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Prioritization of Waste-to-Energy Technologies Associated with the Utilization of Food Waste

Patricia Torres-Lozada [1,*], Pablo Manyoma-Velásquez [2] and Jenny Fabiana Gaviria-Cuevas [2,*]

1 Study and Control of Environmental Pollution—ECCA Research Group, Faculty of Engineering, Universidad del Valle, Cali 760001, Colombia
2 Logistic and Production (LOGYPRO) Research Group, Faculty of Engineering, Universidad del Valle, Cali 760001, Colombia
* Correspondence: patricia.torres@correounivalle.edu.co (P.T.-L.); jenny.gaviria@correounivalle.edu.co (J.F.G.-C.)

Abstract: Taking advantage of the growing production of organic waste for its conversion to waste-to-energy (WtE) also contributes to mitigating the problems associated with its final disposal, which is a global trend of increasing application. This work presents an innovative approach for the identification and prioritization of WtE alternatives available from the use of food waste (FW) present in the municipal solid waste (MSW) of a Colombian municipality with source separation and selective collection: (i) a systematic literature review, which allows one to identify WtE alternatives; (ii) the prospective MIC-MAC method (Matrice d'Impacts Croisés Multiplication Appliqués à un Classement) allowed the selection of criteria and sub criteria; (iii) the analytical hierarchical process (AHP) and the technique of order of preference by similarity to the ideal solution (TOPSIS), allowed a ranking of selected alternatives considering the technical, environmental, and social aspects. The WtE technologies identified were anaerobic digestion, gasification, incineration, biogas recovery from landfills, and pyrolysis; this last was excluded due to its greater application potential with substrates such as plastic waste. The six sub-criteria identified and prioritized were social acceptability (36%), greenhouse gas emissions mitigated (16.17%), MSW reduction (15.83%), energy production (13.80%), technological maturity (12.95%), and electrical energy conversion efficiency (5.25%), with the decreasing order of preferences of anaerobic digestion (78.2%), gasification (47.5%), incineration (27.4%), and biogas recovery from landfills (6.6%); the latter was the least desirable alternative (lower social acceptance and CO_2 tons mitigated in relation to the other options). The innovative nature of this study is the identification and consideration of the comprehensive management of this type of waste of a large number of criteria (120 environmental, 52 social, and 59 technical) and the validation of the results through a sensitivity analysis, which allowed us to confirm for this study, that anaerobic digestion is the most favorable technology for the treatment and energy use of FW.

Keywords: analytic hierarchy process; decision-making; energy from waste; food waste; organic fraction of municipal solid waste; renewable energy sources

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1. Introduction

The amount of municipal solid waste (MSW) is estimated to increase by approximately 70% in the next 30 years, with biowaste (BW) and food waste (FW) the predominant components, which is to the order of 40–50% and 60–70% in developed and developing countries, respectively [1].

The implementation of modern and efficient solutions such as waste-to-energy (WtE) technologies are important for sustainable development, to minimize environmental impacts, and to produce renewable energy [2]. According to Ludlow et al. [3], achieving net zero greenhouse gas (GHG) emissions by 2050 requires a radical change in resource management, and the use of organic waste is still an underexplored opportunity in Latin America.

The three main types of WtE technologies that are widely used for sustainable waste management and simultaneous energy production are thermal conversions, biological conversions, and energy recovery in landfills. Among the thermal conversion techniques, incineration is the most significant and widely used route for waste treatment; gasification is an emerging technology that is being developed; pyrolysis is still in the research phase and is not used on a commercial pilot scale for the conversion of MSW into energy [4]. Among the biological conversion techniques, anaerobic digestion (AD), also known as biomethanization, is commonly used to treat substrates with high percentages of biodegradable organic matter and high moisture contents [2,5,6]; in contrast, energy recovery techniques in landfills are the least desirable of the practices due to various aspects such as unpleasant odors, GHGs, leachates, and health problems [7].

The main findings show that the WtE technologies that have been developed and implemented in the countries of Latin America and the Caribbean (LAC) generate multiple benefits such as economic growth and human well-being in general, in addition to the mitigation of the effects of climate change in the long-term [8].

