Journal of Cleaner Production 176 (2018) 1198–1212

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Using a fuzzy TOPSIS-based scenario analysis to improve municipal solid waste planning and forecasting: A case study of Canary archipelago (1999–2030)

Charles Estay-Ossandon [a], Angel Mena-Nieto [b, *], Nina Harsch [c]

[a] University of Muenster, Fliednerstraße, 21, 48149, Muenster, Germany
[b] University of Huelva, Campus La Rabida, 21819 Huelva, Spain
[c] University of Muenster, Hammer Straße 95, 48153, Muenster, Germany

ARTICLE INFO

Article history:
Received 6 April 2017
Received in revised form
22 September 2017
Accepted 30 October 2017
Available online 20 November 2017

Keywords:
Municipal waste management
Scenario analysis
Fuzzy TOPSIS
System dynamics
Decision-making
Canary islands

ABSTRACT

In this paper the Canary archipelago is used as a study case to analyse and improve the municipal solid waste (MSW) planning process. The research has been conducted in four steps, namely, the Delphi technique helped to capture the knowledge of the local experts, the fuzzy TOPSIS to rank the MSW treatment methods more consistently, the System Dynamics to design a mathematical model based on MSW official historical data from 1999 up to 2014, and Scenario Analysis to forecast the future evolution of the MSW until 2030 under different policies. According to the results obtained by simulating several possible and desirable scenarios, the model predicts that by maintaining the current policies (Business As Usual scenario), it will be impossible to meet the targets of the MSW European Directive. The model also estimates the annual ratios to be reached for each component of the MSW so that they can comply with the European Directive, e.g. regarding to recycling (Scenario 2) and organic and rest fraction collection (Scenario 3) and the influences of the resident population and the equivalent touristic population on the total MSW generation until 2030. This methodological approach could be replicated in other territories.

1. Introduction

An increase in the population, rapid urbanisation and a rise in community living standards have significantly accelerated municipal solid waste (MSW) generation (Song et al., 2015), and so a sustainable and efficient waste management strategy is needed to balance the need for development, the quality of human life and the environment (Tan et al., 2014). The management of this growing and complex problem requires approaches that deliver more consistent and robust results for decision-making.

This study has two objectives:

1. To select the best MSW treatment methods to be applied for the amount of waste generated in a specific territory. It should be based on the interests and wishes of the main local stakeholders, mainly citizens and their political representatives, academic experts and environmental decision-makers.
2. To estimate and forecast the evolution of the MSW generation under different assumptions and scenarios for a future period, using a mathematical model developed on the basis of the historical official data for a given territory such as the Canaries was applied. This help to disentangle how the different factors affect MSW generation and to determine when the current landfill capacity would be overcome in that territory.

To achieve those objectives, a decision model based on Delphi, fuzzy TOPSIS, system dynamics (SD) and scenario analysis that supports decision-making for the comparison of different potential alternative MSW treatments was developed.

Changes and incentives in public policies and consumption habits may increase the uncertainty and variability of the forecasts regarding the future amount of different waste fractions. Some of the relationships between those factors are dynamic, so the feedback mechanism may provoke non intuitive responses. Many long-term decision-making processes are dynamic, and critical decisions often require multiple and interrelated decision within extremely

* Corresponding author.
E-mail addresses: charles.estay@gmail.com (C. Estay-Ossandon), mena@uhu.es (A. Mena-Nieto), nina.harsch@uni-muenster.de (N. Harsch).

https://doi.org/10.1016/j.jclepro.2017.10.324
0959-6526/

uncertain and complex scenarios. Therefore, scenarios analysis is a strategic planning method that can help decision makers make more flexible long-term planning (Salmeron et al., 2012).

The Canary Islands are an interesting case study because they are among the most important tourist islands in the European Union (EU). The tourist industry contribution to the total gross domestic product (GDP) of Spain reaches 31.4% and the population working in this industry reaches 33.1%, and to improve the MSW management is a key issue for the sustainable tourism development of that territory.

In the study area, the topic of MSW management planning has been investigated very little, e.g. Garcia-Falcon and Medina-Muñoz (1999) studied the sustainable tourism development in the main island of the Canary archipelago and Santamarta et al. (2014) identified some weaknesses of the MSW Canary management system for the period 2005–2011 and proposed recommendations to improve it but without neither calculations nor modelling.

This paper helps by responding to this gap in the Canaries and the tourist islands, because, this study area which can be considered as a closed system and it was nominated as biosphere reserve by UNESCO, no research has been conducted to determine the key factors that directly affect the generation of waste and the impact they may have in the long term. As well no mathematical models or fuzzy or hybrid approaches have been applied as prospective aid to improve solid waste planning. At the same time, this case study is very useful to study the influence of the variations of the tourism on the MSW generation in touristic island, where the contribution of the tourist industry to the GDP is very high (e.g. 31.9% in Canary island in 2015).

The main contribution of this paper is the development of a prognostic tool to improve the consistency of decision-making and the forecasts of the future MSW generation in any territory. It is needed because this European territory has to comply with what was established by the European Directive 2008/98/EC, where the countries have to develop waste prevention plans and programmes (articles 28 and 29).

There are many initiatives that can be put in place to improve the management of waste in the Canary Islands. These include implementing systems for self-management of the organic fraction, establishing models of collection door-to-door, promoting small scale treatment plants, creating taxes for the more pollutant treatments or adjusting rates of waste to the same generation (known as economic tools), as has been tested in experiences carried out on other European islands, especially if differential treatment is given to the waste generated by tourist activity.

2. Literature review

During the last decade, improvements in the MSW management issue have received increasing interest from the scientific community from different perspectives: environmental, political, governmental and legal, educational and socioeconomical. Su et al. (2007) analyze the potential impact of applying different MSW policies as support for environmental decision-making. Triguero et al. (2016) and Afroz et al. (2011) analyze the factors that influence the MSW generation and the willingness to minimize it, and they show that the individual acceptance of the MSW management policies is essential for the implementation of proactive and preventive approaches towards the improvement of the responsibility and the involvement of all stakeholder groups. Niza et al. (2014) state that in order to improve MSW management, responsibility policies should be applied to the producers of goods and services. Gonzalez-Martínez et al. (2012) suggest that a more sustainable system requires the incorporation of governmental policies and regulations, sustainable consumption patterns, adequate costing and education, as well as technological development.

In terms of the social perspective of the resident and the touristic population, authors such as Nair and Jayakumar (2008) and Zorpas et al. (2014) focus on the MSW generation in tourist areas and how to improve and achieve zero residues. They argue that zero residues combine the ethical practice with a sound economic vision for both local communities and large corporations.

The question of how education can affect the MSW generation. Authors like, Márquez et al. (2008) and Ojeda-Benıtez et al. (2008) find a correlation between the generation of domestic waste and the educational level which determines certain patterns of consumption. Villavicencio et al. (2014) analyze important externalities such as education and tourism, as well as the combination of socioeconomic factors that influence MSW management.

Regarding economic prospects, some authors have found a correlation that can be directly proportional between MSW generation and the income per capita, because economic growth leads to increasing levels of consumption, which causes a higher generation of MSW and may lead to environmental degradation (Dangi et al., 2011), Mazzanti and Zoboli (2008) analyze to what extent the income level and the MSW generation are linked and at which income level they are disconnected until they find a turning point.

Many different methods and techniques can be applied to develop a decision support system (DSS), which helps to predict the MSW generation, and to select the ideal MSW treatment mix, including Life Cycle Analysis (LCA), Econometric studies, System Dynamics (SD), Scenario Analysis (SA) and multicriteria decision-making methods (MCDM). In this study we have applied SD, SA and MCDM.

The LCA method has been widely used to evaluate the environmental impact of waste generation and treatment alternatives, e.g. Kalakula et al. (2014) developed a soft LCA tool that helps to evaluate the environmental impacts of biochemical processes. Nadzirah et al. (2012) reviewed and evaluated the life cycle of waste in some Asian countries, adopting an integrated approach to solving the problem of waste generation. Al-Salem and Lettieri (2009) evaluated the waste life cycle through the creation of scenarios to compare the current and future scenario in Kuwait. Kim et al. (2009) suggested an evaluation method to assess recycling potential considering both the environmental and economic factors for the materials recovered from waste home appliances. den Boer and Lager (2007) focused on the LCA and integrated waste management strategies as an evaluation tool that supports decision making for waste management planning allowing the creation and comparison of different scenarios, but the inclusion of additional criteria, such as cost and social effects, must make the decisions more consistent.

Some econometric studies have tried to find the key drivers affecting waste management, e.g. Ghinea et al. (2016) applied a prognostic tool, regression analysis and time series analysis in order to predict the generation of solid waste. Ali et al. (2011) applies multivariate econometric approach to select the most relevant explanatory variables related with the MSW generation. Weng et al. (2011) quantified the consumer behavior using a multinomial logit model to analyze the individual consumption expenditure and the influence on the MSW generation. Beigl et al. (2008) reviewed the MSW generation literature showing some simple and multiple regression models with the aim at explaining or estimating the present or future waste generation using socioeconomic data.

The application of the MCDM to MSW management problems, the analytic hierarchy process (AHP) and the analytic network process (ANP) must be highlighted, e.g. Tascione et al. (2016) applied multiobjective linear programming as a tool to define the best scenario to find an optimal waste management system. Vučijak et al. (2015) used of multicriteria decision-making tools to select the best waste management for Bosnia and Herzegovina. Arıkan et al. (2017) determined the most appropriate solid waste disposal methodology, based on a multicriteria analysis and considering all factors that may be related to waste. Victor and Agamuthu et al. (2013) examined the strategic environmental assessment policy and find that it is influenced directly by drivers, environmnetal attitude and environmental awareness. Milutinovic et al. (2014) applied multicriteria analysis can be applied to the selection of a waste management scenario with energy and resource recovery.

SD and SA, both of them are effective methods for studying the dynamic conditions and changes in complex systems, such as the MSW management system. They can help to predict the future behaviour of the variables that affect the system under different scenarios and the right forecast of future MSW generation is critical for decision-making and strategic planning. For this reason they have been selected to develop this study.

Table 1 shows a sample of previous studies and territories where SD and SA have been applied to model, simulate and analyse policies to improve MSW management and planning.

The TOPSIS method has been applied to MSW management, mainly with AHP. Behzadian et al. (2012) present a wide review of this method. Beskese et al. (2015) and Ekmekcioglu et al. (2010) apply this method to determine the optimal selection of a landfill site. Onut and Soner (2008) use this method to select the transshipment site of the waste (transfer stations), Rao and Baral (2011) use this method to evaluate different MSW treatment methods and propose the best combination. Vinodh et al. (2014) and Gumus (2009) integrate Fuzzy TOPSIS and AHP methods to improve the recycling of plastics.

