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

The waste sector currently accounts for around 3% of the total GHGE in Australia; mainly due to fugitive methane (CH$_4$) emissions from landfills. Although, landfills remain the dominant form of waste disposal in Sydney, a legislative target to reduce the proportion of landfilled waste by 66% before 2015 has been set in NSW. On the other hand, government-imposed levies and stringent regulations on siting new landfills are pushing landfill costs up. At the federal level, a carbon trading scheme is to be introduced by the government in 2010. This may present challenges, as well as financial opportunities earned through carbon credits, to waste management practitioners. MSW has reasonable calorific value and contains high-organic-content material such as food and garden waste (Table 1). Hence, carbon dioxide (CO$_2$) emitted from such waste is considered biotic and not counted as anthropogenic GHGE (Longden et al., 2007, Ryu et al., 2007). EfW could therefore serve more than one function: energy generation and reduction of CO$_2$ emissions. In addition, it is a way of diverting waste from landfills.

Choosing the correct mix of recycling, incineration and landfilling is a complex planning problem, from the point of view of the waste management industry, for two reasons. First, given the range of available technologies and sometimes conflicting legislative requirements and commercial pressures, identifying optimal policies is far from straightforward. Second, even if such an
optimum is identified under deterministic conditions, the high level of uncertainty
inherent to the decision-making framework (present and future waste generation;
calculation of relevant environmental, economic or social outcomes from a given
waste management alternative; weights accorded to decision criteria and so on) is
such that optima might change and the risks of adverse financial or environmental
impacts can be high. On the positive side, research on multi-criteria decision-
making over the last few years has made significant advances in incorporating
uncertainties in decision-making algorithms, hence allowing a better integration of
decision-making and risk assessment (Hyde et al., 2005, Tervonen, 2007). In this
paper, we apply a stochastic multi-criteria decision aid (MCDA) system we have
developed in previous research to the study of the questions raised above (El
Hanandeh and El-Zein, 2007).

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

v. SO\textsubscript{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\textsubscript{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:

\[
SysCost = NPV(Cost - Revenue) \tag{1}
\]

where

\[
Cost = f(FCC, FOC, OC, CC, PC) \tag{2}
\]

\[
Revenue = f(CTR, ESR, RSR) \tag{3}
\]

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 ($Z_1$) and descending ($Z_2$), are constructed which are then used to generate a comprehensive-order ($Z$). $Z$ 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 $0.155 per kWh. CO$_2$ emissions are assumed to trade at $28/Mg. Electricity prices are expected to rise in the future in response to the carbon trading scheme. CO$_2$ 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
short-range impact of pollutants is important. Our analysis is also limited by the
quality of data available. Although the model accounts for uncertainty in the input
data, assumptions made regarding waste generation growth, greater variability in
CO₂ market prices, collection route distances and so on may affect the final results.
A VBA-MS Excel® model is developed and used in our analysis. We run
the model with 10,000 simulations which takes, on average, 8.5 minutes on a
Pentium4™ (1.7 GHz Duo-core) processor.

3. Results and discussion

3.1. Results

3.1.1. Performance of Management Strategies

The performance of each management strategy for each criterion is shown in
Table 4 and the overall ranking, under conditions of uncertainty, is shown in Fig. 1.
The results suggest that the waste management sector could indeed benefit
financially from carbon trading if it were to modify or change its current practices.
On the other hand, persisting with the current strategy may lead to an increase in the
cost of waste management to up to $194 per household per year, which is more than
$20 from the base cost of $171 per household per year, as estimated by Nolan ITU,
2004. Modifying the current practices to include landfill gas (LFG) collection and
electricity generation would result in significant benefits over current practice in
almost all criteria except for VOCs emissions which would be expected to increase
as a result of the combustion of LFG. In fact, any attempt to recover energy from
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 CO$_2$ 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
Sydney household electricity needs at a comparable cost as S3. However, it ranks seconds because of the increased release of dioxins and particulate matter it would yield.

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

Strategies based on bio-reactor landfill (S4, S5 and S10) are rated low because they would result in an increased waste-to-landfill quantities, poor electricity generation potential and poor performance under the GHGE criterion compared to other strategies. Incineration-based strategies (S8 and S9) rank lowest despite their good performance under the green electricity production and waste-from-landfill diversion criteria.

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

3.2. Discussion

The waste hierarchy suggests that incineration is a better choice of waste treatment than landfilling. This is supported by the findings of several researchers (eg. Arena et al., 2003; Dahlbo et al., 2005; Giugliano et al., 2008). However, we have shown that this notion may not hold true when considering more than a limited set of criteria.
For example, Fig. 1 show that strategy S10 (based on bio-reactor landfilling) is ranked higher than S7 and S9 (based on incineration). In fact even S1 (traditional landfill based strategy with electricity recovery) out-performs incineration strategy S9. Hence, the rationale for incineration preference weakens when economic criteria are considered alongside energy generation and environmental criteria. This is in agreement with the findings of other researchers such as Dijkgraaf and Vollebergh (2004), Emery (2007) and Rabl et al. (2008).

