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TITLE:

STRATEGIES FOR THE MUNICIPAL WASTE MANAGEMENT
SYSTEM TO TAKE ADVANTAGE OF CARBON TRADING
UNDER COMPETING POLICIES: THE ROLE OF ENERGY
FROM WASTE IN SYDNEY

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Abstract

Climate change is a driving force behind some recent environmental legislation around the world. Greenhouse gas emission reduction targets have been set in many industrialised countries. A change in current practices of almost all greenhouse-emitting industrial sectors is unavoidable, if the set target is to be achieved. Although waste disposal contributes around 3% of the total greenhouse gas emissions in Australia (mainly due to fugitive methane emissions from landfills), the carbon credit and trading scheme set to start in 2010 presents significant challenges and opportunities to municipal solid-waste practitioners. Technological advances in waste management, if adopted properly, allow the municipal solid waste sector to act as carbon sink, hence earning tradable carbon credits. However, due to the complexity of the system and its inherent uncertainties, optimizing it for carbon credits may worsen its performance under other criteria. We use an integrated, stochastic multi-criteria decision-making tool that we developed earlier to analyse the carbon credit potential of Sydney municipal solid waste under eleven possible future strategies. We find that the changing legislative environment is likely to make current practices highly non-optimal and increase pressures for a change of waste management strategy.

Keywords: Climate change, municipal solid waste, environmental management, stochastic MCDA, ELECTRE-SS

1. Introduction

Sydney, with a population of 4.1 million (Australian Bureau of Statistics, 2006), is the largest city in Australia. On average, a Sydneysider produces more than 1000 kg of solid waste each year, of which 385 kg per year is classified as MSW. Solid waste presents unique and complex problems partly because it is both a source of pollution and secondary resources (Skordilis, 2004), with waste management systems aiming to achieve a balance between environmental, technical, economic and regulatory factors (Emery et al., 2007).

Climate change has been a major driving force behind many legislative policy changes in many countries (Finnveden et al., 2005). In Sydney, the waste management and energy generation are undergoing significant changes, in reaction to new climate-driven statutory regulations. The energy sector in Sydney is heavily dependent on coal-fired power stations which generate large amounts of greenhouse gas emissions (GHGE). The government of New South Wales (NSW) has introduced legislative targets to increase the amount of clean energy generated from renewable sources to 9.5% by the year 2020. Energy from waste (EfW) has been identified as one possible source of green energy.

Several researchers have discussed the merits and drawbacks of EfW (Lea, 1995; Hokkanen and Salminen, 1997; Porteous, 1998; Porteous, 2005; Finnveden et al., 2005; Consonni et al., 2005a; Consonni et al., 2005b; Giugliano et al., 2008). Earlier studies focused on recovering EfW via combustion. However, several other technologies for harvesting the energy potential of waste have since emerged. A comparison of the technical, environmental and economic aspects of four EfW

1 technologies (two combustion-based and two digestion-based methods) concluded
2 that digestion-based methods were superior to combustion methods under both
3 environmental and economic criteria. Nevertheless, all methods had a potential for
4 reducing GHGE (Murphy and McKeogh, 2004).

5 The waste sector currently accounts for around 3% of the total GHGE in
6 Australia; mainly due to fugitive methane (CH_4) emissions from landfills.
7 Although, landfills remain the dominant form of waste disposal in Sydney, a
8 legislative target to reduce the proportion of landfilled waste by 66% before 2015
9 has been set in NSW. On the other hand, government-imposed levies and stringent
10 regulations on siting new landfills are pushing landfill costs up. At the federal level,
11 a carbon trading scheme is to be introduced by the government in 2010. This may
12 present challenges, as well as financial opportunities earned through carbon credits,
13 to waste management practitioners. MSW has reasonable calorific value and
14 contains high-organic-content material such as food and garden waste (Table 1).
15 Hence, carbon dioxide (CO_2) emitted from such waste is considered biotic and not
16 counted as anthropogenic GHGE (Longden et al., 2007, Ryu et al., 2007). EfW
17 could therefore serve more than one function: energy generation and reduction of
18 CO_2 emissions. In addition, it is a way of diverting waste from landfills.