There are two important premises for the correct application of the usable and recoverable materials present in MSW: the separation at the source and selective collection, which allow for the obtaining of high-quality recovered materials; this process translates into an improvement in the economic value, the improvement in the working conditions of the recyclers, and the optimization of the different options for using any type of waste [9]. The process is in line with the circular economy approach, which involves analyzing trends in supply chains and waste generation processes so that they are not taken directly to final disposal, but rather undergo different key stages that favor energy recovery, biological recovery, or material recovery [10].

The multidimensional nature of waste management makes the selection of an appropriate energy conversion option a complex problem [11]. The challenging goal of providing sustainability through a balance between society, economy, and ecology requires an integrated approach; therefore, to evaluate the multiple effects of waste management systems, it is necessary to consider all the processes involved [12]. The method must be goal oriented and provide an overview of the advantages and disadvantages of the different options; additionally, it must be objective, transparent, and understandable [13].

These phenomena are the reason why multicriteria analysis and decision tools provide a methodological structure that makes it easier for a group of decision makers to contribute their point of view when faced with a selection among several technological alternatives [14,15]. These tools, combined with others for promoting collective reflection such as those used to evaluate technological prospects (microglia and immune cells morphologies analyzer and classifier (MIC-MAC) type), help to identify influential and dependent variables, finding those that are essential for the development of any system. According to various studies such as those of Gavareshki et al. [16] and Barati et al. [17], combinations of prospective tools such as MIC-MAC and multiple-criteria decision analysis (MCDA) methods for problem solving are evidenced.

Longsheng et al. [18] carried out a strengths, weaknesses, opportunities, and threats (SWOT) analysis that identified the most relevant factors for the implementation of the sustainable conversion of waste into energy using strategic tools such as MCDA methods and incorporating fuzzy set theory and gray systems to improve the efficiency of a proposed model that prioritizes the defined strategies. Liang et al. [19] also used MCDA methods such as an analytic hierarchy process (AHP) to support decision-making regarding energy recovery from waste. Benato and Macor [20] and Nizami et al. [21] used optimization techniques for the control of biogas generation and biomass treatment; others such as Sadr et al. [22] and Wallerand et al. [23] used heuristic management and fuzzy theory to analyze environmental decisions.

The use of hybrid multicriteria methods allows for the selection of appropriate waste-to-energy technologies for distributed generation. Akanni et al. [11] studied this aspect based on the use of integrated determination of objective criteria weights (IDOCRIW) and technique for order preference by similarity to ideal solution (TOPSIS); the researchers found that in general, AD is the most attractive WtE technology with a great relative proximity to the ideal solution.

The formulation and evaluation of the sustainability levels of WtE technologies utilizing organic waste that are efficient, socially, and environmentally viable and economically feasible are of great importance for LAC countries; these studies are mainly beneficial for municipalities with populations of less than 15,000 inhabitants (80% of the population) that have economic capacities of low- to medium-level incomes and that generally have low access to basic services such as energy, especially in rural areas [9,24].

In accordance with the above, the present study involved evaluations of applying tools such as a systematic literature review, and the MIC-MAC prospective method and multicriteria analyses (AHP and TOPSIS), considering environmental, social, and technical aspects for the prioritization of technological alternatives applicable to the use of FW from a Colombian municipality in which, according to [25], separation at the source and the selective collection of MSW were carried out. Additionally, a sensitivity analysis was performed to validate the results and confirm the order of priorities of the WtE strategies considered in the study.

2. Methodology

Figure 1 shows the methodological steps followed in this study.

