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Thematic Section - Future of Energy-efficient Operations and Production Systems

Multicritery analysis for prioritizing the energy use of urban solid waste as a fuel in Paulista-PE

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Abstract

Paper aims: To carry out a multi-criteria analysis to assist decision making regarding the indication of the best alternative for converting solid waste energy into fuel.

Originality: The innovative and advantageous approach analyzes the feasibility of deploying the technology, mainly due to new and significant information on waste energy recovery.

Research method: The application of the system based on multi-criteria analysis, through the method of hierarchical analysis, according to previously established criteria, enables decision-making based on multiple criteria.

Main findings: The criteria generated by the mathematical process presented the priorities of heat treatment technologies and energy potential according to the levels of preference and order of importance.

Implications for theory and practice: The production refused derived fuel replaces petroleum-derived fuel sources, and reduces the amount of waste disposed of in landfills.

Keywords

AHP. Multicritery analysis. Waste energy. Energy recycling.

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1. Introduction

The problem of increasing the generation of Urban Solid Waste (USW) is present in all Brazilian municipalities. The protection of the environment against the anthropic impacts caused by urban growth is being highlighted in the energy sector, given the characteristics of Brazil, it is possible to explore a wide variety of renewable energy inputs. According to Oliveira & Carneiro (2020), among these energy sources is the use of energy from the USW, whose exploration has recently started to be debated in the country, although in a not very significant way. Waste subject to energy recovery is classified as an alternative source of energy for all purposes provided for in the legislation (Brasil, 2019).

The energy produced through waste uses discarded resources that demand adequate final disposal. In recent years, new USW management technologies allow these to be transformed, having economic value, decreasing the disposal in landfills, in addition to respecting the socio-environmental and economic aspects of the place to be implemented (Berticelli et al., 2017).

Among the different forms of USW destination, landfill is currently the most used and widespread modality (Fugii, 2019). However, as recommended by the National Solid Waste Policy (Brasil, 2010), the use of landfills is a resource for the final disposal of waste. The Law also prioritizes the destinations for waste, which includes reuse, recycling, composting, recovery and energy use or other destinations accepted by environmental agencies.

According to the Intergovernmental Panel on Climate Change (2006), the increase in USW disposal in landfills is responsible for the growth of greenhouse gas (GHG) emissions. A landfill can be considered as a biological reactor, where the decomposition of organic matter emits several gases, some in large quantities, such as methane (CH_4) and carbon dioxide (CO_2). These come from the anaerobic decomposition of biodegradable compounds from organic waste (Gama et al., 2019).

Araújo Júnior (2019) emphasizes that the current methodology for landfill disposal has negative effects on socio-environmental and economic aspects, in addition to the GHG emissions that are related to the USW have been the target of environmental concerns regarding global warming. Waste disposed without treatment in landfills or dumps has a major contribution to the intensification of the greenhouse effect, as well as air, water and public health problems (Yang et al., 2018).

Among the forms of destination of USW, energy utilization and treatment provide more efficiency in environmental terms and that the current management systems of USW in landfills (Soares et al., 2017). However, depending on the type of material, in order to be in accordance with the PNRS priority order (Brasil, 2010), the energy recovery of recyclable USW must be avoided, since recycling is a priority in relation to heat treatment.

In turn, the urbanization process intensifies the use of energy, increasing the demand for fossil fuels, which has caused an increase in carbon in the atmosphere. For Jucá et al. (2014), a solution to this problem would be the valorization of residues that are viable in recycling processes and that have energy value, through the conversion of these into Refused Derived Fuel (RDF), in order to be used in industrial units such as, for example, in cement production.

In the cement industry, RDF is applied as an exchange for non-renewable fossil fuels, such as petroleum coke, representing the second main alternative in the sector (Visedo & Pecchio, 2019). According to Araújo (2020), the cement industry is fundamental for the world economy, however the production process consumes large amounts of fuel and electricity, being responsible for up to 7% of CO_2 emissions.

The Brazilian government made a voluntary commitment, through the National Policy on Climate Change (Brasil, 2009), to reduce projected GHG emissions by 2020. Thus, the states that have a Waste Treatment Center (WTC) where there are actions that collaborate to reduce GHG, contribute to achieving the commitment signed by Brazil. In Pernambuco, the WTC-PE receives an average of approximately 456,000 tons. Year^{-1} of USW from nine municipalities, including the city of Paulista, contributing an average of 97,200 tons. Year^{-1}, based on the collection routes of the four regional administrations of the city.

The USW appear, among all solid waste, as the ones with the greatest potential for growth. Future management scenarios point out as promising or study alternatives to minimize impacts on USW management. Starting from the main hypothesis that the energy recovery of waste through the production of RDF, being a less impactful alternative during management, compared to a final disposal without treatment.

In this context, the objective of this work is to carry out a multicriteria analysis using the Analytic Hierarchy Process (AHP) method, to assist in the indication of the best alternative for the thermal treatment of solid waste for the studied municipality, according to the previously established criteria, as well as to verify the potential of RDF production in order to select the best alternative for municipal management.