The Fuzzy TOPSIS method by itself has been applied much less to MSW management. For example, Torkamani et al. (2012) use it as tool for decision-making in urban management, Yong (2006) uses it to select the location of a waste treatment plant, and Aghajani et al. (2016) combined TOPSIS and VIKOR methods to obtain the best MSW treatment method by comparing and classifying the different scenarios.

3. Material and methods

3.1. Overview of the study area

The Canary Islands are a Spanish archipelago composed of seven islands, which by the end of 2015, had a resident population of 2.1 M/inhabitants and the waste generation rates reached 2.0 kg/pers/day in 2014 (ISTAC, 2015). In recent decades, the tourism development of the islands has caused an increase in the generation of MSW, which has caused an increasing need for infrastructure and treatment facilities for their internal flows. The MSW management in the Canary Islands is currently rather poor, and the islands have not reached the goals set by the Spanish Integrated National Waste Plan (SINWP, 2008–2015) for the generation and treatment of waste. Landfilling is the primary treatment, even if it means a high risk of environmental contamination as well as harm to public health.

One of the main problems is that in the grey containers (mixed MSW deposited no associated with the selective collection), approximately 72% of the waste deposited is not organic since there is no separation at the origin and different types are mingled.

Currently in the territory Canary archipelago around 88% of the total generated waste goes to a landfill, and only around 12.29% is collected selectively. Also, it can be highlighted that 38–40% of the total waste generated is organic.

There is currently a biomethanisation facility, which, even after eight years, has not come into operation because of social rejection of this type of treatment. It is necessary to find out which methods would be best advised to modernise and improve the MSW management system in the Canaries. One must bear in mind that not just landfilling but also incineration and biomethanisation are socially rejected. This make it difficult to find a solution, even knowing that certain methods in developed countries of the EU have achieved considerable results in reducing landfilling. For example, Germany and Denmark are currently achieving ratios of below 1% sent to landfill (EUROSTAT, 2015).

3.2. Evolution of the MSW generation in the Canary Islands

Table 2 presents panel data of the main variables involved in the MSW generation in the study area. As well as the calculated indicator of the Equivalent Tourist Population (ETP) has been calculated. It helps to better visualise the impact on the MSW generation that is being exerted by tourists.

The ETP is defined as the quotient of the number of overnight stays by groups of tourists divided by 365 days.

$$\text{ETP in hotels in a given area} = (Pes + Pex)/365,$$

where:

Pes = Number of overnight stays by Spanish tourists.
Pex = Number of overnight stays by foreign tourists.

Fig. 1 presents the total population and MSW generated by the Canaries' MSW system. The curves are fitted based on 16 data points (1999–2014). For scaling reasons, the total population values are expressed as indexes (basis 1999 = 100) to facilitate the comparison of the relative changes in the variables (absolute values can

Table 1
Previous studies.

Author(s)	Methodology	Region
Marzouk and Azab (2013)	SD and SA	Egypt
De Oliveira and Löbler (2012)	SD and SA	Southern Brazil
Karavezysis et al. (2002)	SD and fuzzy logic	Generic region
Guo et al. (2001)	SD and SA	Erhai Lake, China
Nesli and John (2012)	SD and SA	Istanbul, Turkey
Ahmad (2012)	SD and SA	New Delhi, India
Manga et al. (2011)	SD and SA	Cameroon, Africa
Kollikkathara et al. (2010)	SD and SA	Newark, New Jersey, USA
Inghels and Dullaert (2010)	SD and SA	Flanders, Belgium
Resources and Livelihoods Group, Prayas, PUNE (2009)	SD and fuzzy logic	India
Pai et al. (2014)	SD and SA	Karnataka, India
Adamides et al. (2009)	SD and SA	Generic region in Greece
Yan et al. (2007)	SD and SA	Kunming City, China
Sufian and Bala (2007)	SD and SA	Dhaka City, Bangladesh
Dyson and Chang (2005)	SD and SA	Texas, USA

Table 2
Main variables involved in the MSW generation (Souces: ISTAC, 2015).

Period	Tourist arrival	Resident Population	Equivalent Tourist Population (ETP)	Total population (ResPop + ETP)	GDP per capita [€]	Total MSW generated [kg/pers/year]
1999	9,855,592	1,672,689	110,100	1,773,789	14,200	825.63
2000	9,972,184	1,716,276	115,340	1,817,616	15,570	788.18
2001	10,137,202	1,781,366	121,273	1,882,639	16,759	710.22
2002	9,778,512	1,843,755	136,513	1,942,268	17,476	687.51
2003	9,836,785	1,894,868	152,449	1,997,317	18,227	695.01
2004	9,427,265	1,915,540	171,606	2,017,146	18,778	770.02
2005	9,276,963	1,968,280	193,094	2,071,374	19,595	735.86
2006	9,530,039	1,995,833	210,266	2,119,099	20,422	700.12
2007	9,328,546	2,025,951	129,303	2,155,254	21,167	597.50
2008	9,216,585	2,075,968	217,810	2,203,778	21,186	604.85
2009	7,982,256	2,103,992	228,782	2,336,774	20,006	547.22
2010	8,590,081	2,118,519	237,092	2,355,611	20,091	679.71
2011	10,318,178	2,126,769	249,718	2,388,487	19,792	693.51
2012	10.591.269	2,118,344	253,369	2,371,713	19,115	705.36
2013	11.511.108	2,110,109	261,893	2,372,002	18,965	715.89
2014	13.332.465	2,126,144	271,357	2,397,501	19,238	714.72

be seen in Table 2, fifth column).

Fig. 2a and b presents the evolution of the total MSW collection of various types in the Canary Islands from 1999 to 2014. In 2014, the selective collection (Fig. 2b) amounted to 17.5 kg/pers/year of glass waste, 18.7 kg/pers/year of paper and cardboard waste and 8.8 kg/pers/year of packaging per inhabitant.

Improving the forecasts for future MSW generation and treatment is of great importance for decision-making and the planning of waste facilities. Combining one or more scientific methods is certainly beneficial. In this study, a combination of the Delphi technique, fuzzy TOPSIS, system dynamics and scenario analysis was applied to increase the consistency of the obtained results. The reliability and robustness of the presented methodology as a decision-supporting tool is assessed through a validation of the model.

Fig. 3 summarises the methodology presented in this paper. In phase 1 the Delphi technique is applied to capture the experts' knowledge about the problem. In phase 2 the fuzzy TOPSIS method is used to rank the treatment methods based on the quantitative and qualitative data extracted from phase 1. Then in phase 3, SD and SA are applied to model and forecast scenarios (starting from a baseline scenario). This helps to gain greater knowledge and more understanding of the MSW problem, which is the ideal basis for well-founded decision-making.

3.3. Application of the Delphi technique

For a better understanding of the complex problem of MSW management and planning, and in order to take into consideration the opinions of the interested parties in the archipelago, the Delphi technique (Dalkey and Helmer, 1963) was applied by interviewing to the 16 MSW experts involved in the MSW management of the archipelago, which met the criteria of: MSW expertise, experience in the topic to be investigated, availability of time for the research and wishes to participate.

At the end, only 12 experts could participate due to their workload and availability of time. A detailed description about the identification of the experts can be found in Table A.1 of the supplementary material Appendix A.

The use of the Delphi technique as a tool for the validation of questionnaires has been widely used in numerous studies (Hung et al., 2008). Delphi is a methodology structured to systematically collect judgments of experts on a problem, while the information is processed through statistical resources to obtain a consensus that allows decision-making (García and Suárez, 2013).

In this study, 12 MSW management experts shared their professional experiences and provided valuable information on the current and future MSW situation in the Canaries, including MSW generation as well as possible treatment methods providing qualitative and quantitative assessments and weights for the five selected criteria, which were environmental, social, political, economic and technological, and for the 12 sub-criteria (see Table 3). The alternatives proposed for the treatment of MSW in the Canaries were: recycling, landfilling, incineration and biomethanisation (see in details the experts' valuations in Table A.2 of Appendix A).

Fig. 1. Evolution of the total MSW generation vs. Total population (Source: SINWP, 2008–2015).