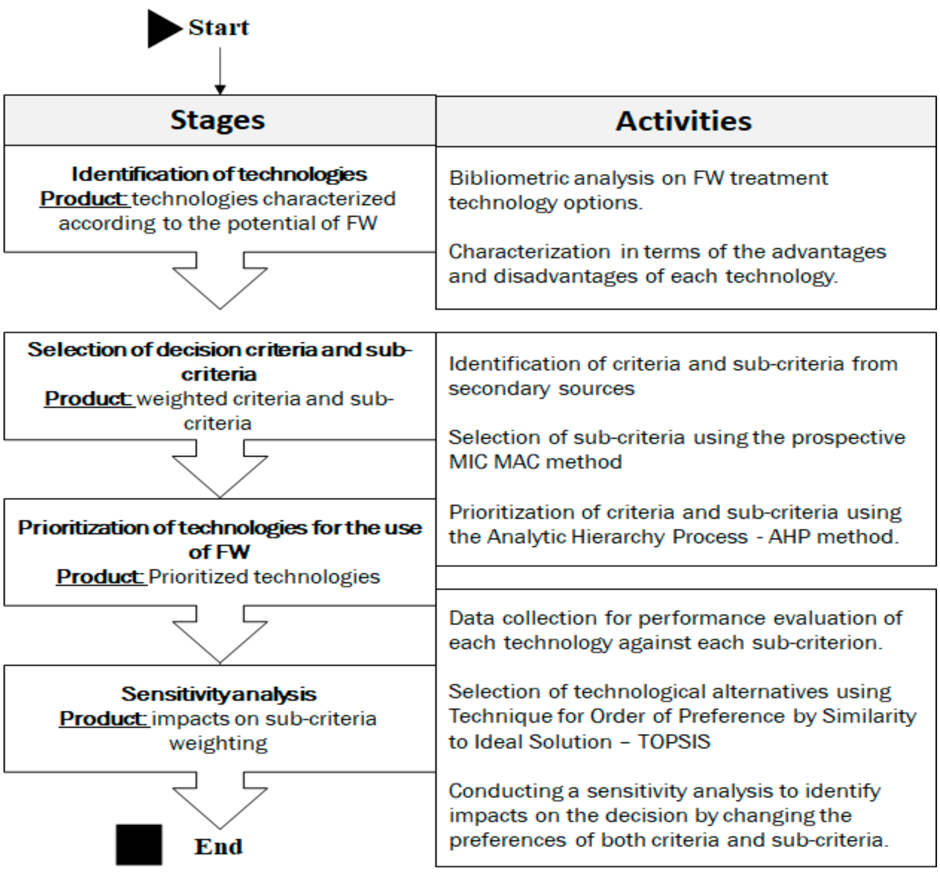


Figure 1. Methodological route of the study.

2.1. *Identification of WtE Technological Options for FW Utilization*

Through a systematic literature review, the WtE technologies applied to FW utilization were identified, characterizing the advantages and limitations of the implementation of each. For this purpose, search equations were created based on keywords such as "waste-to-energy AND technology selection AND food waste". Additionally, the criteria and subcriteria (environmental, social and technical) associated with the decision problem were identified considering the studies in which MCA methods were applied related to the selection of energy recovery technologies from organic waste.

2.2. Selection and Weighting of Decision Criteria and Subcriteria

The different subcriteria were preselected according to the similarity of concept, reaching a smaller number. Through the application of the prospective tool MIC-MAC, the criteria and subcriteria were filtered to obtain the key elements in the decision, considering the concept of a first panel of academic, industry, and state experts related to the development and use of WtE technologies in the environmental and energy fields (20 in total); these technologies classified these elements in terms of their influences on each other through an electronic sheet matrix.

Each of the respondents rated whether the subcriterion of Row "*I*" had a direct influence on the subcriteria of Column "*j*", according to a scale proposed by the method; thus, zero (0) represents the absence of influence, one (1) represents a slight influence, two (2) moderate, and three (3) represents a strong influence. Finally, the potential influence was evaluated through the notation P, indicating that there could be influences between subcriteria; however, the magnitude of the influence was not clear.

Once the matrix that unified all the qualifications of the experts consulted was formed, each row was totaled to find the influence levels of each subcriteria, and each column was totaled to find the magnitude of the dependence of each subcriteria. The values were in a Cartesian plane [26]; the subcriteria acted as variables and were classified into six types (Figure 2).