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

Finally, in order to assess the effect of uncertainty and multi-criteria framework on the final ranking of alternatives, Fig. 2 shows results based on environmental criteria only, while Fig. 3 reflects rankings with no uncertainty considered. Both uncertainty and multiple criteria have a strong impact on rankings. For example, S3 which ranks first in a multi-criteria framework, slides to third place when considering
only environmental criteria (Fig. 2) and shares its ranking with alternatives 4, 5 and 10 when no uncertainty is considered (Fig. 3). Similar observations can be made regarding alternatives 8 and 7. This is consistent with findings by Hokkanen and Salminen (1997) who used an ELECTRE III method to help choose an appropriate MSW management system in a real case study. They found their results to be sensitive to the values of the thresholds and weights assigned to each criterion.

4. Conclusions

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

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References


Dalemo, M., Sonesson, U., Bjorklund, A., Mingarini, K., Frostell, B., Jonsson


1 TABLES

2
Table 1
Municipal solid waste composition of Sydney adapted from Nolan ITU (2004) and National Waste Inventory (http://awd.csiro.au accessed on 30/01/2008)

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**Table 2**  
Waste management strategies

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<td>AD</td>
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<td>AD</td>
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Table 4
Sale price per Mg of recycled material adapted from West (2008)
Table 5
Performance values of each alternative for each criteria

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<th>Criteria</th>
<th>S0</th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
<th>S4</th>
<th>S5</th>
<th>S6</th>
<th>S7</th>
<th>S8</th>
<th>S9</th>
<th>S10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity (kWh)</td>
<td>0.00E+00</td>
<td>-3.63E+09</td>
<td>-6.64E+09</td>
<td>-1.02E+10</td>
<td>-7.40E+09</td>
<td>-1.16E+10</td>
<td>-1.97E+10</td>
<td>-1.93E+10</td>
<td>-1.97E+10</td>
<td>-2.11E+10</td>
<td>-1.03E+10</td>
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<tr>
<td>Energy (GJ)</td>
<td>7.77E+06</td>
<td>-2.64E+06</td>
<td>-2.86E+07</td>
<td>-2.65E+07</td>
<td>-1.80E+07</td>
<td>-2.45E+07</td>
<td>-7.10E+07</td>
<td>-6.94E+07</td>
<td>-7.19E+07</td>
<td>-7.58E+07</td>
<td>-3.69E+07</td>
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<tr>
<td>GHGE (CO$_2$eq Mgs)</td>
<td>2.11E+07</td>
<td>-6.69E+06</td>
<td>-2.97E+07</td>
<td>-1.18E+07</td>
<td>-1.18E+07</td>
<td>1.29E+07</td>
<td>-1.66E+07</td>
<td>-2.98E+06</td>
<td>-1.52E+07</td>
<td>-2.33E+04</td>
<td>1.55E+07</td>
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<tr>
<td>VOCs (Mg)</td>
<td>2.10E+04</td>
<td>4.30E+04</td>
<td>-4.32E+04</td>
<td>3.20E+04</td>
<td>3.20E+04</td>
<td>1.46E+04</td>
<td>-1.25E+03</td>
<td>-2.70E+02</td>
<td>-1.03E+03</td>
<td>1.13E+04</td>
<td>1.51E+04</td>
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<tr>
<td>PM (Mg)</td>
<td>3.70E+02</td>
<td>-5.45E+03</td>
<td>-7.04E+03</td>
<td>-6.39E+03</td>
<td>-6.39E+03</td>
<td>-3.72E+01</td>
<td>3.48E+03</td>
<td>1.09E+04</td>
<td>4.14E+03</td>
<td>3.95E+03</td>
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<tr>
<td>NOx (Mg)</td>
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<td>-2.90E+04</td>
<td>-4.32E+04</td>
<td>-2.69E+04</td>
<td>-3.75E+04</td>
<td>-1.88E+04</td>
<td>-1.32E+04</td>
<td>2.83E+04</td>
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<td>3.46E+04</td>
<td>-1.97E+04</td>
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<td>SOx (Mg)</td>
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<td>-4.11E+04</td>
<td>-7.22E+04</td>
<td>-7.93E+04</td>
<td>-5.92E+04</td>
<td>-6.08E+04</td>
<td>-1.03E+05</td>
<td>-9.84E+04</td>
<td>-1.01E+05</td>
<td>-9.16E+04</td>
<td>-5.56E+04</td>
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<tr>
<td>Pb (Mg)</td>
<td>9.93E+01</td>
<td>-3.14E+01</td>
<td>-1.54E+02</td>
<td>-2.54E+02</td>
<td>-1.02E+02</td>
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<td>-3.49E+02</td>
<td>-3.59E+02</td>
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<td>-2.25E+02</td>
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<tr>
<td>Waste diversion rate (%)</td>
<td>27%</td>
<td>27%</td>
<td>43%</td>
<td>50%</td>
<td>-22%</td>
<td>-38%</td>
<td>67%</td>
<td>26%</td>
<td>51%</td>
<td>83%</td>
<td>-43%</td>
</tr>
<tr>
<td>Cost ($ per hhld per year)</td>
<td>$194.62</td>
<td>$125.83</td>
<td>$114.76</td>
<td>$104.74</td>
<td>$134.75</td>
<td>$130.32</td>
<td>$104.99</td>
<td>$151.33</td>
<td>$113.77</td>
<td>$166.80</td>
<td>$128.10</td>
</tr>
</tbody>
</table>
Fig. 1. Ranking of alternatives under 20% uncertainty in threshold values and 25% uncertainty in CWs.
Fig. 2. Ranking of alternative considering the environmental criteria alone with 25% uncertainty in CWs and 20% in threshold values.
Fig. 3. Ranking of alternatives considering the environmental criteria alone and no uncertainty.