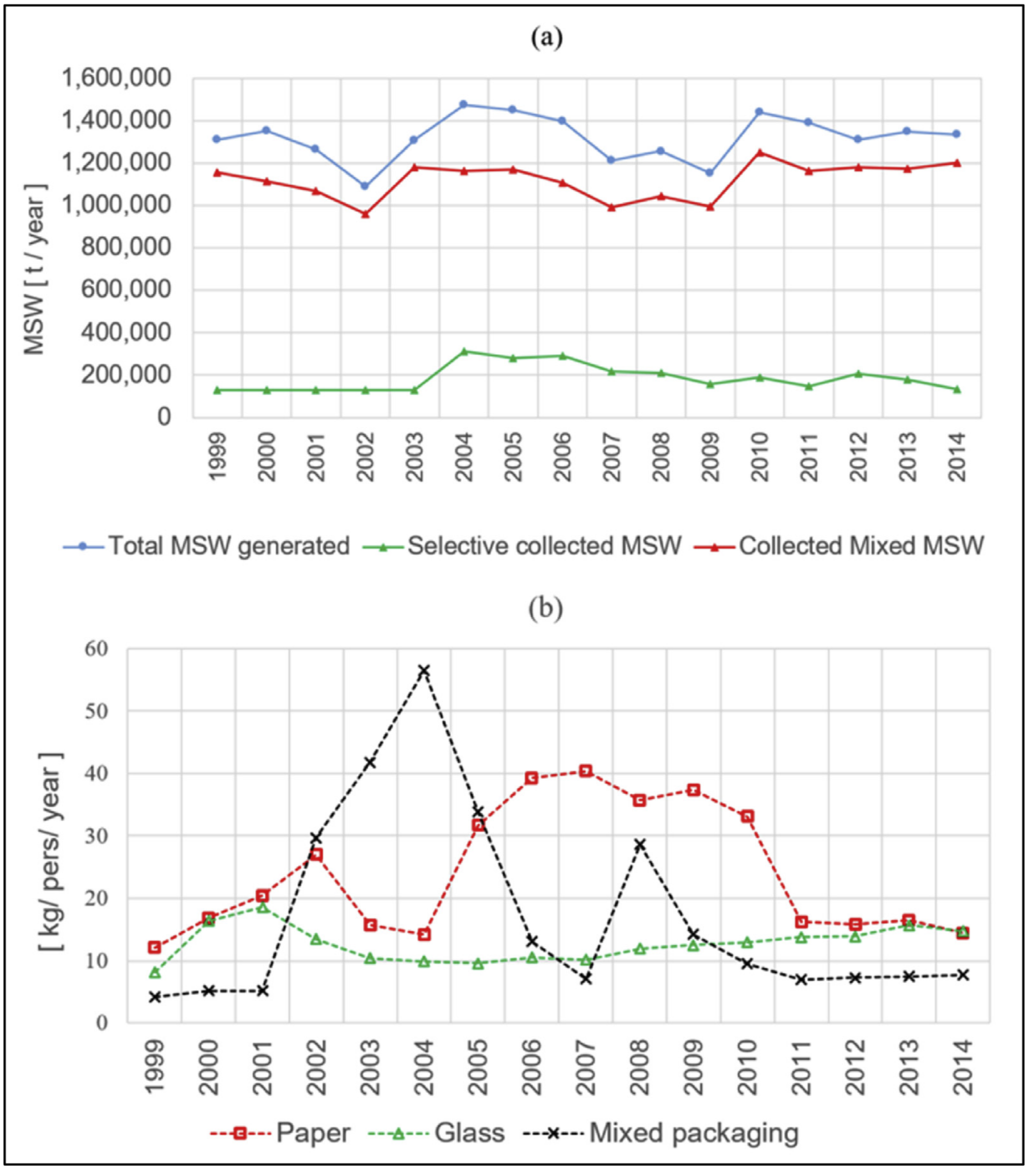

Fig. 2. a. Evolution of the total MSW, selective, mixed collection and Fig. 2b. The evolution of the main three types of MSW selective collected.

3.4. Application of the fuzzy TOPSIS method

When a decision is based on information derived from speculation and personal views, the final decision tends to be subjective and thus comprises a certain risk. So the aim should be to find a way to solidify the decision by basing it on scientific research facts, e.g. mathematical structures. The fuzzy TOPSIS application allows combining quantitative and qualitative criteria in the decision-making process. It reduces the vagueness and uncertainty that is presented in the qualitative judgments given by the experts regarding the evaluations of criteria, sub-criteria and the proposed alternatives.

The choice of fuzzy TOPSIS in this case study is justified by several reasons. Following Lima-Junior et al., 2014 (p. 206, Table 24) fuzzy TOPSIS has the advantages of changes in alternatives, changes in criteria, agility in the decision process, quantity of criteria and alternatives. Also, Yong (2006) identifies it to be better for group decision-making problems. It is a commonly applied method not only in MSW but also in other areas such as water resources (Dai et al., 2010).

The aim of applying the fuzzy TOPSIS method is to find the best alternative of a decision problem by identifying weights for each criterion, normalizing scores for each criterion and calculating the geometric distance between each alternative and the ideal alternative, which is the best score in each criterion (For more details see Appendix A).

3.4.1. Structure of the problem

As the construction of a decision matrix to evaluate a problem as complex as MSW management can be critical, the application of fuzzy TOPSIS is a reasonable way to approach the problem a (Salmeron et al., 2012). Using fuzzy TOPSIS, the dataset allows both numeric and semantic values, and to each of these values, weights can be assigned. The aim is to find the best advised MSW treatment methods for the Canary Islands. The steps of the fuzzy TOPSIS method are explained in phase 2 of Fig. 3. The algebraic development of the calculations for the identification of criteria and their weights, the evaluation of alternatives, the construction of matrixes

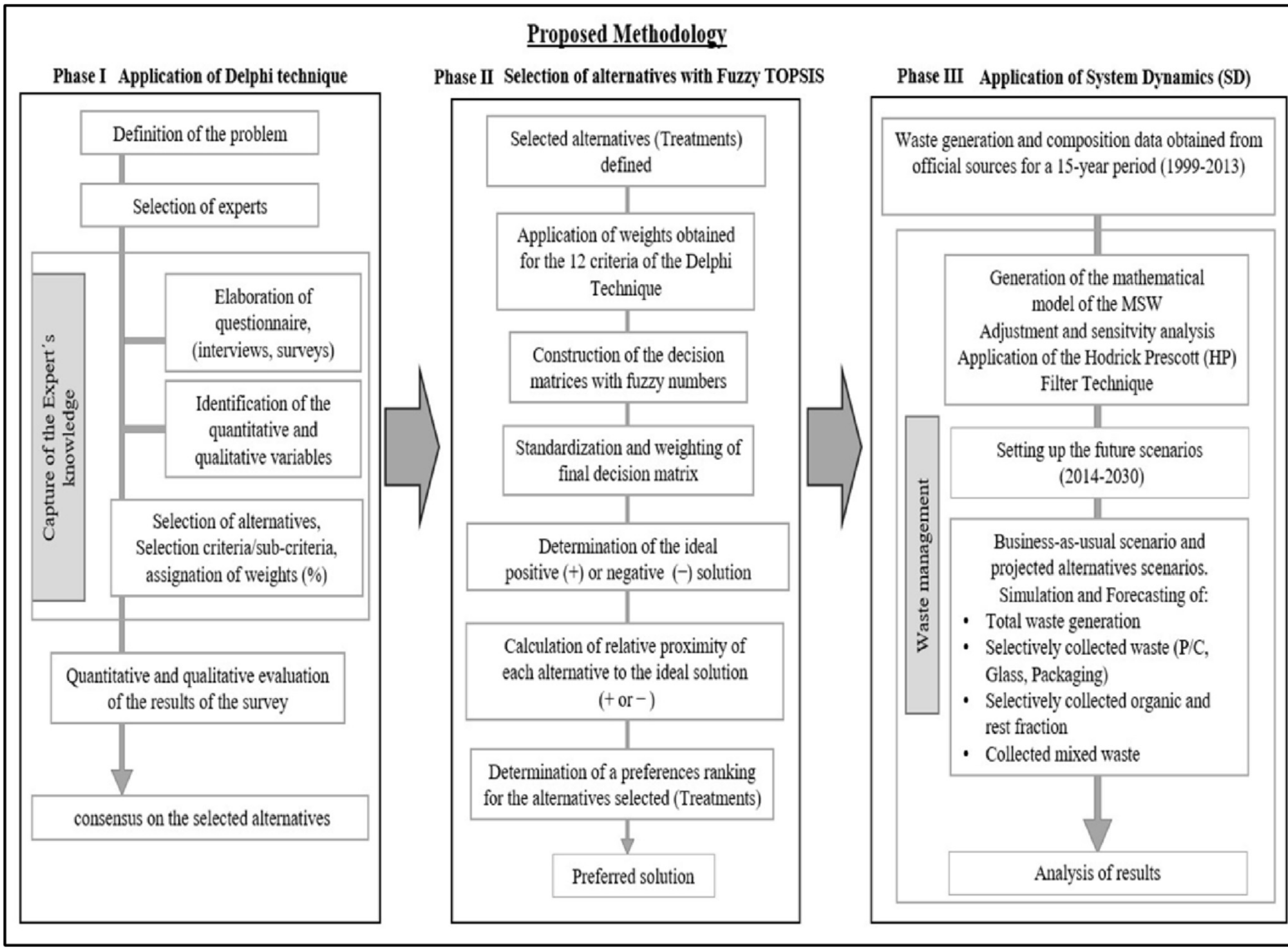

Fig. 3. Proposed methodology.

and the equations and outputs of the values can be seen in supplementary material (see Appendix B). The established criteria for the decision-making were established by the authors based on Aghajani et al. (2016); Su et al. (2007) and Abarca et al. (2013), and on our own experience and agreed with the MSW experts.

3.5. System dynamics model

An SD model was developed to estimate the future MSW generation up to 2030 and to analyse and compare different MSW management strategies by applying alternative action plans. The model was built based on official MSW generation data obtained from the Canary regional government for the period 1999 to 2014, and predictions were developed until 2030 using different scenarios and hypotheses. This is because in 1999 the law 1/1999 of January 29 was approved. The objective of this law applicable to the territory of the Canary Islands was to improve the management of the waste generated in this territorial area, following the guidelines established by the European Union (Community Directive 91/156 EEC of 18 March 1991). It was analyzed until 2014 which is the last year that has the official statistics available at the date of the study.

As the historical data regarding the total MSW generated, selectively collected and not selectively collected showed strong fluctuations, the Hodrick-Prescott (HP) filter was applied. This serves to remove the cyclical component of time series from raw data, obtaining a smoothed curve representation of the time series (Harvey and Trimbur, 2008). This made it possible to curve out the tendency of the time series and to use it as a basis for the forecast scenarios. The HP filter enables an estimation of the cyclical fluctuations of the series, giving an additional element for decision-making.

Table 3
Summary of the criteria and alternatives.

Types of criteria (C)	Subcriteria (S)	Level	Target
Environmental (C1)	Emission of pollution	S 1.1	Min
	Damage to public health	S 1.2	Min
	Deterioration of landscapes	S 1.3	Min
Politic (C2)	Political support	S 2.1	Max
	Control and regulation	S 2.2	Max
Social (C3)	Public acceptance	S 3.1	Max
	Generation of employment	S 3.2	Max
	Awareness	S 3.3	Max
Economic (C4)	Implementation cost	S 4.1	Min
	Availability of resourses	S 4.2	Max
Technological (C5)	Technological efficiency	S 5.1	Max
	Technological reliability	S 5.2	Max
Alternatives	Treatment method		
A1	Recycling		
A2	Biomethanisation		
A3	Incineration		
A4	Landfill		

3.5.1. Estimation of future MSW generation of the Canary archipelago using SD modelling

After analysing the current MSW management and its deficiencies, SD was applied to model the behaviour of the main variables of the Canaries' MSW management system. This diagram is based on information obtained through the Delphi technique (Chia-Chien and Sandford, 2007) and cross-checked with public authorities and other stakeholders responsible for MSW management in the Canary Islands. The definition of the causal model was the starting point for understanding the problem of MSW generation. SD utilises feedback loops, stocks and flows in order to understand the behaviour of complex systems (Chen et al., 2012). By considering the interactions among a number of related social, economic, environmental and regulatory systems using different scenarios, an integrated concept of the whole system can be achieved.

3.5.2. Structure of the system dynamics model

Fig. 4 shows the stock and flow diagram of the MSW management system. This diagram includes the two level variables: Resident population and GDP income. There are also the flow variables (e.g. Birth, increase rate per capita) that influence the level variables being able to increase or decrease the stock. The MSW treatment is an auxiliary variable that is based (function) on the generated waste and parameters associated with the flow variables are expressed in ratios (e.g. birth rate, mortality rate).

