The analytical hierarchy process (AHP) in the analysis of the sustainability of Municipal Solid Waste (MSW) management in Northwest Spain

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Abstract

The generation of Municipal Solid Waste (MSW) continues to be responsible for several environmental and human health problems, so that the development of suitable management technologies has become an issue of critical importance. However, according to literature, the selection of the most efficient scenario among different waste management alternatives is a complex task that depends on various criteria. Therefore, the combination of both Analytic Hierarchy Process (AHP) and Life Cycle Assessment (LCA) has emerged as an important support decision tool within the waste management sector.

In this context, this study primarily concentrates on implementing AHP coupled to LCA as a decision support tool to compare the sustainability of several configurations for MSW management in Galicia (Northwest Spain): landfilling, incineration and composting. The environmental profile of each alternative together with both economic and social indicators were taken into account. On the basis of overall sustainability results, composting scheme shows the most sustainable performance when a balanced weight distribution of criteria is assumed, mainly due to its favourable environmental component compared to the other alternatives. However, either incineration or landfilling depict better profiles if social and economic dimensions are considered, respectively. Therefore, the priority ranking of waste management alternatives can be strongly dependent on variation in the criteria scores.

Keywords: sustainability; waste management; multi-criteria decision analysis (MCDA); Life Cycle Assessment (LCA); Galicia.

1. Introduction

In recent times, the production of Municipal Solid Waste (MSW) has grown around 2% in the European Union, being responsible for several environmental and human health problems [1]. Meanwhile, conventional management alternatives have been improved and new technologies have also been developed [2, 3]. However, there is no single solution to MSW management problems since each scenario have specific challenges to be addressed [2-5]; accordingly, the selection of an appropriate treatment process is an important issue before designing and implementing any waste management facility [2, 4, 6-7].

In this context, the multi-criteria decision analysis (MCDA) have arisen as interesting support decision tools in the waste management sector [2]. MCDA techniques allow the comparison and evaluation of different alternatives taking into account both quantitative and qualitative parameters, as well as experts' subjective decisions [2, 4, 8-9]. Among the different MCDA methods, the Analytic Hierarchy Process (AHP) has been mostly preferred when the optimal alternative of waste management schemes has to be identified [2, 9]. Indeed, many research works on waste management deal with the AHP linked to environmental analysis through the Life Cycle Assessment (LCA) methodology [3-4, 10]. However, although some studies focused on the eco-efficiency assessment of waste treatment in different Spanish regions (Cantabria, Valencia, Madrid…) have been already published, Galicia region (NW Spain) has not been yet evaluated in the literature [5-6]. This study applies the AHP method coupled to LCA approach to evaluate and compare the sustainability of Galician alternatives for MSW management on the basis of environmental, economic and social indicators. Not only the optimal treatment option can be identified but also the most favourable alternative for each of the three pillars of sustainability. Present results could make a useful contribution to the proposal of potential improvements actions for helping to address the drawbacks associated with MSW concerns.

2. Materials and methods

2.1. Waste management alternatives

Three waste management systems were considered in the present study according to the models available to date within Galician framework: (i) landfilling with biogas valorisation (ii) incineration with energy recovery and (ii) aerobic biological treatment to produce compost (composting). The main stages considered for each alternative are displayed in **Fig. 1 – 3**. A cradle-to-gate approach was considered, taking into account all processes from the MSW collection (including transportation) to the final management of the different fractions. Several recovered products can be obtained from the different systems evaluated: energy, recycled materials and compost. However, to avoid allocation issues, the system expansion approach was selected. Thus, not only the benefits derived from the production of renewable energy (instead of electricity from the grid) and the reuse of recovered materials (such as plastic, paper and metals) were taken into consideration, but also the advantages associated with the production and later application of compost to agricultural soils. For comparison purposes, a functional unit (FU) of 1 ton of treated MSW was selected as a common basis for calculations.