2. Literature review

This section presents a theoretical framework, highlighting characteristics of the RDF, factors that influence the choice of the best USW treatment technology for the purpose of harnessing energy through the AHP method, used to support decision making in the evaluation of multiple alternatives and in the indication best choice in order of priority.

2.1. Urban solid waste energetic

USW from domestic activities in urban residences may be eligible for energy recovery. These residues have a high calorific value, and one of the treatment possibilities is energy recovery through thermochemical processes (Drudi et al., 2019). For Mamede (2013), the local valuation of the USW and its use for energy purposes may assist in diverting a significant amount of waste for more noble purposes, as they would be destined for landfills.

The NBR 16,849 (Associação Brasileira de Normas Técnicas, 2020) establishes the requirements for the energetic utilization of USW, promoting the use in a safe and sustainable way, through the rational use of USW in the preparation and the use of suitable burning technologies.

2.1.1. Refused Derived Fuel (RDF)

Refused Derived Fuel (RDF) is a term applied to materials that have a high calorific value, usually around 18 $MJ.Kg^{-1}$, recovered from waste collection. According to Caputo & Pelagagge (2002), this recovery of USW material is one of the options available for waste management in municipalities, through the production of RDF.

The São Paulo State Secretariat for the Environment, through Resolution No. 38 (São Paulo, 2017), establishes the minimum characteristics of Refused derived Fuel (RDF), in addition to operating conditions, emission limits, monitoring criteria and control to discipline the environmental licensing of RDF energy recovery in cement production furnaces.

To obtain a good quality RDF, the composition must contain organic material of low humidity and without fractions of critical contamination, such as heavy metals, such as chromium (Cr), cadmium (Cd), lead (Pb) and mercury (Hg). It should also not contain critical organic substances, as well as halogenic radicals, medications or infected residues (Jucá et al., 2014).

This fraction contained in energy from the USW has a diverse mixture of various materials and, therefore, the physical properties and chemical composition are not predictable, having as main components paper, textile waste, plastic, wood and domestic organic waste (Caputo & Pelagagge, 2002; Rezaei et al., 2020). The RDF production line consists of stations arranged in series, in which the unwanted components are conditioned to the combustible material, in order to obtain an RDF with predetermined characteristics (Mamede, 2013).

RDF can be used in furnaces of biomass plants, in the cement industry and in boilers (Valente Junior, 2015). According to Hajinezhad et al. (2016), in addition to providing energy, the RDF can be used / incorporated in the paper and wood industries, as well as waste incinerators and thermal power plants.

2.1.2. RDF coprocessing

Coprocessing is known through the integration of burning solid waste with the production of items through high temperatures. According to Freitas & Nóbrega (2014), it is the simultaneous recovery of recycling and energy from materials used to replace primary fossil fuels in cement kilns.

In Brazil, the main use of USW as RDF is in the rotary kilns of the cement manufacturing industries. According to CONAMA (Brasil, 2020), the RDF can be used in kilns as a raw material substitute as long as it presents similar characteristics to the components usually used in the cement industry, as a fossil fuel substitute, as long as the necessary energy gain is proven.

In the coprocessing process, the traditional sources of energy in the manufacture of cement are fossil fuels such as oil and coal, and these are replaced by fuels derived from residues and biomass, called alternative fuels, and, due to the high temperatures and the residence time in the cement kilns, the destruction of such alternative fuels is considered complete and efficient (Araújo, 2020).

According to Cembureau (2020), coprocessing contributes to the solution of environmental problems such as the reduction of GHG and consequently the reduction of climate change, the reduction of the volume of waste that is deposited in landfills and the efficient use of the energy content of waste and promoting the circular economy through the use of waste minerals in the cement factories that would be landfilled.

According to the Brazilian Association of Portland Cement (Associação Brasileira de Cimento Portland, 2020), in Brazil there are around 61 cement factories with the potential to reinsert USW into the production process for cement manufacturing. This technology has been internationally recognized since the 70s and has been used more intensively in Brazil for a little over 20 years. The European Standard being the best reference worldwide for the scope of RDF applications.

2.2. Analytic Hierarchy Process (AHP)

The act of making decisions through multicriteria analysis aims at solving problems with multiple alternatives, criteria and subcriteria of relative importance, becoming an important instrument of increasing use in the scope of decision making through hierarchies (Costa, 2006).

According to Saaty (1990), AHP is a method to support decision making that evaluates alternatives in order to indicate the best in order of priority, through criteria established by the decision maker. This method allows the modeling of a problem with degrees of certainty and uncertainty, using quantitative and qualitative data (Saaty & Vargas, 2001).

Among the methods of Multicriteria Decision Assistance (AMD), AHP is the most used method in several areas of knowledge, as it helps to solve complex problems through conflicting and subjective criteria (Ishizaka & Labib, 2011; Mendes et al., 2019). In the area of choice of technologies for waste treatment, the focus of this work, this method is the most used (Müller et al., 2021).