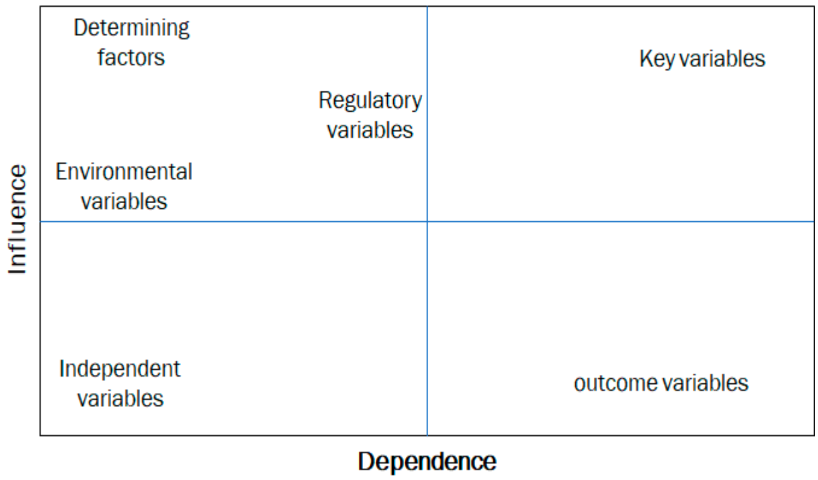


Figure 2. Influence vs. dependence matrix based on MIC-MAC. Source: Adapted from [26].

The determining variables had little dependence with respect to the others in the analyzed system, depending on their nature and their interactions with the variables involved in the decision; likewise, they acted as brakes or motors in the system. Environmental variables were secondary to the system and did not add significant importance. Regulatory variables were considered subcriteria that must be addressed to achieve the objectives of the key variables.

Autonomous variables were not very influential, and they were dependent on the system of analysis; thus, they did not have significant importance in the system given their independence. The outcome variables became independent indicators; for treatment, they must be addressed through the dependent variables of the system, and the key variables became the unknown values of the system. For this case of analysis, the variables corresponded to the subcriteria that were the objective of the analysis and were decisive in the evaluation of analysis system.

2.3. Prioritization of Technologies for FW Utilization

After categorization by MIC-MAC, the definitive subcriteria that needed to be weighed were obtained through the application of the AHP method. In this process, validation and weighting involved the support of the panel of experts consulted, who carried out this qualification through a predefined questionnaire to obtain the criteria and subcriteria. Subsequently, a matrix was created in which the WtE technologies (rows) were crossed against each subcriteria, recording the performance data of the technologies against the requirements of each subcriteria.

For some subcriteria, more than three data were found from the literature for the technologies evaluated, which led to taking the most likely data (the positive and negative ideal solution) to unify an assessment according to Equation (1), which corresponded to an estimation involving three values, also known as program evaluation and review technique (PERT) [27].

$$\mu = \frac{a + 4m + b}{6} \quad (1)$$

The total vector of weights is hereafter referred to as the result vector or priority of the criteria and subcriteria; it constituted one of the inputs for the application of the TOPSIS multicriteria method once the input information for each technology was specified against each subcriterion and was then evaluated by PERT [27]. Subsequently, the multicriteria analysis tool TOPSIS [28] (Table 1) was applied.

Table 1. Original matrix for TOPSIS.

	w_1	w_2	……	w_n
	C_1	C_2	……	C_n
A_1	x_{11}	x_{12}	……	x_{1n}
A_2	x_{21}			
……	……	……	……	……
A_n	x_{m1}	x_{m2}	……	x_{mn}

Source: [28].

Through Equations (2) and (3), the normalized data n_{ij} were obtained because in the original matrix, the values obtained were not of equal magnitude and varied in their units; these were multiplied by the weighted vector of the subcriteria w_j to obtain the weighted normalized data (Table 2).

$$n_{ij} \frac{x_{ij}}{\sqrt{\sum_{j=1}^{m} (x_{ij})^2}} \quad (2)$$

$$v_{ij} = w_j \times n_{ij} \quad (3)$$

$$i = 1, 2, \ldots, m; j = 1, 2, \ldots, n;$$

Table 2. Weighted normalized matrix.

	w_1	w_2	……	w_n
	C_1	C_2	……	C_n
A_1	v_{11}	v_{12}	……	v_{1n}
A_2	v_{21}			
……	……	……	……	……
A_n	v_{m1}	v_{m2}	……	v_{mn}

Source: [28].