In addition, having defined the key elements, they were quantified and their influences were formulated mathematically (see the equations in Appendix C).

3.5.3. Scenario setting

The evolution of the MSW management system is determined by the variations in the resident and tourist population, selective collection, collection of organics fraction and rest fraction, etc. To estimate the future behaviour of these variables, a lot of possible and desirable scenarios were simulated, however only four of them are shown in this paper.

The first scenario (Sc 1) was named as "Business As Usual" (BAU scenario). In it, the MSW generation of all the variables of the Canary archipelago system were simulated following the tendential evolution of the last 16 years from 1999 to 2014. This BAU scenario has been compared with three other scenarios.

Scenarios Sc2 and Sc3 are based on the achievement of the targets provided by the European Directive, the Spanish Integrated National Waste Plan (SINWP) and the State Plan Waste Management Framework of Spain (2016–2022), and the Sc4 are based on the Spanish Tourism Plan Horizon 2020 (2015) and, according with the forecasts of the, World Tourism Organisation (WTO, 2015) the international tourism increases a 3.3% until 2030.

The initial conditions for the simulations from 2015 were: Total MSW generated: 1,210,000 t; Selective collected waste: 185,699 t; Recycled waste: 161,960 t; Mixed waste sent to landfill 1,070,000 t, and total population: 2,120,000 inhabitants.

The Sc2 scenario simulates a policy of increases in the ratios of selective collection, maintaining "ceteris paribus" the other variables involved, the Sc3 scenario incorporates the selective collection of the organic and rest fraction that does not exist in the current MSW management system, maintaining "ceteris paribus" the other variables involved, and the Sc4 scenario evaluates the influence on the MSW generation of an increase of the total population maintaining "ceteris paribus" the other factors involved. Table 4 presents a more detailed description of the scenarios simulated.

In the next section, the results from the comparison between the scenarios Sc2, Sc3 and Sc4 versus the BAU Scenario, are shown.

4. Results

Regarding the results from the application of the fuzzy TOPSIS method, Appendix B presents the fuzzy triangular numbers associated with the linguistic labels (very high, high, medium, low and very low) applied to assess the importance of each criterion and each alternative, and the detailed steps followed to find the most suitable treatment method for this case of study. The linguistic output measures the importance of the alternatives after having completed the defuzzification, for example, in the case of the recycling alternative (IA_1), the result of the defuzzification output is 0.7354, which corresponds to a linguistic output of "Very High" (VH), applying the relationships defined in Table B.1 of Appendix B (values associated with linguistic tags).

The results obtained by applying the fuzzy TOPSIS method are shown in Table 5.

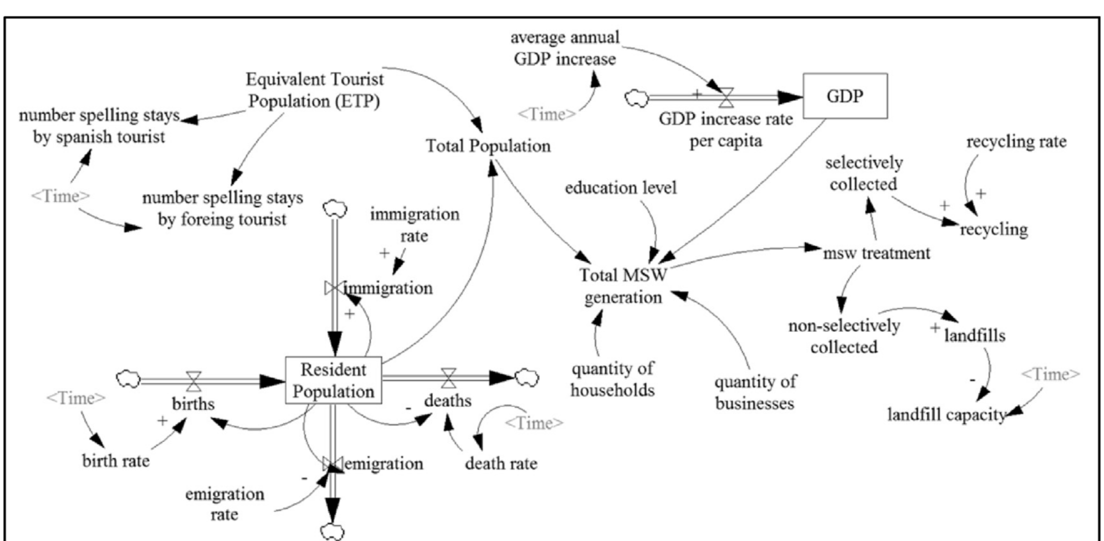

Fig. 4. Stock-flow diagram of the MSW management for the Canary Islands.

Table 4
Description of the main scenarios simulated.

Scenarios		Features	EU and national targets
Sc1	**BAU scenario** Maintaining the trend of the last 16 years. Ratios applied: Selective collected 1.35% Mixed waste 11.70% MSW generated 2.69% Population growth 1.68%	In this scenario, the MSW generation ratios applied were the average of the last 16 years for all variables of the system.	Not taking into consideration the EU targets.
Sc2	**Increase of the Selective collection** (ceteris paribus other variables involved) Ratios applied: From 2015 to 2020, high annual increase of the selective collection: 6.6% From 2020 to 2030, medium-high annual increase: 2.2%	To estimate the increase of the ratios of the selective collection of paper, glass and mixed packaging until 2030 needed to meet EU targets.	Recycle at least 50% of selective collection for 2020 and achieve at least 70% by 2030.
Sc3	**Incorporating the organic and rest fraction collection** (ceteris paribus other factors involved) Ratios applied: From 2015 to 2020, high annual decrease of mixed waste sent to landfills: 8.78% From 2020 to 2030, medium-high annual decrease of waste sent to landfills: 3.0%	To estimate the increase of the ratios of the selective collection of organic and rest fraction until 2030 needed to meet EU targets.	Limit the waste sent to landfills up to 35% in 2020, and increase the energy recovery by 15%. 0% deposit in landfills of Paper/cardboard, Glass and Mixed Packaging by 2030.
Sc4	**Evaluating the effects of the total population (Resident and Touristic)** growth (ceteris paribus other factors involved) Ratios applied: Low growth of the Resident population (average 1.68% annual). High increase in the ratios of Equivalent Tourist Population (average 8.5% annual until 2030)	Study the influences of the variations of the Resident population and Touristic population on the total MSW generation until 2030.	According to the WTO, international tourism will grow 3.3% between 2010 and 2030.

The order of alternatives and the output linguistic results are:

1st Recycling, **2nd** Landfill, **3rd** Biomethanisation and **4th** Incineration.

According to the order of importance obtained in Table 5, the method of recycling has been identified as the most appropriate method occupying the first position, although the costs in its implementation are greater, in the long term this method improves the management of MSW. The landfilling occupies the second position, despite the fact it is considered to be the least appropriate option on the hierarchical scale. However, both biomethanisation and incineration have very low social acceptance in the Canaries. This is due to the high costs of implementation and the lack of knowledge concerning functionality by the community. Although both options are convenient for reducing the amount of MSW sent to landfills, the experts did not prioritise them.

4.1. Model validation and verification

In order to reduce the marked fluctuations, the historical data analysis and the pre-processing of the time series were performed using the Hodrick-Prescott (HP) filter, which allows for the isolation of outliers (economic crises, random behaviour, etc.) of the time series under study. It is possible to determine the trend of a time series and to perform estimations that are more appropriate. The smoothing parameter, λ, of the filter, which penalises acceleration in the trend relative to the cycle component, is stated as equal to 100. Most of the business cycle literature uses this value for the λ parameter, as has been suggested by Hodrick and Prescott (1997).

Another way to validate the model and to test its robustness and reliability in order to reduce uncertainty is to calculate the MAPE (mean absolute percentage error), see Table 6. In this context, Hyndman and Koehler (2006) compared three accuracy of the forecasts and recommended the use of the MAPE. Robalino-López et al. (2015) applied MAPE to test the robustness and reliability of a model to forecast CO2 emissions.

This measures the size of the error in percentage terms. It is calculated as the mean of the absolute differences between the actual and predicted values and is expressed as a percentage of the

Table 5
Output defuzzification.

Importance of alternative $_{Ai}$	Defuzzification output	Order	Linguistic output	Technology
I_{A1}	0.7354	1st	Very High	Recycling
I_{A2}	0.5562	3rd	Medium–High	Biomethanisation
I_{A3}	0.4678	4th	Low–Very Low	Incineration
I_{A4}	0.6136	2nd	High	Landfill
I_{EC}	0.8402	VH		
I_{PC}	0.7130	H		
I_{SC}	0.6312	H		
I_{EcC}	0.5462	MH		
I_{TC}	0.4348	L		

$E_{C=}$Environmental criteria; $P_{C=}$Political criteria; $S_{C=}$Social criteria; $Ec_{C=}$Economic criteria; $S_{C=}$ Technological criteria.

Table 6
MAPE outputs.

Variables	MSW generation	GDP per capita	Tourist population	Resident population
MAPE	7.36%	1.43%	5.22%	8.31%

actual values, which is defined as:Where:

y_t =Actual or present value
$\hat{y}_t$ =Adjusted value forecasted
n = Number of observations

$$\frac{\sum(y_t - \hat{y}_t)/y_t}{n} * 100, (y_t \neq 0) \quad (1)$$

The low values obtained indicate that the forecasts are good because they are under 10%, and an allowable error interval of [0; 10%] is recommended by the literature.

With regard to the simulations figures, they are based on the SINWP (2008–2015) and adapted to the peculiarities of the Canary Islands, such as the insularity, their ultraperipheric location, the impossibility of reaching economies of scale and the weight of the tourist sector. Fig. 5a shows the results for the three main types of selective collection. In BAU Sc, the current waste generation and disposal ratios are kept nearly constant until 2030, but in Sc2 (generated from the EU directive targets), the current ratios of waste generation and disposal are increasing. With regard to glass (*red colour curve*), the current ratios of glass collection reach 14.5 kg/pers in 2014 and in BAU Sc they reach 28.2 kg/pers/year in 2030. In Sc2 (*green colour curve*) the ratios are close to 51.2 kg/pers/year in 2030, equivalent to 35.31% more with regard to 2014.