The AHP is based on three principles of analytical thinking, which synthesize the steps for the construction of the multicriteria model (Costa, 2006):

The first principle uses the AHP method to structure the problem in hierarchies, in the resolution of any problem, so that it allows a better assessment and understanding, in which it displays focus, alternatives to be analyzed, criteria, the specialists and the person responsible for making decisions, final decision. Thus, there is the separation of the problem by hierarchical levels, with the creation of the hierarchical tree (Figure 1). For Brunelli (2014), the construction of the tree collaborates with the best visualization of the problem, as well as the division of the problem into subgroups.

In the second principle, priorities and judgments are defined, so that the priorities of one criterion over another or an alternative over another are established through pairwise comparisons based on the observation of experts, which determines the relative importance between them through priorities. analyzed in a consensus (Bandeira et al., 2010).

The third principle is known as the principle of logical awareness, where the comparison of each alternative, criteria and subcriteria in question is carried out, which makes the experts' opinion easier and more precise (Costa, 2006). The method is based on peer comparisons by decision makers who assess preferences between alternatives using different criteria (Taylor, 2010).

For Alves & Alves (2015), even if the professionals in the area have knowledge and experience, inconsistencies in their judgments can occur, especially when there are several comparisons to be made in the model. Therefore, it is important that there is a way to validate the assessments and ensure that they are consistent.

The AHP methodology indicates that the evaluation phase is carried out through judgments on the criteria, sub-criteria and alternatives in square matrices, whose elements recommend the importance of one object in

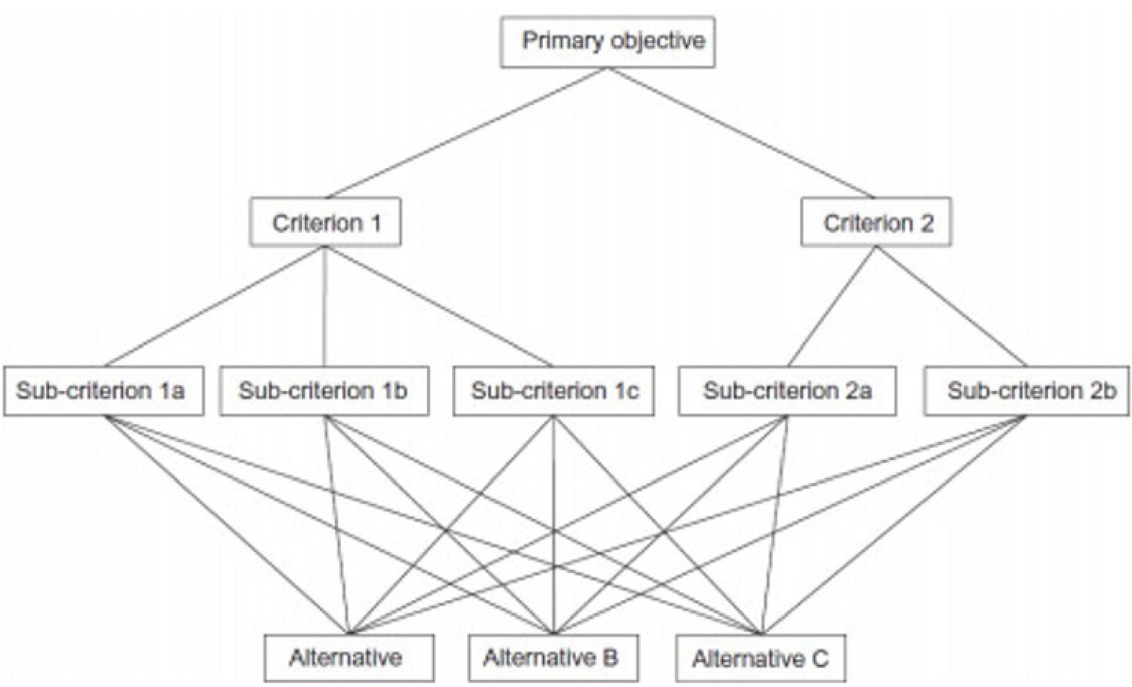

Figure 1. Hierarchical tree model. Source: Brunelli (2014).

relation to another. Saaty & Vargas (2001) suggest the use of a ratio scale, representing the intensity in preference or relative importance of nine points (Table 1).

Table 1. Fundamental scale for comparative judgments of Saaty.

INTENSITY OF IMPORTANCE	DEFINITION	EXPLANATION
1	Same importance	Both attributes contribute equally to the objective.
3	Weak importance of one over the other	Experience and judgment strongly favor one attribute over the other.
5	Strong or essential importance	Experience and judgment slightly favor one attribute over the other.
7	Very strong or demonstrated importance	One attribute is strongly favored over the other; its predominance of importance is demonstrated in practice.
9	Absolut importance	The evidence favors one attribute over the other with the highest degree of certainty.
2,4,6,8	Intermediate values between adjacent values	When looking for a favorable condition between two definitions.

Source: Saaty & Vargas (2001).

