although, there is no national legislation regarding municipal solid waste, other environmental legislations have an impact on municipal solid waste management.
Waste management industry	In Sydney, the disposal of municipal solid waste is controlled by Waste Services NSW (WSN), which is a government enterprise. It operates landfills and two alternative waste management facilities around Sydney. However, the collection and recycling industry is deregulated.

Table 3

Stakeholders views regarding municipal solid waste management

Agent	Views
Public	It supports environmentally responsible policies. It is used to separating waste into streams. However, convenience, health risk and nuisance rate high among its concerns as well as the cost of the system. Temporary storage space could be an issue, especially in the inner city dwellings were space is usually constrained.
Local government	It supports environmentally responsible management strategies. However, the operational complexity of the system, cost, health risk and nuisance are important.
State government	The NSW government has set targets to reduce the amount of waste sent to landfills by 66% and increase green energy production by 9.5%.
Federal government	The Australian government is pushing a legislation to adopt a carbon trading scheme by year 2010. It also promotes green energy production.
Disposal industry	WSN is profit driven government corporation. However, they will need to comply with legislative requirements. WSN is trying to reduce landfilling practices through the adoption of alternative waste management technologies. They support the idea of EfW. However, incineration has not been, so far, a part of their strategy.

Table 4

Summary of criteria and agents level of concern

Criteria	Agent				
	Public	**Local government**	**State government.**	**Federal government**	**Waste management industry**
Temp. Storage	High	High	Low	Low	Low
Operational complexity	Low	Moderate	Low	Low	High
Collection frequency	High	High	Low	Low	Low
Noise	High	Moderate	Low	Low	Low
Employment	Moderate	Moderate	High	High	High
GHGE	Moderate	High	High	High	High
System Cost	High	High	Moderate	Low	Low
Landfilled waste	Low	High	High	Low	High
Health risk	High	High	High	High	High
Electricity	Low	Moderate high	High	High	High

Table 5

Criteria weight estimation

Linguistic Descriptor	Lower bound	Upper bound
Low	0	30
Moderate	20	60
Moderate high	40	90
High	60	100

Table 6

Performance of Alternatives obtained from LCA modelling

Criteria	**Alt1**		**Alt2**		Alt3		Alt4		Alt5	
	AVG	STD	AVG	STD	AVG	STD	AVG	STD	AVG	STD
GHGE	-0.40	0.15	0.48	0.08	0.35	0.11	0.07	0.03	-0.53	0.07
Cost	237.06	18.18	212.35	17.30	204.55	18.11	227.69	27.64	150.44	13.58
Electricity	-19.92	11.57	-21.99	3.53	-25.74	4.22	-32.26	4.81	-80.49	9.81
TCDD	-1.9E-15	5.3E-16	-6.5E-15	1.0E-15	-7.6E-15	1.2E-15	1.6E-12	2.8E-14	-2.4E-14	2.9E-15
Heavy Metals	-1.3E-08	9.8E-09	-6.8E-08	1.1E-08	-8.0E-08	1.3E-08	3.4E-06	7.1E-08	-2.5E-07	3.1E-08
Landfilled waste	39%		100%		100%		7%		27%	

Table 7

Performance of alternatives compared to BAU case

Criteria	Alternative				
	Alt1	Alt2	Alt3	Alt4	Alt5
Temp. Storage	0	1	1	1	0
Operational complexity	0	1	-1	-1	-1
Collection frequency	0	1	1	1	0
Noise	0	1	1	1	0
Employment opportunity	0	-1	-1	-1	-1
GHGE	0	-1	-1	-1	1
Cost	0	0	0	0	1
Landfilled waste	0	-1	-1	1	1
Health risk	0	1	1	-1	1
Electricity	0	1	1	1	1

Table 8

Performance of alternatives from the perspective of each agent

Criteria	Alternative				
	Alt1	Alt2	Alt3	Alt4	Alt5
Public	-1	0	-1	0	1
Local gov.	-1	1	0	-1	1
State gov.	0	0	0	0	1
Federal gov.	0	0	0	-1	1
Waste mgmt industry	0	1	0	0	1