As regards paper/cardboard, the current ratio is 23.3 kg/pers/year in 2014. For BAU Sc (*lilac colour curve*) does not experience strong changes, reaching 28.5 kg/pers/year in 2030. Sc2 (*calypso colour curve*) shows a considerable increase because it reaches 56.1 kg/pers/year by 2030, equivalent to 58.51% more with regard to 2014.

Concerning mixed packaging, the current ratio is 17.4 kg/pers/year in 2014, and for the BAU Sc1 (*black colour curve*) it reaches a ratio of 14.02 kg/pers/year by 2030, while in Sc2 (*orange colour curve*) it reaches a ratio near 35.12 kg/pers/year by 2030 equivalent to 38.18% more with regard to 2014. These increases are derived from the attempt to assume the quantitative objectives of the comprehensive plans of waste (EU Directive targets), which aim for an increase in recycling of 50% for glass and paper/cardboard, and packaging by 2020. To achieve these objectives, the incorporation of drawback systems, deposit and return of packaging materials and the separation of waste at the origin (door-to-door collection) are critical, as has been demonstrated in most developed countries.

Fig. 5b shows the evolution of the organic fraction and the rest fraction collected. Both figures are based on BAU Sc1 and Sc3.

In BAU Sc1 (organic fraction), the *black colour curve* follows a constantly growing trend under the same initial conditions until reaching 760,000 t of organics fraction collected in 2030 (2014 = 700,000 t, equivalent to 6.29% more). The *lilac colour curve* of the Sc3 (organic fraction) shows that under conditions required by strategic plans, the ratios of this fraction show a decrease until 2030, when they reach 640,000 t collected (120,000 t less with regard to BAU Sc1 and 60,000 t less than in 2014). With respect to the rest fraction (*green colour curve*), a growing trend under the same initial conditions the BAU Sc1 can be observed, reaching 780,000 t collected in 2030 (2014 = 725,000 t, equivalent to 10.75% more). In Sc3 (*calypso colour curve*) starts to decrease due to high ratios of separate collection and recovery of material for recycling, which diminishes the flow of this type of waste sent to a landfill. This leads to 630,000 t/year until 2030 (95,000 t less with regard to 2014).

To achieve this objective, the separation of waste at the origin and the implementation of biotechnological treatment methods are fundamental (increase in the organic fraction of at least 2 MT, as aspired to by the SINWP (2008–2015)).

Fig. 6a shows the BAU Sc1 of the MSW generation smoothed with the HP filter. For the BAU Sc1 and Sc4 the simulations are based on the influence that the population has on the MSW generation. The BAU Sc1 (*black colour curve*) shows an increasing tendency from 1.21 MT of MSW generated in 1999 to 1.31 MT of MSW generated in 2014. Within the study horizon, the MSW generation reaches 1.33 M/T (Maintaining total population rates of 1.54% annually).

The Sc 4 shows what would happen with the MSW generation if there were an increase in the Equivalent Tourist Population rate (ETP). For this purpose, the geometric growth has been applied because this method of estimating future populations for the BAU scenario assumes that the population is growing at the same rate as for the last census period, before the geometric growth rate has been calculated. Considering that, the growth is due to the following expression:

$$ETP_n = ETP_{2014} * (1 + \text{annual growth rate})^{(2014-2030)}$$

At the end of the study horizon in 2030, the ratios of MSW generation in Sc4 (*red colour curve*) are close to 1.38 MT, with a calculated total future of 419,489 ETP for 2030. This scenario would help to determine the dimensions of future waste management facilities.

Fig. 6b shows the evolution of the MSW generation, resident population and tourist arrival from 1999 to 2014. The changes experienced by both variables are the product of the different economic cycles (growth and decrease of the economy) that the Canary Islands have experienced in recent years. According to the calculations to predict the future population of the Canaries (Resident Population + ETP) through the application of geometric growth to 2030, the amount approximates to 3,882,670 inhabitants. It is also, estimated that each tourist generates an average of 2.5 kg–3.0 kg of MSW per/day, which leads to the need for a considerable size of waste management facilities.

Fig. 7 presents the quantities of mixed waste sent to landfills versus the optimal capacity of the landfills. It can be seen that the curve of the BAU Sc1 undergoes a significant increase of 6% approximately until 2030 (1,202,583 MT per year in 2014 to 1,330,000 t per year in 2030).

The Sc3 (EU Directive targets with regard to waste deposited in landfills) shows a decreasing behaviour from 2014 on, reaching 781,683 t/year in 2020, which is 52.71% less than in 2014 and 62.5% less than the BAU Sc1 in 2020. However, the curve also shows that from 2020 on, the quantities of waste deposited in landfills begin to decrease significantly, reaching a maximum discharge of 39,084 t in 2030. Assuming a possible situation without changes in the MSW management, it is estimated that the operational capacity of the landfills would reach its limit towards the end of 2018.

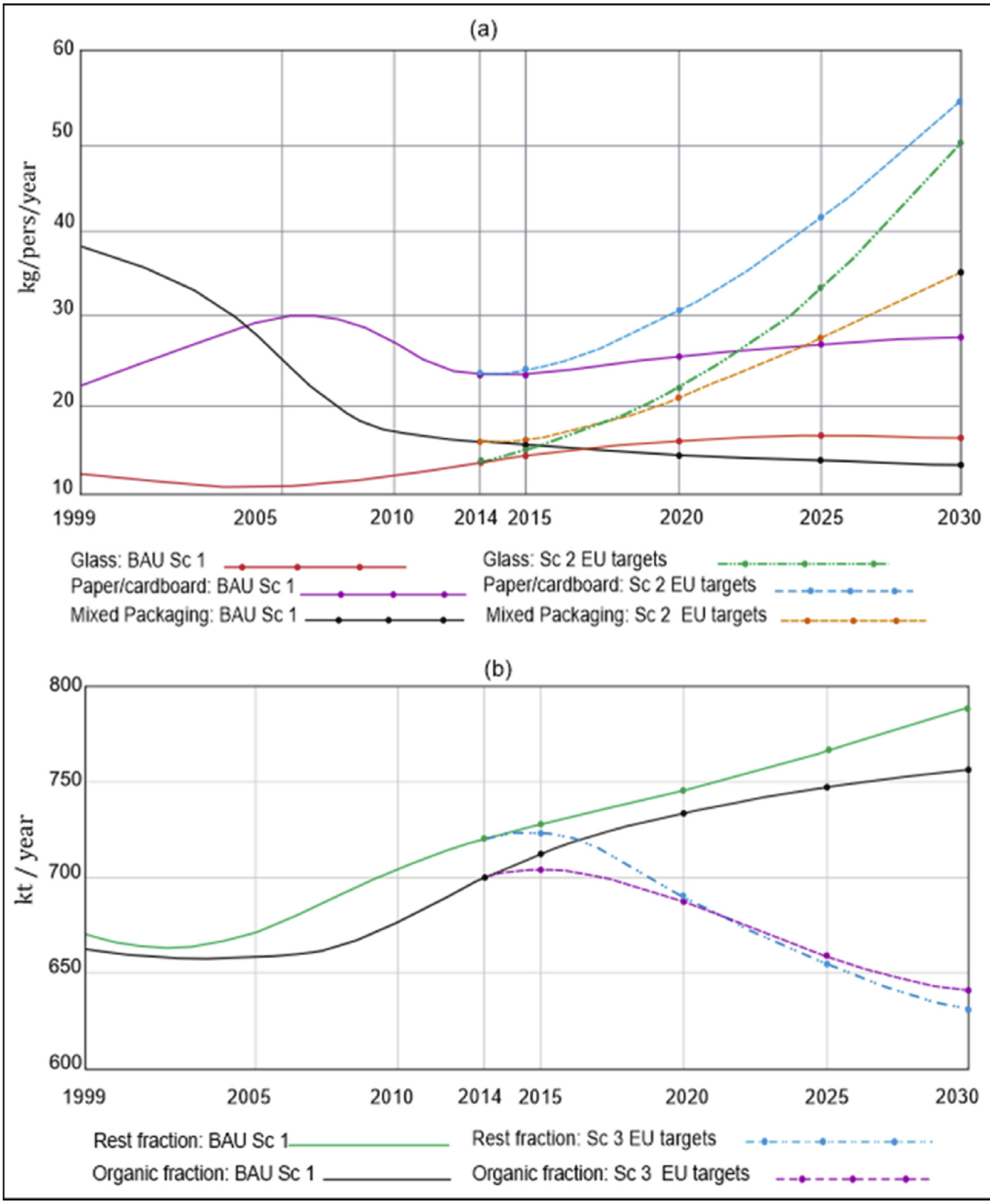

Fig. 5. a. Total MSW selective collection in BAU and projected Sc and Fig. 5b. Rest fraction and organics fraction collected for different scenarios.

5. Discussion

Poor MSW management is endangering the environmental sustainability of the Canary archipelago. In house separation and a separate collection of waste have to be promoted in order to increase the recycling and composting rates in the long run. So the question to ask is: why have the Canary Islands not yet applied any of the evidentially beneficial MSW management strategies and treatment methods, which are already very efficient in many other EU countries?