After the preferred choice of each alternative or criterion, the element of a higher level is taken as a reference to then generate the square decision matrix, in which the objects are ordered in relation to the scale of importance or preference, providing a relative priority. According to Saaty (1980), eigenvectors represent the average of the possible ways of comparing objects through the decision matrix and are associated with the largest eigenvalue of the matrix it represents.

A comparison between the highest eigenvalue and the order of the matrix determines a measure of inconsistency in the judgments represented in the matrix. According to Saaty & Vargas (2001), the inconsistency is a factor proper to the human being, there must be a tolerance within certain parameters for its validation and propose the following criterion for the calculation of the Consistency Index (1):

$$IC = \left|\left(\lambda máx - n\right)\right| / \left(n-1\right) \quad (1)$$

Where:

(n) is the matrix order;

(λmáx) the maximum judgment eigenvalue estimator.

To calculate the maximum eigenvalue estimator, the following formula is used (2):

$$\lambda máx = T.w \quad (2)$$

Where:

(T) is the sum of the matrix columns;

(w) is the eigenvector normalized to Σ vl = 1.

To assess the inconsistency according to the maximum order of the judgment matrix, the Consistency Ratio (RC) is used through the Formula 3:

$$RC = IC / IR \quad (3)$$

Where:

(IR) is a random consistency index obtained for a reciprocal matrix, with non-negative elements generated randomly (Table 2).

Table 2. Random consistency indices (IR).

Matrix order (n)	2	3	4	5	6	7	8	9	10
IR value	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.51

Source: Saaty & Vargas (2001).

According to Saaty & Vargas (2001), the judgments of the decision matrix will be considered consistent: RC = 0 for n = 2, RC <0.05 for n = 3, RC <0.09 for n = 4 and RC ≤ 0.10 to n> 4. If adverse, it indicates that there is some inconsistency in the judgments and the specialist should be required to review his opinion.

3. Method

The methodological process of this research aimed to verify the potential of RDF production in a municipality and to compare it with other USW heat treatment technologies through multicriteria analysis. The decision-making process included criteria for determining priorities according to degrees of importance.

The method chosen to assist decision making in choosing the best alternative is based on the concepts of the hierarchical analysis process (AHP), which is an aid procedure in decision making between multiple alternatives (Saaty & Vargas, 2001). It is based on multiple binary comparisons of quantitative and qualitative attributes, making it possible to compare various alternatives and to show in order of priority the most indicated in hierarchical structure (Costa, 2006).

An improvement of the AHP method was carried out based on the integrations related to the solution of the proposed problem (Costa, 2006; Mendes & Sthel, 2017). Thus, the work was divided as follows: (I) Formulation of the problem; (II) Survey of criteria; (III) Expert analysis; (IV) Modeling the problem using the AHP method; and (V) Final result.

The analysis was divided into two phases, the first being the realization of an AHP by the evaluation of feasibility criteria for heat treatment of USW. The second was an assessment of the municipality's production potential through the characterization of waste and viability, according to characteristics pre-established by specialists.

3.1. Study area

The case study was developed with the application of the methodology for the USW produced in the municipality of Paulista, Pernambuco, which is part of the Metropolitan Region of Recife and is 15.5 km away from the capital of the State of Pernambuco. The municipality is located at 13 meters of altitude and positioned in the geographical coordinates: Latitude 7 ° 56'24 "South and Longitude 34 ° 52'20" West. With an area of 96, 932 km^2, it is divided into 24 neighborhoods. According to the Brazilian Institute of Geography and Statistics (IBGE), it has an estimated population for the year 2020 of 334,376 inhabitants, demographic density of 3,087.66 $hab.km^{-2}$ (Instituto Brasileiro de Geografia e Estatística, 2021).

MSW collection is divided by collection sectors, making a total of 34 sectors. The municipality collects and manages, on average, 270 $ton.day^{-1}$ of MSW daily. The waste collected after the transshipment unit is transported to the Pernambuco Waste Treatment Center (Ecoparque).

At Ecoparque, the USW not made viable in recycling processes, and with energy value, are valued and transformed into RDF, for use as fuel, in cement industries or electric power plants.

3.2. Method application

The first phase of the study was applied using the AHP method, analyzing the socio-environmental impacts, technical characteristics, market and cost, enabling the verification of the most viable heat treatment technology. The criteria adopted in this research were established through research developed by Mendes et al. (2019). In this way, the criteria commonly used for this type of problem were used, which are environmental, economic, social and technical criteria.

As for heat treatment technologies, specific strategies were used for RDF coprocessing, incineration, gasification and pyrolysis. Subsequently, following the steps of Silva (2017), the hierarchical tree was set up through the analysis of alternatives and the attribution of weights to the criteria and subcriteria carried out by specialists who have mastery of the products or services present among the research options based on the Brainstorming technique. (Figure 2).