19 Choosing the correct mix of recycling, incineration and landfilling is a
20 complex planning problem, from the point of view of the waste management
21 industry, for two reasons. First, given the range of available technologies and
22 sometimes conflicting legislative requirements and commercial pressures,
23 identifying optimal policies is far from straightforward. Second, even if such an

1 optimum is identified under deterministic conditions, the high level of uncertainty
2 inherent to the decision-making framework (present and future waste generation;
3 calculation of relevant environmental, economic or social outcomes from a given
4 waste management alternative; weights accorded to decision criteria and so on) is
5 such that optima might change and the risks of adverse financial or environmental
6 impacts can be high. On the positive side, research on multi-criteria decision-
7 making over the last few years has made significant advances in incorporating
8 uncertainties in decision-making algorithms, hence allowing a better integration of
9 decision-making and risk assessment (Hyde et al., 2005, Tervonen, 2007). In this
10 paper, we apply a stochastic multi-criteria decision aid (MCDA) system we have
11 developed in previous research to the study of the questions raised above (El
12 Hanandeh and El-Zein, 2007).

13 Specifically, we investigate several energy-generating municipal waste
14 management strategies and explore their potential for taking advantage of the
15 carbon-trading scheme under competing state and federal policies, namely those
16 aiming to increase the use of renewable energy, reduce landfilled waste and reduce
17 greenhouse emissions through the creation of a carbon-trading market. For each
18 option, we perform a life-cycle analysis to estimate its Global Warming Potential
19 (GWP), and we calculate its net present value as an indicator of economic
20 performance. We compare alternatives in relation to their cost, their abilities to
21 reduce GHGE, increase green energy production, meet targets of waste diversion
22 from landfills as well as indicators of environmental and health impacts. We derive
23 conclusions about the adequacy of current policies and possible directions for the

sector.

2. Methodology

2.1. Framework Overview

We use a decision-making framework that incorporates

- a) health and environmental impacts, quantified through life cycle analysis (LCA) and represented by emissions of
 - i. volatile organic compounds (VOCs)
 - ii. dioxin
 - iii. particulate matter (PM)
 - iv. NO_x release and
 - v. SO_x release

These pollutants are used by a number of environmental agencies around the world as indicators of air pollution (e.g. European Environment Agency, US EPA and NZ Ministry of the Environment) and are listed on the national pollutant inventory of Australia (NPI) as toxins with significant health and environmental impacts. In addition, NO_x contributes to the GHGE inventory.

- b) economic indicators represented by the net present value (NPV) of each alternative.

- c) policy compliance represented by

- i. GHGE reductions,
 - ii. net energy savings and green electricity production potential and
 - iii. waste diversion from landfill quantified through LCA.

2.2. *Strategies*

Eleven combinations of technologies are formulated, with a view of addressing the policies under consideration.

S0 represents current practices and acts as a base reference. Strategy S1 is designed to introduce energy recovery while keeping changes to current practices to a minimum. S2 and S3 maximize energy recovery, GHGE reduction and waste diversion by applying anaerobic digestion to the organic fraction of waste and boosting recycling. Only waste fractions for which the above two options are technically or economically unfeasible are landfilled. S3 is used to examine the advantages of anaerobic digestion of paper waste over recycling. Strategies S4 and S5 are two different combinations of recycling and landfilling in bio-reactor landfill type. Strategies S6 and S8 are elaborate alternatives which aim to maximize energy recovery and waste-diversion through a combination of technologies that are optimal for each waste stream. S7 and S9 are incineration-based strategies designed to maximize waste diversion from landfills. S10 is a highly simplified strategy that diverts all waste to a bio-reactor landfill. Each strategy is described as a matrix of type of waste and method of disposal/treatment (Table 2). Scores reflecting the relative performances of the 11 strategies against the criteria described above were developed, as described next.

2.3. *Life Cycle Analysis*

Life-cycle analysis (LCA) is a process used to evaluate environmental

burdens resulting from a product, service or process throughout its life cycle (Emery et al., 2007). We use it here to calculate the GWP of each alternative. In addition, we estimate the capacity of each alternative to generate green energy and divert waste from landfills. For each strategy, an LCA is conducted over an expected 20 years life span of the system. We further assume 100 years surveyable time after closure for landfill to be consistent with other models such as ORWARE (Dalemo et al., 1997) and WASTED (Diaz and Warith, 2005).

2.4. Economic Performance

To measure the economic performance of each alternative, costs and revenues are estimated.