The high MSW generation levels in the Canaries are the consequence of unsustainable consumer habits. As the islands' internal market is limited, many products have to be imported, and this creates a certain amount of waste, e.g. from packaging material. At

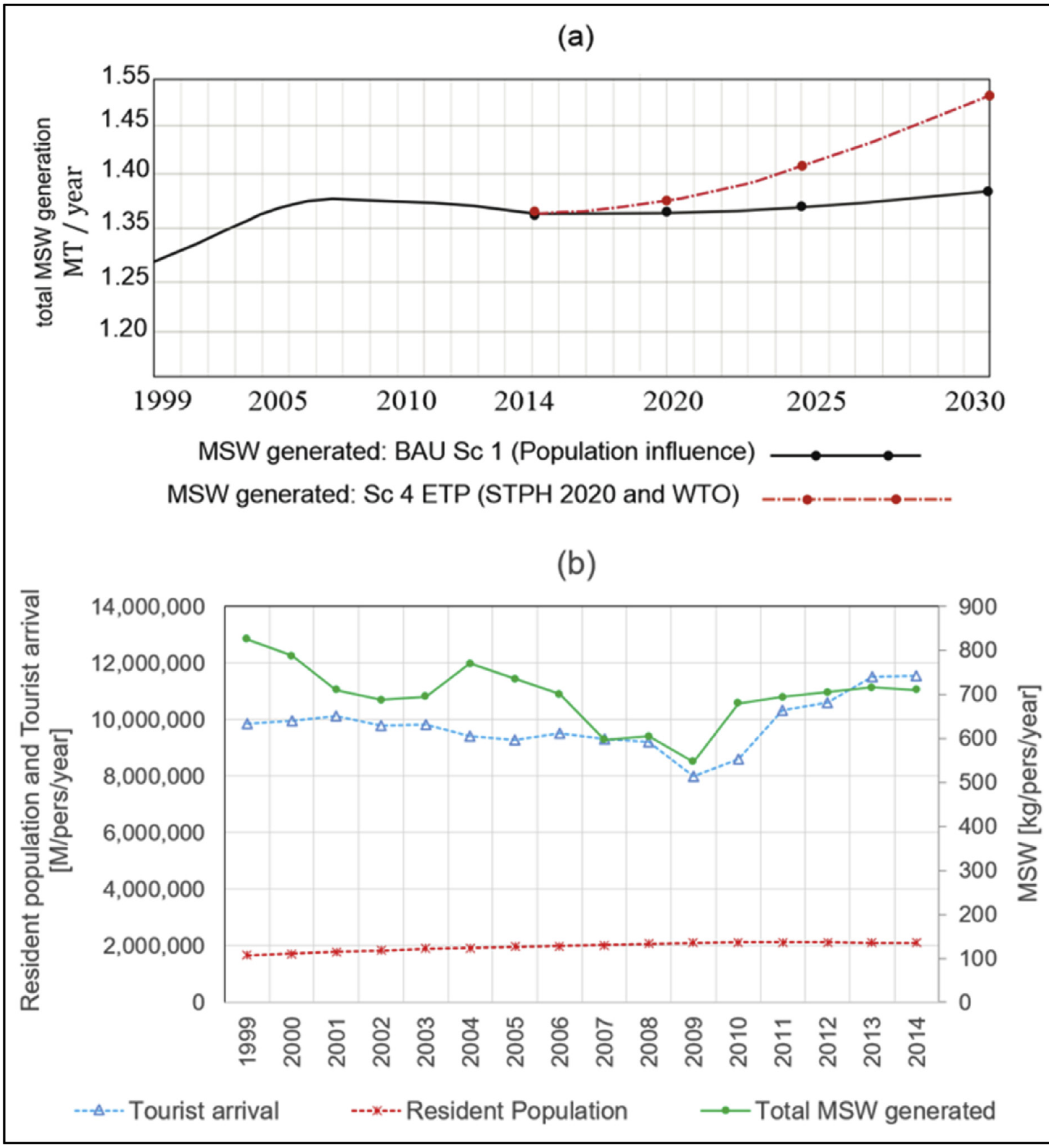

Fig. 6. a. Projected of total MSW generation vs. Resident population and ETP and Fig. 6b. Historical data of total MSW generation vs. Resident population and tourist arrival.

the moment, most of this waste is sent to landfills. Landfilling, however, is one of the environmentally least recommendable options as it contributes to the contamination of water, soil and air. The Canary government has tried to introduce more favourable methods and social policies, such as biotechnology (Estay and Harsch, 2015), but due to social rejection and environmental activist groups, these methods (incineration, biomethanisation and others) are a long way from being implemented. This confirms the findings of Triguero et al. (2016) regarding the factors that influence the willingness of people to accept different MSW public policies.

It is urgently necessary to reduce the quantity of MSW delivered to landfills and to switch over to a system based on recycling as the first option in the long run. The Canary government has tried to define new aims and MSW management strategies, as the introduction of a door-to-door collection system. This would involve high costs at the beginning, but in the long run, it would create many benefits. Countries like Germany, the Netherlands and Denmark (Lavee, 2010) have demonstrated that selective collection helps to reduce the quantity of residual waste. In order to make door-to-door collection function correctly, people have to be motivated to undertake in-house MSW separation. This is why environmental education and active citizen participation are key factors for efficient MSW management, e.g. Andraca and Sampedro (2010) highlighted the importance of environmental education to reduced the MSW generation and De Feo and De Gizi (2010) identified active citizen participation as key factor in the MSW management. With regard to the separate collection of plastics and mixed packaging, this is currently much less developed than the

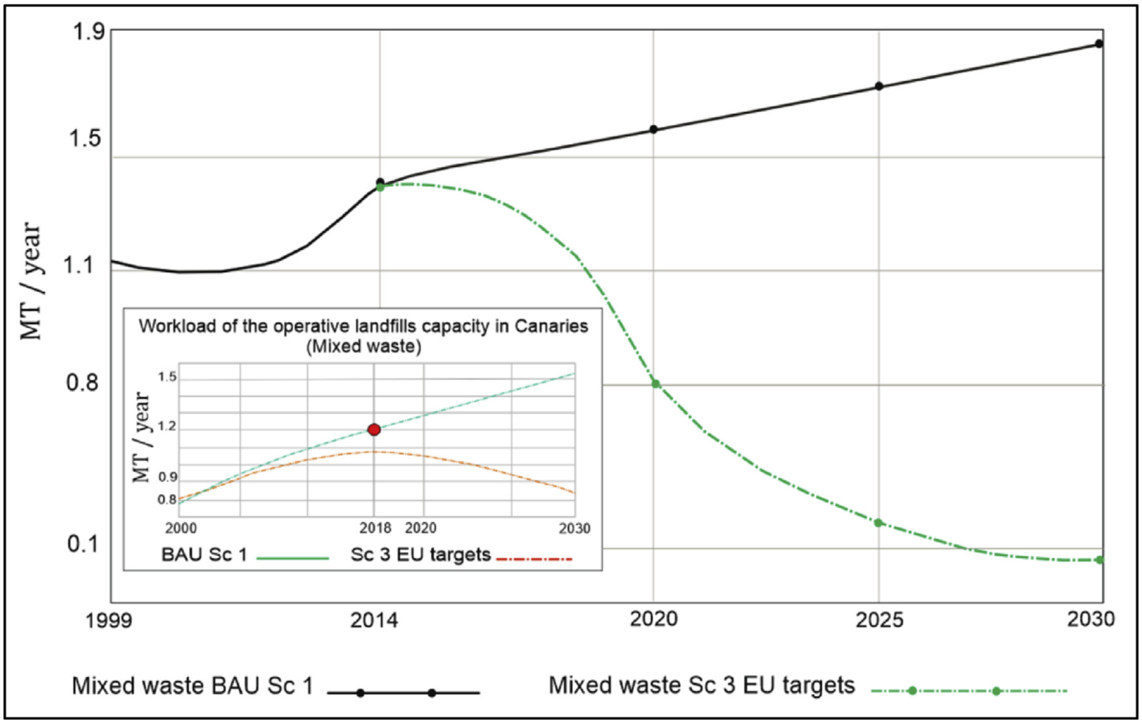

Fig. 7. Mixed waste deposited in landfills vs. operative capacity.

collection of glass and paper/cardboard. It is clear that a system of refunds and returns significantly helps to reduce the amount of mixed waste and to strengthen recycling (Lavee, 2010). The generation of organic MSW, account for 40% of the total weight of the MSW generated in the Canary Islands. Organic waste has high fertilisation potential for agriculture. Freire et al. (2008) estimated that each 100 kg of treated organic waste could yield 30 kg of fertile soil. As regards the rest fraction, it is estimated that around 35% of this could be recycled. This would increase the recycling rates and reduce the flow of mixed waste sent to landfills. In terms of this, the Canaries are currently a long way from the reference values of the SINWP (2008–2015), which propose that a maximum of 15% of the generated MSW should go to landfills. Seng et al., 2013 studied the adoption and integration of organics waste treatment technologies such as recycling, biogas and composting and furthermore effective separation at the origin helps to achieve economic and environmental benefits. Blanch (2010) analysed the application of the biotechnology in order to improve the environmental management.

It is necessary to change the current treatment model by prioritising the separation of waste at the origin, but an efficient waste treatment strategy should be cost-effective and minimise potential impacts on various stakeholders and the environment (Soltani et al., 2015).

These results are consistent with the information obtained from the MSW management experts interviewed for this study, as well as with the data extracted from the EU Directive; SINWP and State Plan Waste Management Framework of Spain (2016–2022).

6. Policy implications

The study area is strongly influenced by the tourist industry, and variations in the MSW generation are caused by the pronounced seasonality of demand in the tourist industry, which has increased in recent years due to tourist preferences and other externalities such as the current situation of terrorism in competitive tourist areas like Tunisia, Turkey and Egypt. This has provoked a greater entry of tourists per year to the Canary archipelago, which serves as a basis for adjusting existing waste management plans in terms of collection facilities and methods. This leads to increases in the MSW generation in the archipelago as simulated in Sc4 (see Fig. 6a).

The increased MSW generation causes an accelerated filling of the landfills of the archipelago. According to the results of the model (see Fig. 7) the saturation point of the landfills would appear by the end of 2018, which makes it necessary to take urgent measures. It will contribute to mitigate global warming because the methane emissions, a greenhouse gas with a potential global-warming 25 times greater than CO_2 gas, will be reduced (Hoornweg and Bhaza-Tata, 2012).

The levels of selective MSW collection are very low (Fig. 5a, BAU Sc1), in particular due to the insufficient collection of the organic fraction (Fig. 5b). The high dependence on landfills will force the Canary government to activate a biomethanisation facility, which, due to social rejection, has not yet come into operation.

The tourist industry is the main revenue activity for the archipelago and also one of the major influences on the generation of MSW (as shown in Sc4). In the Canary Islands, tourism represents approximately 31.4% of the GDP and 33.15% of the employment.

The current waste management system in the Canary Islands should comply with the European Directive, which until now due to the economic crisis could not be applied, even though the archipelago that has been declared by UNESCO in 2001 as a world biosphere book must be much more sustainable than the current one.

7. Conclusions

A more sustainable MSW management requires the selection of the best combination of MSW treatment methods to apply in a given territory and it should also be based on the interests and wishes of the main local stakeholders. Our study show recycling is the most suitable method based on the application of the Fuzzy Topsis method on the criteria established by the stakeholder of the Canary territory.

With regard the recycling benefits from environmental and social criteria with respect to other alternatives are taken as the most advisable option the method of recycling has been identified as the most appropriate method. Landfilling is not favoured in terms of its impact on the environment but it is favoured from the point of view of economic criteria, so it is selected as a second option. Although the European Union wants the discharges to be completely eliminated by 2030, the fact is that given the current ecological situation of the Canary Islands this process will be very slow. From the point of view of MSW managers (public or private), the construction of a landfill could be considered to be an investment. It has to be taken into account that landfilling is an alternative to MSW elimination and allows us to save the costs of other more expensive treatment methods. Furthermore, the biotechnological means are very limited. Thus, landfilling is the cheapest option available albeit with more critical consequences for the environment.