In the second phase, the bibliographic and field survey on the relevant characteristics for technical feasibility for RDF production began, in which six criteria were defined as lower calorific value (PCI), number of inhabitants (HAB), sustainability index (ISLU), distance between the municipality and the RDF consumer market (DIST), quantity of USW generated (QTD) and gravimetric composition of the USW (GRAV), these criteria were evaluated

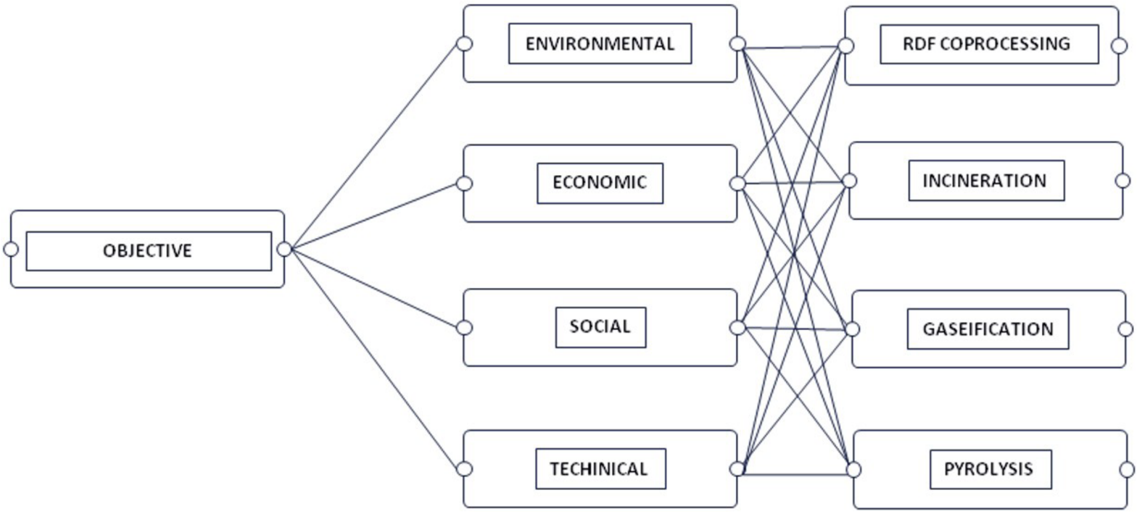

Figure 2. Hierarchical tree of the heat treatment technology selection problem.

according to the expected results described by the authors, being possible the formulation of the problem in relation to the municipal potential.

Thus, preferences were established according to the technical criteria previously established, through a questionnaire completed by specialists in the field of waste treatment. Then, preferences were determined for each of the six criteria considered, that is, the degree of importance in each of them in relation to the others. The experts assigned values on a scale of 1 to 5, with a value of 5 being the most important and 1 being the least important for each of them (Alves & Alves, 2015).

4. Analysis of the results

4.1. Criteria priorities

The preference of experts for each criterion in relation to the main objective was determined through peer comparisons, analyzing the alternatives side by side and indicating the one that best meets the criterion (Table 3). Thus, it was possible to calculate the priorities of the criteria according to the fundamental scale of comparative judgments (Saaty & Vargas, 2001). Six parity comparisons were analyzed, according to formula $(n^2-n) / 2$, where: n = matrix order.

Table 3. Parity comparison matrix of the criteria.

CRITERIA FOR THE OBJECTIVE	ENVIRONMENTAL	ECONOMIC	SOCIAL	TECHNICAL
ENVIRONMENTAL	1.00	0.20	7.00	1.00
ECONOMIC	5.00	1.00	7.00	3.00
SOCIAL	0.14	0.14	1.00	0.20
TECHNICAL	1.00	0.33	5.00	1.00
SUM	7.14	1.68	20.00	5.20

The table was normalized by dividing the value of each cell by the sum of the respective column (Table 4). With the table of the normalized matrix, the priority vector of the criteria is obtained, calculating the average of the values of each criterion.

Through the normalized comparison it is possible to check the ranking of the criteria through the calculated priority vector. For Alves & Alves (2015), the higher the average of the lines, the better the level of preference. Therefore, for the USW treatment technology attribute, the four criteria, in order of importance generated by

Table 4. Normalized comparison of the established criteria.

CRITERIA FOR THE OBJECTIVE	ENVIRONMENTAL	ECONOMIC	SOCIAL	TECHNICAL	PRIORITIES VECTOR
ENVIRONMENTAL	0.140	0.119	0.350	0.192	0.200
ECONOMIC	0.700	0.597	0.350	0.577	0.556
SOCIAL	0.020	0.085	0.050	0.038	0.048
TECHNICAL	0.140	0.199	0.250	0.192	0.195

the AHP mathematical process (the higher the score, the higher the preference level), are: Economic (55.6%); Environmental (20.0%); Technical (19.5%); and Social (4.8%).

The economic criterion pointed out by specialists as the main factor to be considered highlights the importance of verifying the economic viability due to the high investment cost of thermal treatment technology for USW compared to its disposal in landfills. According to Mamede (2013), the treatment tariff for landfills practiced in Brazil is small compared to European countries, since these countries raise the costs of disposal in landfills as a way to encourage alternative practices, such as treatment.