The net system cost (SysCost) of each alternative is calculated as the net present value as follows:

$$SysCost = NPV(Cost - Revenue) \quad (1)$$

where

$$Cost = f(FCC, FOC, OC, CC, PC) \quad (2)$$

$$Revenue = f(CTR, ESR, RSR) \quad (3)$$

FCC: Net present value of the facility's capital costs

FOC: Net present value of the facility's operation costs

OC: Net present value of the overheads and administration costs associated with the system

CC: Net present value of the collection cost

PC: Net present value of the processing cost

CTR: Net present value of carbon trading revenue

ESR: Net present value of the electricity sale revenue

RSR: Net present value of recyclables sale revenue

2.5. ELECTRE-SS

ELECTRE-SS is a modified stochastic ELECTRE III method which we have developed to account for uncertainties in both criteria weightings and threshold values (El Hanandeh and El-Zein, 2007). The method modifies the exploitation phase in ELECTRE III, through a new definition of the pre-order and the introduction of a ranking index (RI). ELECTRE-SS makes it easier to accommodate strategies where incomplete or uncertain preference data are present. A set of alternatives A are judged based on a set of criteria G . Each criterion g_j is assigned a criteria weight (CW) and three threshold values: indifference (q); preference (p) and an optional veto (v). CWs and threshold values are defined as stochastic variables over a restricted range hence taking into account the uncertainty in preferences and criteria values. ELECTRE-SS comprises two stages: outranking phase and exploitation phase. To construct the outranking relation a *credibility index* $\rho(a,b)$ is generated. The credibility index is defined using both a comprehensive *concordance index* $C(a,b)$ and a *discordance index* $d_j(a,b)$ for each criterion $g_j \in G$ by running a Monte-Carlo simulations. In the exploitation phase two complete pre-orders, ascending ($\bar{Z}_1$) and descending ($\bar{Z}_2$), are constructed which are then used to generate a comprehensive-order ($\bar{Z}$). $\bar{Z}$ is a multi-dimensional vector representing the number of times each alternative (a_i) has

ranked in each rank (l) in the final pre-order. An overall performance index (z_i) is calculated so as to take into account the reliability of each alternative's performance by penalizing poor performance. Finally, for easier comparison of the performance of alternatives, a ranking index is calculated (RI). Alternatives with the highest RI are the best performing options. In the current study we do not use the veto threshold so that we do not exclude any of the strategies.

2.6. Criteria weights and threshold values

Three equally important criteria groups: a) economic, b) policy and c) environmental and health are used to compare alternatives. Each set of sub-criteria of the policy group are assumed to carry equal weight while those of the environmental and health group are assigned weights proportional to their environmental and health index published in the NPI. We follow the advice of Rogers and Bruen (1998) who have suggested that indifference and preference threshold values to be set at 10% and 20% of the criteria performance values, respectively. In addition, to account for the uncertainty involved in assigning the weights and threshold values, the stability and reliability of the final ranking of alternatives is tested by allowing the CWs and threshold values to vary randomly by up to 25% and 20% of their assigned values, respectively.

2.7. Analysis Assumptions

To estimate waste quantities, waste generation rates and waste composition are taken to be constant over the next 20 years with an average population growth of

0.82% annually (Australian Bureau of Statistics, 2006). We assume 100% recovery rates for each waste stream. While this assumption is not expected to reflect actual performance, it is meant to capture the maximum potential for GHGE reduction and energy recovery of each strategy for comparison purposes.

The interest rate is taken as 6.5% per annum and electricity prices are set at the current market price of \$0.155 per kWh. CO₂ emissions are assumed to trade at \$28/Mg. Electricity prices are expected to rise in the future in response to the carbon trading scheme. CO₂ trading prices may display high volatility. In response to these factors as well as other uncertainties in the system, we allow criteria weights and threshold values to vary randomly by up to 25% and 20% respectively. Cost per Mg for each technology used in this analysis is shown in Table 3, while revenues per Mg of recycled material are listed in Table 4.

2.8. Analysis Limitations

The MCDA model is based on the ‘solution discovery paradigm’; that is the solution lies in the set of alternatives under consideration and is discovered by the MCDA algorithm. Therefore, this model cannot be used to find the optimum solution. Rather, it helps decision makers better understand the impact of their strategies.

On the other hand, a major shortcoming of the LCA is that it does not account for special factors. It estimates the total amount of pollutant that would be released throughout the life-cycle of the process without considering when and where these emissions will occur. This could be of particular concern when the

1 short-range impact of pollutants is important. Our analysis is also limited by the
2 quality of data available. Although the model accounts for uncertainty in the input
3 data, assumptions made regarding waste generation growth, greater variability in
4 CO₂ market prices, collection route distances and so on may affect the final results.