The ideal positive and negative solutions were determined with Equations (4) and (5), respectively.

$$A^{+} = \{v_1^{+}, \ldots v_n^{+}\} = \{(max_i v_{ij}, j \in J)(min_i v_{ij}, j \in J')\} \quad (4)$$

J is associated with the benefit criteria and J' is associated with the cost criteria

$$A^{-} = \{v_1^{-}, \ldots v_n^{-}\} = \{(min_i v_{ij}, j \in J)(max_i v_{ij}, j \in J')\} \quad (5)$$

Equations (6) and (7) were used to calculate how far each alternative was in each criterion from the positive and negative ideal solution, respectively.

$$d_i^{+} = \left\{\sum_{j=1}^{n}\left(v_{ij} - v_j^{+}\right)^2\right\}^{\frac{1}{2}} \quad (6)$$

$$d_i^{-} = \left\{\sum_{j=1}^{n}\left(v_{ij} - v_j^{-}\right)\right\}^{\frac{1}{2}} \quad (7)$$

To finish the application of TOPSIS, the relative proximity R_i to the ideal solution was calculated to find the order of the preferences (Equation (8)); thus, the closer to 1 the value of R_i was, the higher the priority of alternative A_i.

$$R_i = \frac{d_i}{d_i^{+} + d_i^{-}}, i = 1, \ldots m \quad (8)$$

$$SiR_i = 1 \rightarrow A_i = A^{+}; SiR_i = 0 \rightarrow A_i = A^{-}$$

Thus, the procedure for the prioritization of WtE alternatives was completed, selecting the alternative closest to the positive ideal solution and obtaining a ranking of alternatives that indicated the most appropriate technology for the management of FW in the evaluated context.

2.4. Sensitivity Analysis

The importance of sensitivity analysis lies in the fact that it avoids problems of bias and lack of objectivity in the decision. For this study, we considered various methodologies such as those applied by Fernández-González et al. [29] and Qazi et al. [30], which consisted of two stages: (*i*) to create three scenarios to record the variation in the weightings of the criteria and their effects on the weights resulting from the subcriteria and (*ii*) to determine three other possible scenarios while varying the weightings of the subcriteria, visualizing these changes in the results for the prioritization of the WtE technological alternatives.

The decision analysis techniques applied, together with the sensitivity analysis, made it possible to objectively weigh the different criteria and sub-criteria considered and establish the weighting or order of preference of the evaluated WtE strategies.

3. Results and Discussion

3.1. Identification of WtE Technological Options for the Utilization of FW

In different investigations, from the perspective of the three dimensions of sustainability, especially for waste management systems, utilizing, rather than disposing FW in sanitary landfills, creates multiple benefits such as reductions in the volume of waste that reaches final disposal; if not used, FW generates environmental, social, and economic costs [31]. Table 3 shows the five identified WtE technological options for the use of FW and the advantages and limitations of implementing each option.

Table 3. Advantages and limitations of WtE technologies for FW.

Technologies	Advantages	Disadvantages
Incineration	√ Immediate volume reduction in waste by approximately 90% √ Emissions control √ Use of heat for the generation of electrical and thermal energy √ Avoids landfills when there is no space √ Relatively silent and odorless	× High initial investment × High costs for emission control × Requires specialized labor × Possible generation of furans, dioxins and heavy metals × Possible opposition from the nearby community × With high humidity level of waste, requires more energy
Gasification	√ Processes liquids and solids √ Lower toxicity of leachates than in incineration √ Better quality of life for workers √ Produces fuel without impurities √ Reusable final waste	× High initial investment costs × Pretreatment requirement × Produces tar × Requires the cleaning of syngas to remove contaminants × High cleaning costs for inorganics
Pyrolysis process	√ Generation of fuels and electrical energy √ Reduces waste that goes to landfills	× Ashes create potentially hazardous waste × More applicable to plastic waste, not for household waste × Only developed on a laboratory scale or pilot scale
Anaerobic Digestion	√ Low implementation costs and nutrient requirements. Does not require energy for aeration √ Reduction in the generation potential of GHGs if the biogas generated is used or incinerated √ Obtaining biogas rich in CH4 and/or H2, with high potential for renewable energy production, for multiple uses: heat generation, electrical energy, and vehicular fuel √ Obtaining a digested material as an alternative to inorganic fertilizers √ Small- and large-scale applicability	× High to moderate bicarbonate alkalinity requirements × Medium to high start-up period × High to moderate environmental impact due to the generation of odors × Controllable possible corrosion problems × Pretreatment usually required for the liquid effluent and for the biogas, depending on the use
Landfills with biogas recovery	√ Obtaining biogas rich in methane (CH4) with high potential for energy production, for multiple uses: heat generation, electrical energy, and vehicular fuel √ Reduction in the generation of bad odors √ Reduced probability of explosions in the fill √ Cost reduction for landfill	× Highest recovery rates obtained in large or standard landfills × Greatest recovery of biogas obtained at a greater depth × Transport in pipelines at moderate distances × Relatively high maintenance costs for positive ignition engines × Gas turbines used mainly for flow rates greater than 2500 m^3/h × Expensive pretreatment × Mix with natural gas in low proportions.