2.2. Analytical Hierarchy Process

The AHP method was developed by Saaty [11] and it is based on three main principles: (i) structuring of the problem into different hierarchical levels, (ii) pairwise comparison of alternatives, criteria and sub-criteria and calculation of eigenvectors and (iii) priority ranking of alternatives according to sustainability results. The first step of the AHP analysis consists in breaking down the decision-making problem into a hierarchical structure, where the goal occupies the top level, the criteria and sub-criteria hold the second and alternatives are on the third level. Once the hierarchical scheme is defined, comparative matrixes are constructed according to the *Saaty's Fundamental Scale* (**Table 1**). Thus, all alternatives are compared pairwise regarding the different sub-criteria; similarly, the same happens with criteria and sub-criteria each other. Relative weights of the different elements (alternatives and criteria) are ultimately bound together in the eigenvectors. It should be noted that the eigenvector method yields a natural consistency to ensure the reliability of the comparisons considered. Finally, composite weights for the different alternatives result from aggregating the weights of each alternative throughout the hierarchical structure. The alternative with the highest ratio will be appointed as the best treatment option.

2.3. Criteria selection

2.3.1. Environmental criteria

Primary data required for environmental assessment was mainly used and compiled from personal interviewers with staff from the management companies. However, relevant literature was also used in the absence of available primary information. Thus, mass and energy balances were completed according to the information included in the PXRUG [12-13], while diffuse greenhouse gas (GHG) emissions from composting process and further compost application into soils were calculated according to Boldrin et al. [14] and Bovea et al. [15]. Finally, secondary data was also taken from ecoinvent® database to complete the background inventory regarding electricity generation, chemicals manufacture and diesel consumption in transportation activities [16-18].

LCA guidelines were followed [19] and the characterisation factors provided by the ReCiPe Midpoint (H) method were considered to estimate the potential environmental impacts from the different alternatives [20]. The following indicators were selected: climate change (CC), terrestrial acidification (TA), freshwater eutrophication (FE) and fossil depletion (FD).

2.3.2. Economic criteria

The economic performance of the different alternatives was evaluated based on three main criteria: capital costs, operational and maintenance (O&M) costs and revenues. The capital cost is related to the construction of the waste management facilities (including the expenses of the land and transport fleet), while O&M costs are mainly considered in the operation of the waste management plant [4, 21-22]. Both capital and O&M costs were estimated by applying the equations collected from literature [4, 21-22] and mean values were considered for assessment. A summary of equations used is reported in **Table 2**. Note that costs were updated to 2013 values by assuming an annual interest rate of 6%; similarly, the amortised annual capital costs were also estimated taking into account an interest rate of 6% and a lifespan of the facilities of 20 years, in agreement with related studies in the literature [4, 22]. Finally, revenues are generated from the outputs selling, including energy and recovered materials; they can be estimated taking into account the energy generation and recovered rates together with the price of each product. Market prices considered for assessment are summarised in **Table 3** [23-28].

2.3.3. Social criteria

Three criteria were also selected to evaluate the social dimension of the alternatives – employment, social perception and public health and safety (public H&S) – as the most common social indicator used in similar studies in literature. The employment refers to the number of employees dealing with each waste management scheme, so that a great number of employees is preferable. Social perception was evaluated taking into account not only the level of satisfaction of population but also their participation in waste management tasks; qualitative ratios were defined for this indicator. Finally, public health and safety were addressed based on both waste valorisation and waste sent to landfill, in percentage terms. Social results were estimated in agreement with public surveys as well as through personal communications.

3. Results and discussion

3.1. Criteria assessment

Environmental, economic and social results for the different sub-criteria and management alternatives are compiled in **Table 4** assuming equal weight (33.3%) for all criteria. Values are reported per ton of treated MSW (FU). Minimum scores are preferable for both environmental and economic indicators, except for revenues, whose value should be the highest possible; conversely, maximum ratios are desirable in the case of social indicators, although waste fraction to landfill should be diminished. Accordingly, the alternative focused on the disposal of MSW to landfill would be the worst option from both environmental and social perspectives, except for climate change mitigation, due to the environmental credits derived from the valorisation of biogas as a renewable energy source. Only the economic component can partially offset the disadvantageous results of landfilling, with much lower costs than incineration and composting.