5 A VBA-MS Excel® model is developed and used in our analysis. We run
6 the model with 10,000 simulations which takes, on average, 8.5 minutes on a
7 Pentium4™ (1.7 GHz Duo-core) processor.

8 9 **3. Results and discussion**

10 *3.1. Results*

11 *3.1.1. Performance of Management Strategies*

12 The performance of each management strategy for each criterion is shown in
13 Table 4 and the overall ranking, under conditions of uncertainty, is shown in Fig. 1.
14 The results suggest that the waste management sector could indeed benefit
15 financially from carbon trading if it were to modify or change its current practices.
16 On the other hand, persisting with the current strategy may lead to an increase in the
17 cost of waste management to up to \$194 per household per year, which is more than
18 \$20 from the base cost of \$171 per household per year, as estimated by Nolan ITU,
19 2004. Modifying the current practices to include landfill gas (LFG) collection and
20 electricity generation would result in significant benefits over current practice in
21 almost all criteria except for VOCs emissions which would be expected to increase
22 as a result of the combustion of LFG. In fact, any attempt to recover energy from
23 waste results in significant benefits compared to current practices.

3.1.2. GHGE and Energy Recovery

Our results show that energy savings and GHGE are not directly related. For example, alternative S9 results in the best performance in terms of energy recovery but alternative S2 delivers best results under GHGE criteria. This is due to the increased non-biogenic CO₂ releases from the incineration of plastics and inorganic waste as well as the increased NO_x emissions. Therefore, recycling of plastics where possible would result in greater benefits than recovering its heat potential. Similarly, comparing the results of S6 and S8 shows that excluding glass from the recycling stream would result in a negligible gain in energy savings. However, including it in the recycling stream would lead to greater environmental and economic benefits and would contribute positively towards the diversion-from-landfill target. Similar conclusions can be made regarding paper stream, considering the total energy saving and GHGE reduction. Therefore, the results highlight the benefits of waste recycling as an efficient and effective means of reducing GHGE and increasing energy recovery.

Strategy S3 is ranked highest. This strategy contributes positively in all criteria under consideration except for the VOC sub-criteria. It has the potential to produce up to 3% (assuming 85% recovery rate of waste streams) of the household electricity need in the city of Sydney. In addition, it is the least expensive alternative. Nevertheless, it does not achieve the 66% diversion-from-landfill target. Alternative S6, on the other hand, has the potential to achieve the diversion-from-landfill target as well as providing up to 5% (based on 85% recovery rate) of the

1 Sydney household electricity needs at a comparable cost as S3. However, it ranks
2 seconds because of the increased release of dioxins and particulate matter it would
3 yield.

4 S2 is a variation of S3. Comparing results for these two alternatives reveals
5 that despite the gain in electricity generation which results from the anaerobic
6 digestion of paper, recycling of paper leads to greater total energy savings and better
7 GHGE performance. Therefore, if the policy of green electricity is designed with a
8 view of reducing GHGE, total energy savings should be considered rather than
9 green energy output. However, this can become problematic when materials are
10 imported because cross-border energy savings must then be accounted for.

11 Strategies based on bio-reactor landfill (S4, S5 and S10) are rated low because they
12 would result in an increased waste-to-landfill quantities, poor electricity generation
13 potential and poor performance under the GHGE criterion compared to other strategies.

14 Incineration-based strategies (S8 and S9) rank lowest despite their good performance
15 under the green electricity production and waste-from-landfill diversion criteria.

16 Current practice S0 is ranked lowest because it has performed poorly under almost all
17 criteria.

18

19 *3.2. Discussion*

20 The waste hierarchy suggests that incineration is a better choice of waste
21 treatment than landfilling. This is supported by the findings of several researchers (eg.
22 Arena et al., 2003; Dahlbo et al., 2005; Giugliano et al., 2008). However, we have shown
23 that this notion may not hold true when considering more than a limited set of criteria.

1 For example, Fig. 1 show that strategy S10 (based on bio-reactor landfilling) is ranked
2 higher than S7 and S9 (based on incineration). In fact even S1 (traditional landfill based
3 strategy with electricity recovery) out-performs incineration strategy S9. Hence, the
4 rationale for incineration preference weakens when economic criteria are considered
5 alongside energy generation and environmental criteria. This is in agreement with the
6 findings of other researchers such as Dijkgraaf and Vollebergh (2004), Emery (2007) and
7 Rabl et al. (2008).