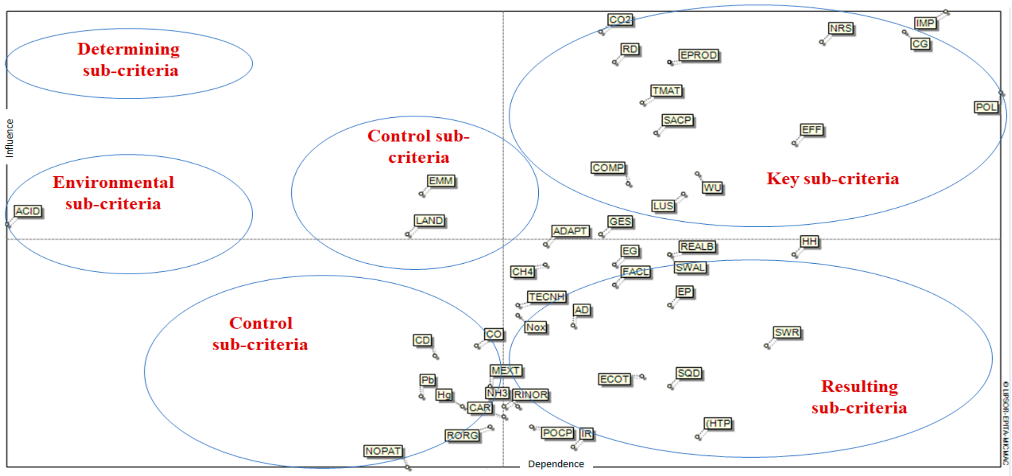
Source: [7,11,25,29,31,32].

For AD, in addition to the general benefits of exploitation, the generation of renewable energy is achieved [33], and it has been found to be the most sustainable technology for converting waste into energy; in contrast, incineration is the least sustainable technique. Although there has always been the possibility of treating organic waste such as FW through pyrolysis, its high economic costs and energy consumption throughout the value chain imply an energy recovery with a negative balance. Many authors have specified that pyrolysis is more suitable for the treatment of plastic waste and is mostly being used in industrialized countries [32]. Therefore, this technological option is not considered in this study.

3.2. Selection and Weighting of Decision Criteria and Subcriteria

Initially, 231 subcriteria were identified (120 environmental, 52 social, and 59 technical), which were grouped by similarity of concept, having a preselection of 44 (32 environmental, five social, and seven technical); the latter were located in the evaluation matrix of influence vs. dependency, where the group of consulted experts evaluated them through the MIC-MAC method for later categorization.

The categorized variables or subcriteria (13), which represent the aspects that must be considered to make a correct decision, were located in the plane proposed in Figure 3: solid waste reduction (RD), energy production (EPROD), resource consumption nonrenewable (NRS), climate change (CG), environmental impact (IMP), pollution (POL), efficiency (EFF), compliance with standards and laws (COMP), technology maturity (TMAT), use of land (LUS), water use (WU)), social acceptability (SACP), and mitigated greenhouse gas emissions (CO_2).