3.2. AHP results

Overall AHP results (**Fig. 4**) demonstrate that the management system based on the composting of MSW holds the first place in the priority ranking, closely followed by incineration and, finally, landfilling alternative. The environmental-friendly results associated with this management alternative would be responsible for its highest sustainable profile, except for climate change, where diffuse emissions from composting stage (and further compost application) exert an unfavourable influence. However, these impacts from composting practices are partially offset by the environmental credits derived from the net energy balance (surplus energy generation), which positively affects to the other impact categories, especially in terms of fossil depletion.

However, different conclusions can be obtained when each criterion is analysed separately. Thus, while incineration would be the best option focussing only in the social dimension, landfilling would lead to the best economic profile. The rationale behind these results lies mainly in the high social acceptation by the population of incineration as a suitable option to manage MSW as well as the lowest capital and operational costs related to landfilling facilities, respectively. This reveals how variations on the relative relevance of the different criteria can lead to entirely different outcomes.

4. Conclusions

The MCDA techniques have been demonstrated to be useful tools for the decision-making in the case of waste management systems in which several criteria have to be evaluated together. Among them, the AHP method has been widely applied to analyse the sustainability of different MSW management schemes. Similarly, the LCA methodology has also been followed in literature in related studies to conduct the environmental assessment of selected waste treatment configurations.

Both methodologies (AHP linked to LCA) have been applied in this study to evaluate the sustainability of three alternatives for the management of MSW in Galicia. According to the results, composting would be the best option when the three pillars of sustainability are similarly weighted, followed by incineration and landfilling. However, the priority ranking can be substantially modified when each criterion is analysed individually. Thus, incineration would be the preferable option on the basis of popular opinion; in this sense, greater awarenessraising actions should be undertaken to lead the popular preferences towards more sustainable alternatives in agreement with European guidelines concerning sustainable waste management strategies. In any case, comparative results demonstrate as the main outcomes can be highly dependent on the dimension – environmental, economic, social – that is given priority against the others. This also shows the usefulness of performing a sensitivity analysis to determine to what extent these variations on criteria weight can affect the comparative results as well as to support the robustness of main outcomes.

Table 1. Saaty's Fundamental Scale for AHP preference [11].

Preference number	Explanation
1	Equally important
3	Weak importance
5	Strong importance
7	Very strong importance
9	Absolute importance
2,4,6,8	Intermediate values

Table 2. Equations applied to estimate both capital and operational costs for the different management alternatives.

Management alternative	Capital costs	O&M costs
Landfilling	$0.0057x^{0.61}$	$103.86x^{-0.30}$
Incineration	$0.0049x^{0.80}$	$726.37x^{-0.29}$
Composting	$0.0021x^{0.76}$	$1624x^{-0.48}$

x: plant capacity

Table 3. Market prices considered for recovered materials and surplus energy.

Output (material/energy)	Market price (€/t)
Energy	0.105 *(€/kWh)*
Compost	27.92
Paper/Cardboard	83.00
PEAD/PEBD	895.0
PET	720.0
Steel	302.8
Aluminium	1785

Table 4. Environmental, economic and social results for the different management alternatives.