This leaves incineration and biomethanisation, which are beneficial from a political perspective but are not favoured from a social perspective, which means that they cannot currently be an alternative treatment for the Canary Islands.

The combination of TOPSIS with fuzzy set theory and SD is an effective tool for providing a more realistic solution for the decision-making process. However, weaknesses in waste management have been found:

1. It is clear that without changes in the MSW management, it will be difficult for the Canary Islands to fulfil the objectives of minimisation and prevention, especially in terms of what the European Union currently requires (European Union (2008), Directive 2008/98/EC, article 11).
2. Incorporating the selective collection of the organic fraction (which is approximately 40% of the total volume of the produced MSW) delays the saturation of landfills.
3. It is estimated that 62% of the total MSW are erroneously deposited in grey containers (mixed waste), although a percentage of them could be recycled.
4. Factors such as seasonality and tourism-provoked increases in human pressure at certain times of the year (Sc4, Fig. 6a) increase the waste generation ratio while causing landfill saturation and MSW exportation. This requires a resizing of the infrastructure and facilities of MSW management.
5. The BAU Sc for the Canary Islands MSW development until 2030 show a situation becoming more difficult to control each year because of demographic and economic increases, in combination with an absence of optimal processes of MSW separation, recycling and valuation.
6. In this case, it would be convenient to use a combination of different treatment methods in order to reduce the saturation of the landfills of these islands.

The incorporation and combination of biotechnological methods are essential to improve the current MSW management. The implementation of pilot schemes to promote new models of waste collection and treatment are essential.

7.1. Limitations and future studies

1. In the official statistical data, the resident population and the tourist population are taken jointly to account for the total generation of MSW. They should, however, be considered separately because this is necessary to adequately size waste management facilities.
2. The number of experts surveyed was small because the Canary archipelago has very few experts in this field.
3. It is recommended that predictions of the proposed model under the hypotheses that have been constructed be verified. Once the input data is obtained after another five years, new outputs may help an even better correct decision-making.

As future lines of research, the following issues can be recommended:

(a) To carry out a pilot study incorporating the hotel establishments in order to estimate the quantity of MSW actually generated by the tourists.
(b) To make a technical and feasibility study to start up the biomethanisation plant, and with that to try to reduce the dependence of landfills.
(c) To develop comparative studies of the MSW management amount Canary archipelago and other tourist islands.

Abbreviations list

MSW	Municipal solid waste
SD	System dynamics
SA	Scenario analysis
S	Subcriteria
C	Criteria
BAU Sc	Business as usual scenario
Sc	Scenario
ETP	Equivalent Tourism Population
Inh	Inhabitants
IWM	Integrated waste management strategies
LCA	Life cycle analysis
M/inhabitants	Millions inhabitants
t	tonnes
M	Millions
MT	Millions tonnes
kt	Thousand tons
STPH 2020	Spanish Tourism Plan Horizon 2020
WTO	World Tourism Organization

Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.jclepro.2017.10.324.

References

Abarca, L., Maas, G., Hogland, W., 2013. Solid waste management challenges for cities in developing countries. Waste Manag. 33, 220–232. https://doi.org/10.1016/j.wasman.2012.09.008.
Adamides, E., Giannikos, I., Mitropolous, P., 2009. A multi-methodological approach to the development of a regional solid waste management system. J. Oper. Res. Soc. 60, 758–770.
Afroz, R., Tudin, R., Hanaki, K., Masud, M., 2011. Selected socio-economic factors affecting the willingness to minimize solid waste in Dhaka city, Bangladesh. J. Environ. Plan. Manag. 54 (6), 711–731.
Aghajani, M., Taheri, P., Sulaiman, N.M.S., Basri, N.E.A., Sahari, S., Mahmood, N.Z., Jahan, A., Begum, R.A., Aghamohammadi, N., 2016. Application of TOPSIS and VIKOR improved versions in a multi-criteria decision analysis to development an optimized municipal solid waste management model. J. Environ. Manag. 166, 109–115.
Ahmad, K., 2012. A system dynamics modelling of municipal solid waste management system in Delhi. Int. J. Res. Eng. Technol. 1, 628–635.
Al–Salem, S.M., Lettieri, P., 2009. Life cycle assessment (LCA) of municipal solid waste management in the state of Kuwait. Eur. J. Sci. Res. 34, 395–405.
Ali, M., Falahnezhad, M., Behboudian, S., 2011. Multivariate econometric approach for solid waste generation modeling: a case study of Mashhad, Iran. Environ. Eng. Sci. 1–7. https://doi.org/10.1089/ees.2010.0234.