N°	Variable	N°	Variable	N°	Variable	N°	Variable
1	Emissions (EMM)	12	Cadmium (CD)	23	NH3	34	Social Acceptability (SACP)
2	Acidification SO2 (ACID)	13	Eutrophication (EP)	24	Photochemical oxidation (POCP)	35	Social welfare (SWAL)
3	CO2	14	Hg	25	Ionizing radiation Bq C-14 eq (IR)	36	Guaranty Energy Supply (GES)
4	Land requirements (LAND)	15	Pb	26	Mineral extraction MJ surplus (MEXT)	37	Energy production (EPROD)
5	Impact on environment (IMP)	16	Water use (WU)	27	Noise exposure to pathogens (NOPAT)	38	Reliability (REALB)
6	Pollution (POL)	17	Abiotic resources depletion (AD),	28	Respiratory inorganicskg PM2.5 eq (RINOR)	39	Technology maturity (TMAT)
7	Climate Change (CG)	18	Carcinogens (CAR)	29	Respiratory organics kg C2H4 eq (RORG)	40	Facilities (FACL)
8	Non-renewable resourses consumption (NRS)	19	CH4	30	Soil quality degradation (SQD)	41	Adaptability (ADAPT)
9	Reduction of MSW (RD)	20	CO	31	Surface water dispersed releases (SWR)	42	Technical know-how (TECNH)
10	Human Health (HH)	21	Ecotoxicity (ECOT)	32	Employment generation (EG)	43	Efficiency (EFF)
11	Nox	22	Human toxicity (HTP)	33	Compatibility and government support (COMP)	44	Land Use (LUS)

Figure 3. Influence vs. dependence map.

These subcriteria were regrouped again under the criteria of a conceptual similarity between them, defining six final subcriteria: CO_2, RD, SACP, EPROD, TMAT, and EFF. The weights of the decision elements are shown in Table 4.

Table 4. Results of weightings between criteria and subcriteria.

Environmental Criteria (32%)		Social Criteria (36%)	Technical Criteria (32%)		
Greenhouse Gases Avoided (CO_2)	**Solid Waste Reduction (RD)**	**Social Acceptability (SACP)**	**Energy Production (EPROD)**	**Technological Mature (TMAT)**	**Electrical Conversion Efficiency (EFF)**
Weightings within each group					
51.0%	49.0%	100%	43.1%	40.5%	16.4%
Vector priorities at the general level					
16.17%	15.83%	36.00%	13.80%	12.95%	5.25%

Source: Results of the questionnaire provided to experts.

3.3. WtE Technologies Evaluated against Weighted Subcriteria

Evaluations of the four selected technologies (incineration, gasification, anaerobic digestion, and recovery of biogas from landfills) are presented in Table 5, which shows the name and unit of measurement of each subcriteria and the weight it has in the total of the decision exercise; the table shows if it is a subcriteria that should be maximized or minimized. Finally, from Row 5 of this table, the performance levels of each alternative were evaluated against each subcriteria according to the literature review.

Table 5. Data by technology for TOPSIS.

Name of Subcriteria	GHG Emissions (Ton CO_2)	Solid Waste Reduction (RD) (%)	Social Acceptability (SACP)	Energy Production (EPROD) (MWh/Day)	Technology Maturity (TMAT)	Electrical Efficiency (EFF) (%)
Criteria	**Environmental**		**Social**	**Technical**		
Weighting	16.17%	15.83%	36.00%	13.80%	12.95%	5.25%
Maximizing (+) or Minimize (−)	(+)	(+)	(+)	(+)	(+)	(+)
Incineration	60	87.50%	3	0.34	9	25.75%
Gasification	4.609	87.50%	5	24.91	5	26.17%
Anaerobic Digestion	29.951	35.80%	6	61.84	5	20%
Biogas from landfill	21	50.00%	2	0.04	4	30%

With the above data, the TOPSIS multicriteria method was applied; after these steps, a percentage ranking was obtained from the highest to lowest value according to the established order of preference (Table 6). This result implies that when implementing WtE technologies in the context analyzed, it is advisable to initially consider a solution such as AD; the recovery of biogas from landfills is the least preferred alternative.

Table 6. Final ranking for WtE technologies selection.

Relative Proximity and Ranking	
Anaerobic digestion (AD)	78.20%
Gasification	47.50%
Incineration	27.40%
Biogas from landfill	6.60%

These results were compared with findings from other studies [29] where the researchers measured the social sphere considering the social acceptance and job creation subcriteria. For the first aspect, AD is more widely accepted; however, for job creation, there is a preference for incineration. Studies of [6,30] have also shown that AD is favored economically in terms of the operation and maintenance costs; in contrast, incineration is preferable in terms of investment costs [30]. At both a social and environmental level, these studies indicate a preference for AD.