The implementation of technological processes for treatment and recovery results in fewer environmental impacts throughout its life cycle, including energy savings (Mersoni & Reichert, 2017). This fact is evidenced in the environmental and technical criteria that they present almost the same priority indicated by professionals in the field of energy use.

Although the level of preference regarding the social criterion is indicated by specialists with a lower percentage in relation to the criterion for choosing the implementation of technologies for the use of MSW energy, they present positive impacts for society. The use of MSW as an energy source generates direct and indirect jobs, as well as contributes to the eradication of landfills and improvement of health (Associação Brasileira de Cimento Portland, 2020).

4.2. Consistency

After the parity comparisons, the consistencies of the judgments were verified. According to Saaty (1990), the AHP method calculates the consistency ratio (CR) by comparing the consistency index (CI) of the matrix with the judgments, with the consistency index of a random type matrix (IR). With the matrix of judgments and priorities, priorities are used as a weight for each column (Table 5).

Table 5. Comparison matrix with assigned weights.

CRITERIA FOR THE OBJECTIVE	ENVIRONMENTAL	ECONOMIC	SOCIAL	TECHNICAL
ENVIRONMENTAL	0.140	0.119	0.350	0.192
ECONOMIC	0.700	0.597	0.350	0.577
SOCIAL	0.020	0.085	0.050	0.038
TECHNICAL	0.140	0.199	0.250	0.192
WEIGHT	0.200	0.556	0.048	0.195

The general preference index for each of the criteria was computed by multiplying the preference vectors for each of the criteria, by the weights of the criteria themselves, adding the products (Table 6).

Then, each of the resulting values was divided by the corresponding weights, which are the preferred vectors (Table 7). Thus, it was possible to calculate the maximum judgment eigenvalue estimator (λ).

The calculated total of the weight / priority ratio divided by the order of the matrix (4) is equal to λmax = 4.235. The Consistency Index (CI) was calculated using the following formula: CI = | (λmax - n) | / (n-1) The calculated value of the IR is given in Table 2. IC = (4,235 - 4) / 4 - 1, then IC = 0.078. Thus, because it is a matrix (4x4), since it has 4 criteria compared pair by pair, therefore the maximum allowed inconsistency according to the Saaty scale is 0.9. The resulting value of the RC to CI / IR consistency ratio was 0.087. Therefore, the degree of consistency for the case studied was shown to be satisfactory, since IC / IR <0.09.

Table 6. General Preference Index.

CRITERIA FOR THE OBJECTIVE	ENVIRONMENTAL	ECONOMIC	SOCIAL	TECHNICAL	SUM OF WEIGHTS
ENVIRONMENTAL	0.028	0.066	0.017	0.038	0.149
ECONOMIC	0.140	0.332	0.017	0.113	0.602
SOCIAL	0.004	0.047	0.002	0.008	0.061
TECHNICAL	0.028	0.111	0.012	0.038	0.188

Table 7. Autovalue Estimator.

SUM OF WEIGHTS	PRIORITIES	WEIGHT / PRIORITY
0.149	0.200	0.743
0.602	0.556	1.082
0.061	0.048	1.266
0.188	0.195	0.964

4.3. Priority of alternatives

The priorities of the alternatives were determined through peer comparisons, following the same method of calculating the criteria to achieve the main objective, indicating the best alternative that meets the established criterion (Table 8).

Therefore, the four alternatives, in order of importance according to the four criteria, generated by the mathematical process of the AHP (the higher the score, the higher the level of preference), are:

- Environmental: RDF co-processing, pyrolysis, gasification and incineration;

Table 8. Summary of Priority Calculation for Alternative.

Environmental Criteria					
C1	RDF coprocessing	Incineration	Gasification	Pyrolysis	Priority
RDF coprocessing	1.000	9.000	7.000	5.000	64%
Incineration	0.111	1.000	0.333	0.200	5%
Gaseification	0.143	3.000	1.000	0.333	10%
Pyrolysis	0.200	5.000	3.000	1.000	21%
Economic Criteria					
C2	RDF coprocessing	Incineration	Gasification	Pyrolysis	Priority
RDF coprocessing	1.000	5.000	1.000	0.333	23%
Incineration	0.200	1.000	0.333	0.200	7%
Gaseification	1.000	3.000	1.000	0.333	19%
Pyrolysis	3.000	5.000	3.000	1.000	51%
Social Criteria					
C3	RDF coprocessing	Incineration	Gasification	Pyrolysis	Priority
RDF coprocessing	1.000	7.000	5.000	5.000	63%
Incineration	0.143	1.000	0.333	0.333	6%
Gaseification	0.200	3.000	1.000	1.000	15%
Pyrolysis	0.200	3.000	1.000	1.000	15%
Technical Criteria					
C4	RDF coprocessing	Incineration	Gasification	Pyrolysis	Priority
RDF coprocessing	1.000	7.000	3.000	5.000	56%
Incineration	0.143	1.000	0.200	0.500	6%
Gaseification	0.333	5.000	1.000	3.000	27%
Pyrolysis	0.200	2.000	0.333	1.000	11%

- Economic: Pyrolysis, RDF Coprocessing, Gasification and Incineration;

- Social: RDF Co-processing, Pyrolysis, Gasification and Incineration;

- Technician: RDF Coprocessing, Gasification, Pyrolysis and Incineration.