8 Incineration of paper material may be successful in reducing GHGE if waste is
9 replacing fossil fuel (Finnveden et al., 2005). Although, our results agree with this
10 proposition, they show that anaerobic digestion of paper may provide a better alternative,
11 environmentally and economically, albeit at the cost of lower levels of electricity
12 production. Lea (1995) suggests that maximum energy recovery can only be achieved
13 through combustion of plastic waste. However, our results raise the possibility that
14 recycling of plastics may achieve better overall performance. For example, recycling
15 lead to greater overall energy saving and GHGE reduction. This is particularly evident
16 considering the grid mix in Sydney which derives more than 90% of its electricity from
17 coal-fired power stations. Therefore, recycling, especially when it replaces virgin
18 material, is likely to outperform energy recovery strategies.

19 Finally, in order to assess the effect of uncertainty and multi-criteria framework
20 on the final ranking of alternatives, Fig. 2 shows results based on environmental
21 criteria only, while Fig. 3 reflects rankings with no uncertainty considered. Both
22 uncertainty and multiple criteria have a strong impact on rankings. For example, S3
23 which ranks first in a multi-criteria framework, slides to third place when considering

1 only environmental criteria (Fig. 2) and shares its ranking with alternatives 4, 5 and 10
2 when no uncertainty is considered (Fig. 3). Similar observations can be made
3 regarding alternatives 8 and 7. This is consistent with findings by Hokkanen and
4 Salminen (1997) who used an ELECTRE III method to help choose an appropriate
5 MSW management system in a real case study. They found their results to be sensitive
6 to the values of the thresholds and weights assigned to each criterion.

7

8 **4. Conclusions**

9 Eleven waste management strategies were assessed under three sets of criteria,
10 namely health and environmental, policy, and economic criteria. Our analyses show
11 that the waste management sector can benefit financially from the carbon trading
12 scheme while contributing positively to environmental protection and complying with
13 other competing policies. A combination of landfilling, recycling and anaerobic
14 digestion of organic waste would deliver what appears to be the most favourable
15 management practice. The analyses highlight the benefits of recycling as an effective
16 and efficient means of GHGE reduction and energy recovery. They show that
17 anaerobic digestion of organic waste is a more effective method of waste diversion,
18 GHGE reduction and energy recovery than incineration. More fundamentally, our
19 study has shown that competing policies and uncertainties can significantly alter the
20 rankings of waste management strategies and that compliance with environmental
21 legislation does not necessarily incur additional costs. Although this study
22 demonstrated the usefulness of integrating LCA methodology to a multi-criteria
23 framework, more research is needed. For example, it would be desirable to extend the

1 study to investigate the impact of short-range pollution and cross-border trade on the
2 performance of various waste management strategies.

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6

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1	TABLES
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1

2 **Table 1**

3 Municipal solid waste composition of Sydney adapted from Nolan ITU (2004) and National Waste

4 Inventory (<http://awd.csiro.au> accessed on 30/01/2008)

Component	Percentage (%wt)
Green waste	18
Food waste	21
Paper	26
Textiles	4
Plastic	7.1
Glass	11
Ferrous metal	2.5
Nappies	3
Inert	3
Other	6.1
Hazardous waste	0.1
Wood	1
Aluminum	0.2
Total	100

5

6

1 **Table 2**

2 Waste management strategies

	S0	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Food waste	LDF	LDF/E	AD	AD	LDF/BE	LDF/BE	AD	IN	AD	IN	LDF/BE
Garden waste	COMP	COMP	AD	AD	LDF/BE	LDF/BE	AD	IN	AD	IN	LDF/BE
Paper	RE	RE	RE	AD	RE	LDF/BE	IN	IN	IN	IN	LDF/BE
Contaminated Paper	LDF	LDF/E	AD	AD	LDF/BE	LDF/BE	IN	IN	IN	IN	LDF/BE
Selected Plastics(PE & PET)	RE	RE	RE	RE	RE	RE	IN	IN	IN	IN	LDF/BE
Other Plastics	LDF	LDF/E	LDF	LDF	LDF/BE	LDF/BE	IN	IN	IN	IN	LDF/BE
Glass	RE	RE	RE	RE	RE	RE	RE	RE	LDF	IN	LDF/BE
Metals (Fe & Al)	RE	RE	RE	RE	RE	RE	RE	RE	RE	IN	LDF/BE
Nappies	LDF	LDF/E	LDF	LDF	LDF/BE	LDF/BE	IN	IN	IN	IN	LDF/BE
Wood	LDF	LDF/E		LDF	LDF/BE	LDF/BE	IN	IN	IN	IN	LDF/BE
Inert waste	LDF	LDF/E	LDF	LDF	LDF/BE	LDF/BE	LDF	IN	LDF	IN	LDF/BE
Others	LDF	LDF/E	LDF	LDF	LDF/BE	LDF/BE	LDF	IN	LDF	IN	LDF/BE