3.4. Sensitivity Analysis

The variations between the weights of the criteria and their effects on the weights of the subcriteria (first stage of the sensitivity analysis) are shown in Table 7.

Table 7. Sensitivity analysis through scenario variation: criteria weighting variation.

Summary of the Scenario			
Changing Cells	**Recent Values**	**Scenario_1**	**Scenario_2**
Environmental criteria	32%	60%	54%
Social criterion	36%	10%	14%
Technical criteria	32%	30%	32%
Result cells			
Mitigated greenhouse gas emissions (CO_2) (Ton CO_2)	16.17%	30.32%	27.29%
Solid waste reduction (RD) (%)	15.83%	29.68%	26.71%
Social acceptability (SACP) Sherry scale	36.00%	10.00%	14.00%
Energy production (EPROD) (MWh)	13.80%	12.93%	13.80%
Technology maturity (TMAT) (TRL—NASA scale)	12.95%	12.14%	12.95%
Electrical efficiency (EFF) (%)	5.25%	4.92%	5.25%

According to these evaluated variations, a greater impact was observed in the environmental subcriteria, followed by the blocks of technical criteria and technical subcriteria. Afterward, the subcriteria variations from Table 7 and the effects that they had on the final ranking of the technological alternatives were analyzed (Table 8).

Table 8. Sensitivity analysis through variations in scenarios: variations in subcriteria weighting.

Summary of the Scenario			
Changing Cells	**Recent Values**	**Scenario_1**	**Scenario_2**
Mitigated GHG emissions (CO_2) (Ton CO_2)	16.17%	30.32%	27.29%
Solid waste reduction (RD) (%)	15.83%	29.68%	26.71%
Social acceptability (SACP) Sherry scale	36.00%	10.00%	14.00%
Energy production (EPROD) (MWh)	13.80%	12.93%	13.80%
Technology maturity (TMAT) (TRL—NASA scale)	12.95%	12.14%	12.95%
Electrical efficiency (EFF) (%)	5.25%	4.92%	5.25%
Result cells			
Anaerobic digestion (AD)	78.20%	73.36%	73.68%
Gasification	47.50%	33.52%	34.65%
Incineration	27.40%	27.43%	27.52%
Biogas from landfill	6.60%	8.61%	8.43%

The effects of the variations in the weightings between the criteria (environmental, social and technical) that were more relevant, were observed in the subcriteria social acceptability, energy production, and mitigated GHG emissions, going from 36% to 14%, from 4.9% up to 13.8%, and from 16.17% to 27.29%, respectively. These changes did not have a changing effect on the final decision; thus, anaerobic digestion is the most recommended technology for the treatment and energy use of FW given its physicochemical characteristics and its opportunities for the implementation of this type of technology in biological, environmental, social, and technical terms.

4. Conclusions

The technologies identified for food waste valorization through the WtE principles were anaerobic digestion, gasification, incineration, and recovery of biogas from landfills; pyrolysis was excluded from the analysis given its lower application potential with this type of substrate, being more recommendable for treating other types of waste such as plastics.

The application of the MIC-MAC prospective method and the AHP multicriteria tool allowed for the identification and prioritization of six relevant subcriteria to evaluate the four technologies identified in terms of their environmental, social, and technical effects; according to their level of preference, these subcriteria were social acceptability (36%), mitigated GHG emissions (16.17%), municipal solid waste reduction (15.83%), energy production (13.80%), technological maturity (12.95%), and electrical energy conversion efficiency (5.25%).

Among the WtE alternatives, anaerobic digestion was the best food waste valorization (the highest level of preference: 78.2%), instead of gasification (47.5%), incineration (27.4%), and the capture of biogas from landfills (6.6%), which was the least desirable due to its low social acceptance and the lower amount of mitigated tons of CO_2.

Despite the drastic variation in the percentages of the subcriteria applied in the sensitivity analysis, the decision did not change regarding the selection of anaerobic digestion as the best technological alternative for the treatment and energy use of FW. However, it is important to note that once the environmental, social, and technical evaluations were applied, the economic aspect and its impacts on possible public or private investors were considered so that they were in line with the social acceptance and beneficial results of anaerobic digestion in terms of by-products and their health and environmental implications.

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