Incineration was considered less viable in all the analyzed criteria, since the RDF coprocessing showed greater viability in the environmental, social and technical criteria, and in the economic criterion it ranks second among the treatment technologies (Figure 3).

In the analysis of consistency for the alternatives, the same calculation was performed for each of the criteria in isolation, resulting in a satisfactory degree of consistency for the studied case, according to the values obtained, since the IC / IR <0, 9 was evidenced in all the criteria judged and also in the preference between the criteria (Table 9).

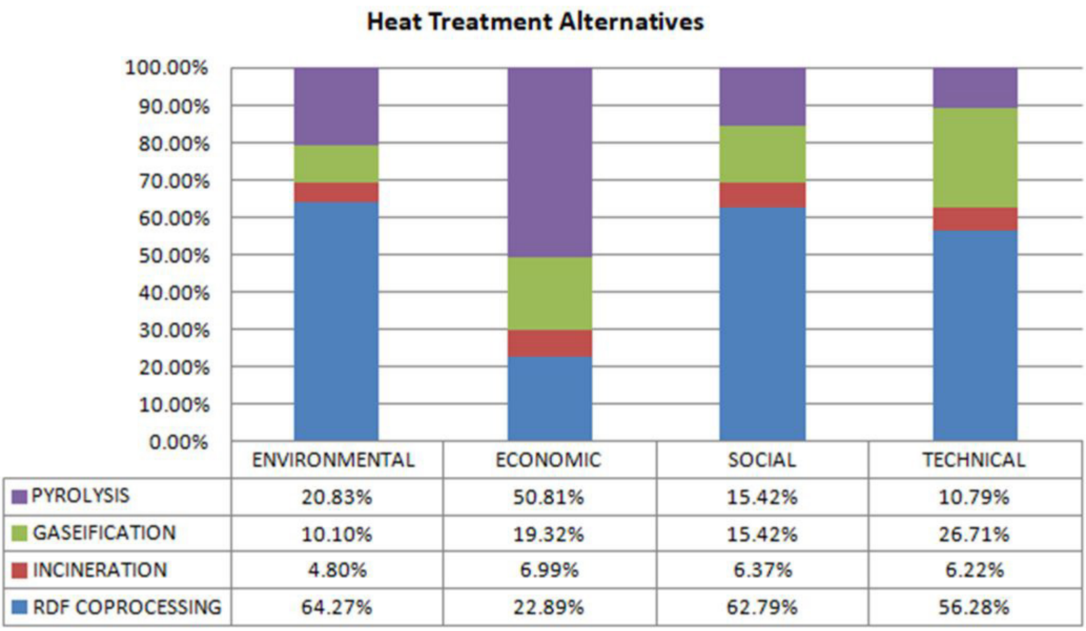

Figure 3. Priorities of heat treatment alternatives according to the criteria.

Table 9. Summary of the judgment consistency calculation.

CONSISTENCY INDEX	IC (λmax-n)/(n-1)	IC	REASON FOR CONSISTENCY (RC=IC/IR)	REFERENCE (IC/IR)	SITUATION
RDF COPROCESSING	0.058	0.9	0.064	<0.9	Consistent
INCINERATION	0.039	0.9	0.043	<0.9	Consistent
GASEIFICATION	0.025	0.9	0.027	<0.9	Consistent
PYROLYSIS	0.023	0.9	0.025	<0.9	Consistent

4.4. Analysis of the technical criteria of the RDF production potential in the municipality

The technical criteria analyzed by the experts through the questionnaire indicate that the closer to the established criteria, the greater the feasibility of implementing the researched technology. According to Aaker et al. (2001), factors such as experience and common sense when filling out the questionnaire can avoid errors, with harmful potential, given its scope and breadth.

The score on a scale from 1 to 5 in levels of importance, with 1 being considered of little importance and 5 being absolute importance. These values were assigned by specialists, which indicate as the main technical factor percentage of organic solid waste, followed equally by lower calorific value, amount of USW generated in the municipality and the Urban Sustainability Index (Figure 4). The results show studies in which they indicate that RDF production potential applies to materials with a high calorific value, and its composition must contain organic material with low humidity, and must not have contamination fractions, nor critical organic substances, as these critical fractions generate a low quality product (Jucá et al., 2014; Mersoni & Reichert, 2017).

The results of the technical criteria are viable for the production of RDF in the city, since of the six criteria analyzed, five reached the minimum requirement recommended by authors in their publications and validated by experts. Only ISLU had a lower than expected result, but this index aims to analyze the adherence of Brazilian municipalities to the National Solid Waste Policy, and, although Paulista does not reach 100% of the target, the city has 100% of USW collection, and this collected waste has energy potential, with the sorting for material capable of recycling being carried out beforehand at the CTR-PE, and the shadows of these materials valued for the energy use of RSU through the production of RDF (Table 10).