3 LDF: traditional landfill without energy Recovery. LDF/E: traditional landfill with electricity generation.

4 LDF/BE: bio-reactor landfill. COMP: aerobic composting. AD: anaerobic digestion. RE: Recycling. IN:

5 Incineration. Fe: ferrous metals. Al: Aluminum.

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1 **Table 3**
2 Cost per Mg of MSW for various technologies adapted from ITU Nolan (2004)

Technology	\$/Mg
Recycle Collection, Operation and administration	130
Composting	75
Traditional Landfill	110
Bio-reactor Landfill	128
Incineration	230
Anaerobic Digestion	109
MRF	75

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1 **Table 4**
2 Sale price per Mg of recycled material adapted from West (2008)

Material	\$/Mg
Aluminum	2200
Plastic	350
Ferrous	500
Glass	60
Paper	150
Compost	45

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1 **Table 5**

2 Performance values of each alternative for each criteria

Criteria	S0	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Electricity (kWh)	0.00E+00	-3.63E+09	-6.64E+09	-1.02E+10	-7.40E+09	-1.16E+10	-1.97E+10	-1.93E+10	-1.97E+10	-2.11E+10	-1.03E+10
Energy (GJ)	7.77E+06	-2.64E+06	-2.86E+07	-2.65E+07	-1.80E+07	-2.45E+07	-7.10E+07	-6.94E+07	-7.19E+07	-7.58E+07	-3.69E+07
GHGE (CO ₂ eq Mgs)	2.11E+07	-6.69E+06	-2.97E+07	-1.18E+07	-1.18E+07	1.29E+07	-1.66E+07	-2.98E+06	-1.52E+07	-2.33E+04	1.55E+07
VOCs (Mg)	2.10E+04	4.30E+04	-4.32E+04	3.20E+04	3.20E+04	1.46E+04	-1.25E+03	-2.70E+02	-1.03E+03	1.13E+04	1.51E+04
PM (Mg)	3.70E+02	-5.45E+03	-7.04E+03	-6.39E+03	-6.39E+03	-3.72E+01	3.48E+03	1.09E+04	4.14E+03	3.95E+03	-2.42E+03
NOx (Mg)	-1.87E+04	-2.90E+04	-4.32E+04	-2.69E+04	-3.75E+04	-1.88E+04	-1.32E+04	2.83E+04	-1.21E+04	3.46E+04	-1.97E+04
SOx (Mg)	-2.58E+04	-4.11E+04	-7.22E+04	-7.93E+04	-5.92E+04	-6.08E+04	-1.03E+05	-9.84E+04	-1.01E+05	-9.16E+04	-5.56E+04
Pb (Mg)	9.93E+01	-3.14E+01	-1.54E+02	-2.54E+02	-1.02E+02	-1.81E+02	-3.58E+02	-3.49E+02	-3.59E+02	-3.77E+02	-2.25E+02
Dioxins (kg)	7.39E-09	-1.57E-07	-4.68E-07	-3.37E-07	-3.37E-07	-5.40E-07	2.93E-05	7.23E-05	2.93E-05	3.17E-05	-5.74E-07
Waste diversion rate (%)	27%	27%	43%	50%	-22%	-38%	67%	26%	51%	83%	-43%
Cost (\$ per hhld per year)	\$194.62	\$125.83	\$114.76	\$104.74	\$134.75	\$130.32	\$104.99	\$151.33	\$113.77	\$166.80	\$128.10

1 **Figures**

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4 Fig. 1. Ranking of alternatives under 20% uncertainty in threshold values and 25%
5 uncertainty in CWs.

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2 Fig. 2. Ranking of alternative considering the environmental criteria alone with 25%
3 uncertainty in CWs and 20% in threshold values.

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2 Fig. 3. Ranking of alternatives considering the environmental criteria alone and no
 3 uncertainty.