Andraca, C., Sampedro, M.L., 2010. Environmental education program in order to emphasize the attitude towards the handling of urban solid waste of adolescents from high school (in Spanish). Rev. Iberoam. Educ. 56 (3).
Arıkan, E., Tuğçe Şimşit-Kalender, Z., Vayvay, Ö., 2017. Solid waste disposal methodology selection using multi-criteria decision-making methods and an application in Turkey. J. Clean. Prod. 142, 403–412. https://doi.org/10.1016/j.jclepro.2015.10.054.
Beigl, P., Lebersorger, S., Salhofer, S., 2008. Modelling municipal solid waste generation: a review. Waste Manag. 28 (1), 200–214.
Behzadian, M., Khanmohammadi, S., Yazdani, M., Ignatius, J., 2012. A state of the art survey of TOPSIS applications. Expert Syst. Appl. 39 (17), 13051–13069.
Beskese, A., Demir, H., Ozcan, K., Okten, E., 2015. Landfill site selection using fuzzy AHP and fuzzy TOPSIS: a case study for Istanbul. Environ. Earth Sci. 73 (7), 3513–3521. Springer.
Blanch, A., 2010. Environmental Biotechnological Application in Orden to Improve the Environment (In Spanish). Nota d'economia 97-98. 3° quarter. University of Barcelona.
Chen, M., Giannis, A., Wang, J.-Y., 2012. Application of System Dynamics model for municipal solid waste generation and landfill capacity evaluation in Singapore. The Macrotheme Review. A multidisciplinary journal of global macro trends. October 1 (1), 101–114.
Chia-Chien, H., Sandford, B., 2007. The Delphi technique: making sense of consensus. Pract. Assess. Res. Eval. Electron. J. 12, 10.
Dai, J., Qi, J., Chi, J., Chen, S., Yang, J., Ju, L., 2010. Integrated water resources security evaluation of Beijing based on GRA (Gray Relation Analysis) and TOPSIS. Front. Earth Sci. China 4, 357–362.
Dalkey, N., Helmer, Olaf, 1963. An experimental application of the Delphi method to the use of experts. Manag. Sci. 9 (3), 458–467. https://doi.org/10.1287/mnsc.9.3.458.
Dangi, M.B., Pretz, Urynowicz, C.R., Gerow, M.A., KG, Reddy, J.M., 2011. Municipal solid waste generation in Kathmandu, Nepal. J. Environ. Manag. 92 (1), 240–249.
De Feo, G., De Gizi, S., 2010. Public opinion and awareness towards MSW and separate collection programmer: a sociological procedure for selecting areas and citizens with a low level of knowledge. Waste Manag. 30 (6), 958–976.
De Oliveira, S., Löbler, M., 2012. Simulation based on system dynamics to evaluate scenarios about the generation and disposal of municipal solid waste. Afr. J. Bus. Manag. 6 (50), 11976–11985. https://doi.org/10.5897//AJBM12.794.
den Boer, E., Lager, J., 2007. LCA-IWM: a decision support tool for sustainability assessment of waste management systems. J. Waste Manag. 27 (8), 1032–1045.
Dyson, B., Chang, Ni-Bin, 2005. Forecasting municipal solid waste generation in a fast-growing urban region with system dynamics modelling. Waste Manag. 25, 669–679.
Ekmekcioglu, M., Kaya, T., Kahraman, C., 2010. Fuzzy multicriteria disposal method and site selection for municipal solid waste. Waste Manag. 30 (8–9), 1729–1736.
Estay, C., Harsch, N., 2015. Environmental biotechnology; potential for the MSW management in the canary islands, Spain. Waste Manag. Law, chapter V 165–192. UBIJUS, México (In Spanish).
European Union, 2008. Directive 2008/98/EC of the european parliament and of the council on waste and repealing certain directives of 19 November 2008. Off. J. Eur. Union, L 312 (3), 3–30.
EUROSTAT, 2015. http://ec.europa.eu/eurostat/guip/themeAction.do (accessed 16.05.16).
Freire, J., Aribau, R., Puig Ventosa, I., 2008. Study of Composting in the Case of Catalunya: Municipality of Tiana. Waste Agency of Catalonia, Spain. In Spanish.
García-Falcón, J.M., Medina-Muñoz, Diego, 1999. Sustainable tourism development in islands: a case study Gran Canaria. Bus. Strat. Environ. 8, 336–357.
García, M., Suárez, M., 2013. Delphi method for the expert consultation in the scientific research. Rev. Cuba. Salud Pública 39 (2), 253–267.
Gonzalez-Martínez, T., Bräutigan, K.-R., Seifert, H., 2012. The potential of a sustainable municipal waste management system for Santiago de Chile, including energy production from waste. Energy, Sustain. Soc. 2 (24), 1–14.
Ghinea, C., Niculina-Drăgoi, E., Comăniţă, E.D., Gavrilescu, Marius, Gavrilescu, Maria, 2016. Forecasting municipal solid waste generation using prognostic tools and regression analysis. J. Environ. Manag. 182, 80–93.
Gumus, A.T., 2009. Evaluation of hazardous waste transportation firms by using a two-step fuzzy-AHP and TOPSIS methodology. Expert Syst. Appl. 36 (2), 4067–4074. Part 2.
Guo, H.C., Liu, L., Huang, G.H., Fuller, G.A., Zou, R., Yin, Y.Y., 2001. A system dynamics approach for regional environmental planning and management: a study for the Lake Erhai Basin. J. Environ. Manag. 61, 93–111.
Harvey, A., Trimbur, T., 2008. Trend estimation and the Hodrick and Prescott filter. J. Jpn. Stat. Soc. 38 (1), 41–49. https://doi.org/10.14490/jjss.38.41.
Hodrick, R., Prescott, E., 1997. Postwar U.S. business cycles: an empirical investigation. J. Money, Credit. Bank. 1, 1–16, 1997; 29, February.
Hoornweg, D., Bhada-Tata, P., 2012. What a Waste. A Global Review of Solid Waste Management. The World Bank. N° 15.
Hung, H.L., Altschuld, J.W., Lee, Y., 2008. Methodological and conceptual issues confronting a cross- country Delphi study of educational program evaluation. J. Eval. Program Plan. 31, 191–198.
Hyndman, Rob J., Koehler, Anne B., 2006. Another look at measures of forecast accuracy. Int. J. Forecast. 22 (4), 679–688.
Inghels, D., Dullaert, W., 2010. An analysis of household waste management policy using system dynamics modelling. Waste Manag. Res. 29 (4), 351–370.
ISTAC (Canary Statistics Institute), 2015. Data on Waste available from. http://www2.gobiernodecanarias.org/istac/jaxi-web/tabla.do [accessed 15.01.15].
Kalakula, S., Malakulb, P., Siemanondb, K., Gania, R., 2014. Integration of life cycle assessment software with tools for economic and sustainability analyses and process simulation for sustainable process design. J. Clean. Prod. 17, 98–109.
Karavezysis, V., Timpe, K.P., Marzi, R., 2002. Application of system dynamics and fuzzy logic to forecasting of municipal solid waste. Math. Comput. Simul. 207, 1–10.
Kim, J., Hwang, Y., Park, K., 2009. An assessment of the recycling potential of materials based on environmental and economic factors; case study in South Korea. J. Clean. Prod. 17 (14), 1264–1271. https://doi.org/10.1016/j.jclepro.2009.03.023.
Kollikkathara, N., Huang, F., Darling, Y., 2010. A system dynamic modeling approach for evaluating municipal solid waste generation, landfill capacity and related cost management issues. Waste Manag. 30, 2194–2203.
Lavee, D., 2010. A cost-benefit analysis of a deposit-refund program for beverage container in Israel. Waste Manag. 30 (2), 338–345.
Lima-Junior, R.F., Osiro, L., Ribeiro, L.C., 2014. A comparison between Fuzzy AHP and Fuzzy TOPSIS methods to supplier selection. Appl. Soft Comput. 21, 194–209. https://doi.org/10.1016/j.asoc.2014.03.014.
Márquez, M.Y., Ojeda, S., Hidalgo, H., 2008. Identification of behaviour patterns in household solid waste generation in Mexicali's City: study Case. Resources. Conserv. Recycl. 52 (11), 1299–1306.
Manga, V., Tening, O., Mofor, L., Woodard, R., 2011. Health care waste management in Cameroon: a case study from the Southwestern Region. Resour. Conserv. Recycl. 57, 108–116.
Marzouk, M., Azab, S., 2013. Environmental and economic impact assessment of construction and demolition waste disposal using system dynamics. Resour. Conserv. Recycl. 82, 41–49.
Mazzanti, M., Zoboli, R., 2008. Waste generation, waste disposal and policy effectiveness: evidence on decoupling from the European Union. Resour. Conserv. Recycl. 52 (10), 1221–1234.
Milutinovic, B., Stefanovic, G., Dassisti, M., Markovic, D., 2014. Multicriteria analysis as a tool for sustainability assessment of a waste management model. Energy 74, 190–201. https://doi.org/10.1016/j.energy.2014.05.056.
Nair, S.K., Jayakumar, C., 2008. A Handbook for Waste Management in Rural Tourism Areas: a Zero Waste Approach. Archana: UNDP India.
Nadzirah, S., Zainon, Z., Halilu, A., Yusuf, R., Abu-Hassan, M., 2012. Review on life cycle assessment of integrated solid waste management in some Asian countries. J. Clean. Prod. 41, 251–262. https://doi.org/10.1016/j.jclepro.2012.09.043.
Nesli, C., John, R.B., 2012. A system dynamics approach for healthcare waste management: a case study in Istanbul Metropolitan City, Turkey. Waste Manag. Res. 30, 576.
Niza, S., Santos, E., Costa, I., Ribeiro, P., Ferrão, P., 2014. Extended producer responsibility policy in Portugal: a strategy towards improving waste management performance. J. Clean. Prod. 64, 227–287.
Ojeda-Benıtez, S., Lozano-Olvera, G., Adalberto Morelos, R., Armijo de Vega, C., 2008. Mathematical modeling to predict residential solid waste generation. Waste Manag. V 28 (Suppl. 1), S7–S13.
Onut, S., Soner, S., 2008. Transshipmet site selection using the AHP and fuzzy TOPSIS approaches under fuzzy environment. Waste Manag. 28, 1552–1559.
Pai, R., Rodriguez-Lewlyn, L.R., Oommen-Mathew, A., Hebbar, S., 2014. Impact of urbanization on municipal solid waste management: a system dynamics approach. Int. J. Renew. Energy Environ. Eng. 2 (1), 31–37.
PUNE, Resources and Livelihoods Group, PRAYAS, 2009. Assessing the Feasibility of Zero-waste Management Using System Dynamics Modeling and Fuzzy Logic. The Urban India Reforms Facility. Tata Institute of Social Science, pp. 1–20.
Rao, P.V., Baral, S.S., 2011. Attribute based specification, comparison and selection of feed stock for anaerobic digestion using MADM approach. J. Hazard. Mater. 186, 2009–2016.
Robalino-López, A., Mena-Nieto, A., García-Ramos, J.E., Golpe, A.A., 2015. Studying the relationship between economic growth, CO2, emissions and the environmental Kuznets curve in Venezuela (1980-2025). Renew. Sustain. Energy Rev. 41, 602–614.
Salmeron, J.L., Vidal, R., Mena-Nieto, A., 2012. Ranking Fuzzy cognitive map based scenarios with TOPSIS. Expert Syst. Appl. 39, 2443–2450.
Santamarta, J., Rodríguez-Martín, J., Arraiza, M., López, J.V., 2014. Waste problem and management in insular and isolated systems. Case study in the canary islands (Spain). Sci. Direct IERI Procedia 9, 162–167. https://doi.org/10.1016/j.ieri.2014.09.057.
Seng, B., Hirayama, K., Katayama-Hirayama, K., Ochiai, S., Kaneko, H., 2013. Scenario analysis of the benefit of municipal organic-waste composting over landfill, Cambodia. J. Environ. Manag. 114, 216–224.
SINWP-Spanish Integrated National Waste Plan, 2008–2015 and State Plan Waste Management Framework of Spain (2016-2022). Ministry of Environmental, Rural and Marine issues.
Soltani, A., Sadiq, R., Hewage, K., 2015. Selecting sustainable waste-to-energy technologies for municipal solid waste treatment: a game theory approach for group decision-making. J. Clean. Prod. 113, 388–399. https://doi.org/10.1016/j.jclepro.2015.12.041.
Song, Q., Li, J., Zeng, X., 2015. Minimizing the increasing solid waste through zero waste strategy. J. Clean. Prod. 104, 199–210. https://doi.org/10.1016/j.jclepro.2014.08.027.
Spanish Tourism Plan Horizon 2020, 2015. http://www.tourspain.es/eses/VDE/Documentos%20Vision%20Destino%20Espaa/Plan_Turismo_Espa%C3%B1ol_

Horizonte_2020.pdf.
Sufian, M.A., Bala, B.K., 2007. Modelling of urban solid waste management system: the case of Dhaka city. Waste Manag. 27, 858–868.
Su, J.P., Chiueh, P.T., Hung, M.L., Ma, H.W., 2007. Analyzing policy impact potential for municipal solid waste management decision-making: a case study of Taiwan. Resources. Conserv. Recycl. 51, 418–434.
Tan, S.T., Lee, C.T., Hashim, H., Ho, W.S., Lim, J.S., 2014. Optimal process network for municipal solid waste management in Iskandar Malaysia. J. Clean. Prod. 71, 48–58. https://doi.org/10.1016/j.jclepro.2013.12.005.
Tascione, V., Mosca, R., Raggi, A., 2016. Optimizing the environmental performance of integrated waste management scenarios by means of linear programming: a Case Study Abruzzo Region, Italy. J. Clean. Prod. 112, 3086–3096. https://doi.org/10.1016/j.jclepro.2015.10.016.
Torkamani, F., Fallah, S., Saadatmand, M., 2012. How urban management can use DSS to facilitate decision-making process: an application of fuzzy TOPSIS. J. Am. Sci. 8 (5), 162–173.
Triguero, A., Alvarez-Aledo, C., Cuerva, M.C., 2016. Factors influencing willingness to accept different waste management policies: empirical evidence from the European Union. J. Clean. Prod. 138, 38–46. https://doi.org/10.1016/j.jclepro.2016.05.119.
Villavicencio, G., Didonet, S., Gutiérrez, I., 2014. Sustainability in efficient management of urban waste: the case of Spanish cities. Rev. Bras. Gestao Desenvolv. Reg. 10 (2), 124–152.
Victor, P., Agamuthu, P., 2013. Strategic environmental assessment policy integration model for the solid waste management in Malaysia. Environ. Sci. Policy 33, 233–245.
Vinodh, S., Prasanna, M., Prakash, N.H., 2014. Integrated Fuzzy AHP-TOPSIS for selecting the best plastic recycling method: a case study. Appl. Math. Model. 38 (19–20), 4662–4672.
Vučijak, B., Midžić Kurtagić, S., Silajdžić, I., 2015. Multi-criteria decision making in selecting best solid waste management scenario: a municipal case study from Bosnia and Herzegovina. J. Clean. Prod. 130 (1), 166–174. https://doi.org/10.1016/j.jclepro.2015.11.030.
Weng, Y.C., Fujiwara, T., Matsuoka, Y., 2011. Econometric modeling of the consumer behavior and its influence on MSW discards: a Taiwan case study. J. Environ. Sci. Sustain. Soc. 4, 1–12.
World Tourism Organization-WTO , 2015. Panorama OMT 2015. www.e-unwto.org/doi/pdf/10.18111/9789284416875 (accessed April 2016). In Spanish.
Yan, H., Hua, W., GuiHong, B., 2007. System Dynamics simulation of domestic waste management system in Kunming City, China. Environ. Sanit. Eng. 15 (3), 20–24.
Yong, D., 2006. Plant location selection based on fuzzy TOPSIS. Int. J. Adv. Manuf. Technol. 28 (7), 839–844.
Zorpas, A., Voukkali, I., Loizia, P., 2014. The impact of touristic sector in the waste management plans. J. Desalination water Treat. https://doi.org/10.1080/19443994.2014.934721. In 4th International Conference on Environmental management, Engineering, Planning and Economics (CEMEPE), 24-28 June 2013, Mykonos, Greece.