Criteria	Sub-criteria	Landfilling	Incineration	Composting
Environmental	Climate Change (kg CO_2 eq)	-8.96	-79.57	379.5
	Terrestrial Acidification (kg SO_2 eq)	$-7.70\cdot10^{-2}$	-0.94	-1.24
	Freshwater Eutrophication (kg P eq)	$-3.00\cdot10^{-3}$	-0.05	-0.10
	Fossil Depletion (kg oil eq)	-1.59	-20.40	-129.8
Economic	Capital Costs (€)	46.41	441.4	402.8
	O&M Costs (€)	3.15	23.30	25.29
	Revenues (€)	4.97	144.2	45.97
Social	Employment (number employees)	$1.99\cdot10^{-4}$	$4.40\cdot10^{-4}$	$5.29\cdot10^{-3}$
	Social perception	Low	High	Medium-Low
	Public H&S (% landfill)	100	51.3	59.1

Figure captions

Fig. 1 System boundaries description of landfilling

Fig. 2 System boundaries description of incineration

Fig. 3 System boundaries description of composting

Fig. 4 AHP results when equal weight criteria are assigned to the three MSW management alternatives evaluated. Right axis makes reference to the score of the different scenarios (landfilling, incineration and composting) while left axis represents the weight of the different criteria (economic, social and environmental)