The production potential of RDF applies to materials with a high calorific value, and its composition must contain organic material with low humidity, and must not have fractions of contamination, nor critical organic substances, because these critical fractions generate a product of low quality (Jucá et al., 2014; Mersoni & Reichert, 2017).

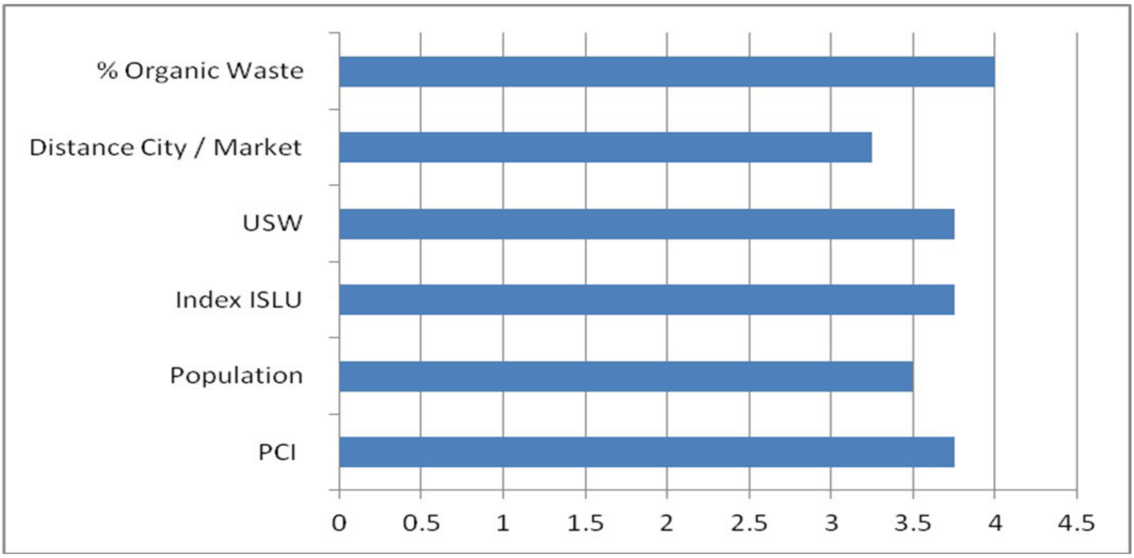

Figure 4. Priorities of technical criteria for the production of RDF.

Table 10. Table of technical criteria for RDF production.

CRITERION	EXPECTED	REAL
C1 - PCI (kcal.kg^{-1})	≥ 2 750	4.666
C2 - HAB (Hab)	300.000	334.376
C3 – ISLU	1	0.622
C4 - DIST (Km)	<150	<100
C5 - USW (Ton.month^{-1})	>6.000	8.100
C6 – GRAV	<60% Organic	34.96

5. Conclusion

This study aimed to analyze USW heat treatment technologies using the Multicriteria Decision Support Methodology - AHP, to evaluate the most viable technique and verify the energy potential of RDF production by the studied municipality. The results found in the application of the multicriteria method to evaluate the treatment technologies proved to be consistent and can be used for municipalities to assist in decision-making based on the evaluations that specialists in the area made on each item that makes up the model. As, for example, in the case of the criteria established in order of importance generated by the mathematical process of the AHP it was the economic one with 55.6%, followed by the environmental one with 20.0%, the technical one with 19.5% and for the latter the 4.8% social criterion. In relation to the four alternatives established, in order of importance according to the four criteria, RDF Coprocessing obtained a higher score in the environmental, social and economic criteria and in second place in the economic criterion. The use of sanitary landfills is a resource for final disposal, after all available and economically viable recovery and treatment possibilities have been exhausted. The use of RDF in Brazil is still inexpressive when compared to other countries, mainly in Europe.

The energy potential for the production of RDF in the municipality of Paulista, according to the technical, socio-environmental and economic characteristics, proved to be viable in all aspects analyzed. The experts attributed the percentage of solid organic waste as the main technical factor, followed equally by the lower calorific value, the amount of USW generated in the municipality and the Urban Sustainability Index. Thus, the use of energy from USW through RDF coprocessing is a technology that establishes a fuel with the potential to replace petroleum-derived fuel sources, also reducing the amount of waste disposed of in landfills, resulting in reduction of GHG generated in landfills.

In this context, the Refused Derived Fuel, due to all its characteristics and the growth in USW production in the municipalities, leads to the most promising fuel scenario, due to economic and socio-environmental benefits. Therefore, the energy utilization of the energy that comes from the USW is a technology with great sustainability potentials when it establishes a fuel with the potential to substitute oil-derived fuel sources, also reducing the amount of waste disposed in landfills.Life cycle assessment studies of the RDF technology are recommended, as well as the analysis of technological routes of USW applied to energy use, which will serve as a basis for other studies, which can contribute to the reduction of environmental impacts as well as to reduction of the environmental liability itself.

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