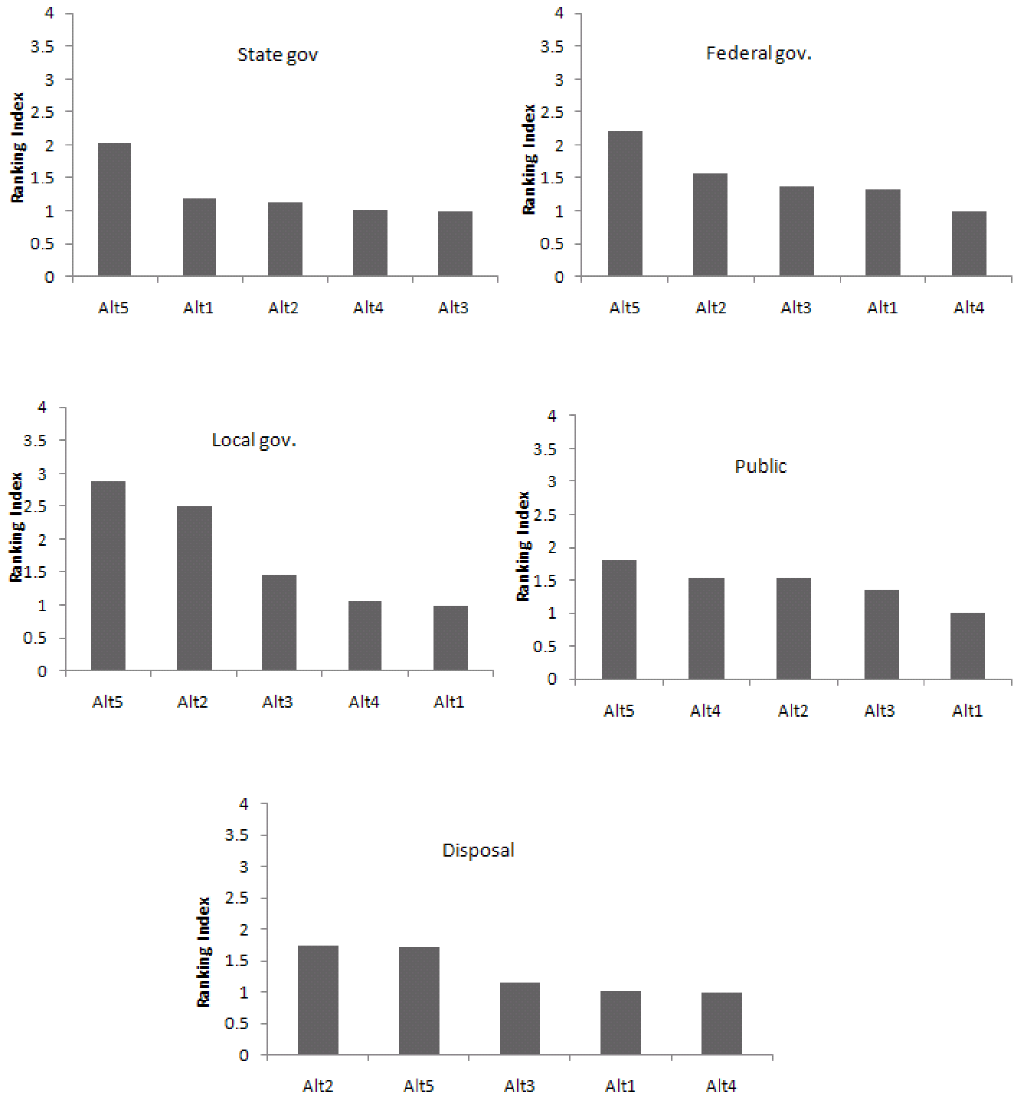

Fig. 1. Alternatives ranking from the perspective of each agent.