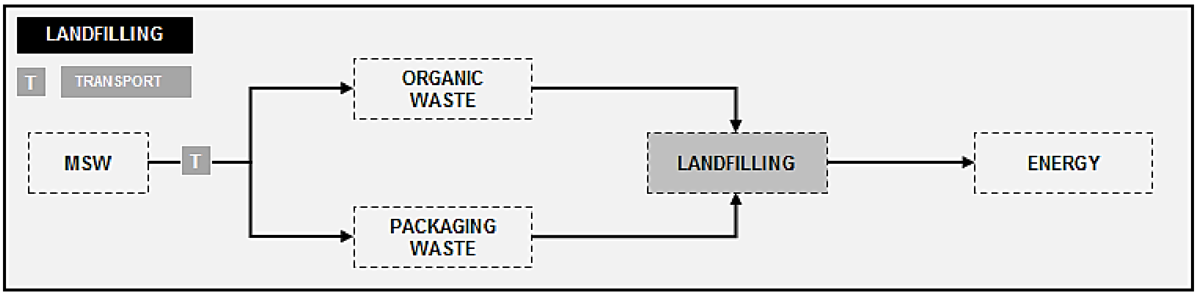


Fig. 1

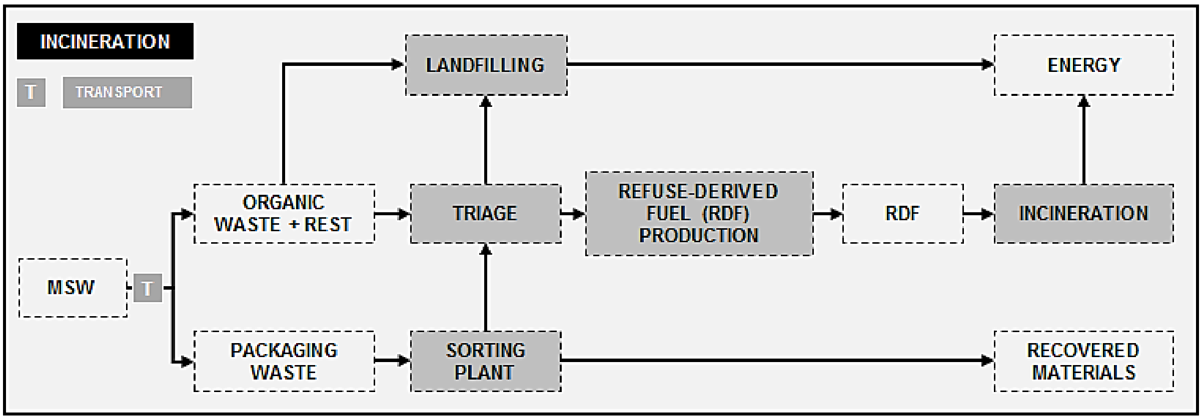


Fig. 2

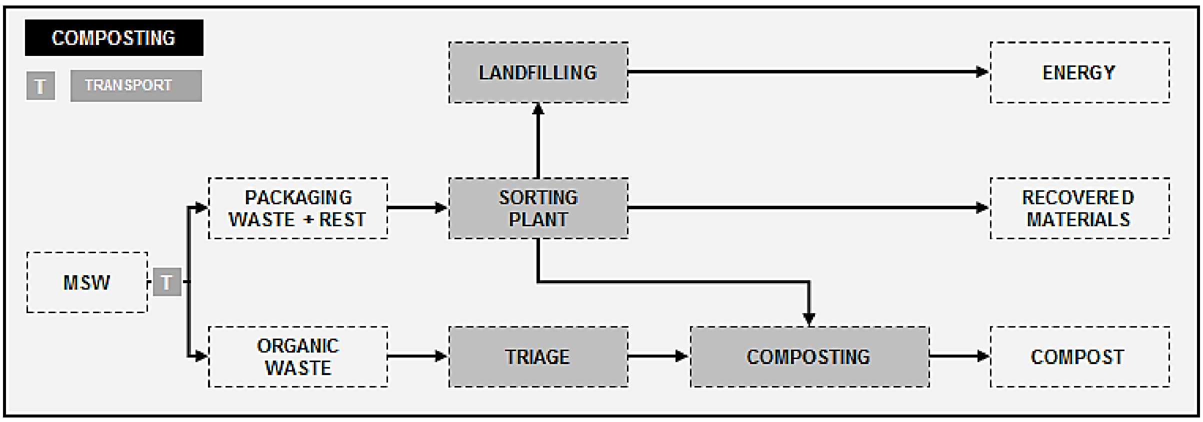
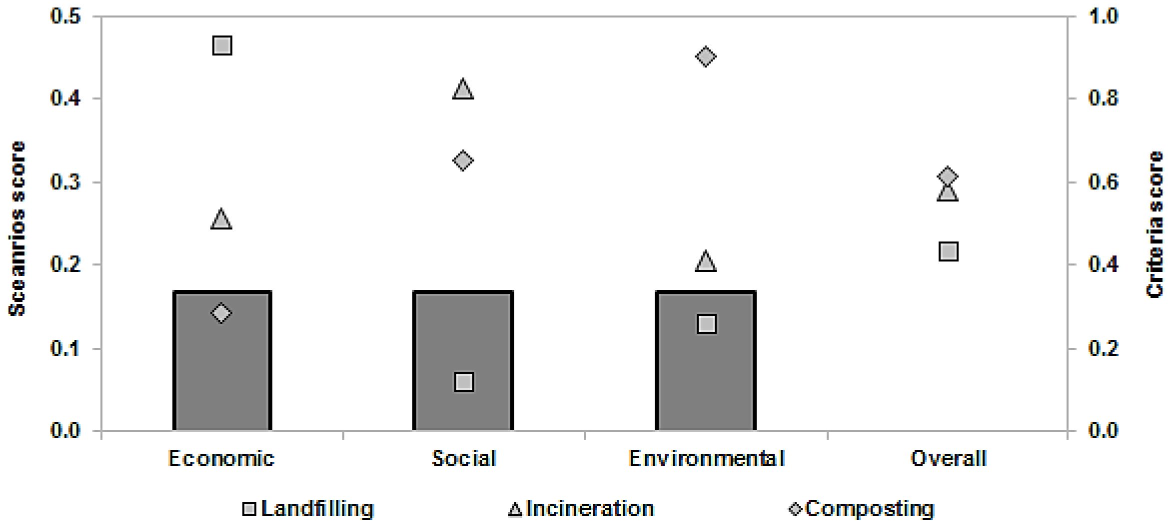


Fig. 3



0.5
0.4
0.3
0.2
0.1
0.0
Sceanrios score
1.0
0.8
0.6
0.4
0.2
0.0
Criteria score
Economic
Social
Environmental
Overall
Landfilling
Incineration
Composting

Fig. 4

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