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Research Article

Multicriteria decision making applied to waste recycling: comparison between THOR and THOR 2 methods

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Abstract

Paper aims: This paper aims to compare the results of the THOR2 Method, in comparison to the original THOR method, and to analyse possible rank changes between the methods, to support decision-making in the evolutionary process of waste recycling in Brazil.

Originality; Proposes a revision of the model for analysis of Waste Recycling, highlighting the vision of three decision makers individually, and later the integrated vision.

Research method: State of the art of the THOR and THOR2 methods, through an investigation in four databases and comparison using THORWeb.

Main findings: As a result of the disposal of plastic waste, reuse, mechanical recycling, chemical and incineration remained in the positions with the consumer as a decision maker. With the other decision makers there was only one significant change, where the landfill went from last to first position.

Implications for theory and practice: There was only one significant change when comparing methods.

Keywords

Waste. Multicriteria. Sustainability. THOR method.

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1. Introduction

There is an increase in concern related to the damage caused by man to the environment and some sustainable strategies are being suggested so that these impacts can be reduced. Thus, one of the concepts of sustainability became known as the form of development that satisfies the current needs of the population without compromising those of future generations (WCED, 1987). Still, according to the sustainable concept, some performance methods have been developed in the literature, such as the Triple Bottom Line (TBL) which considers the social, economic, and environmental dimensions (Elkington, 1998). Regarding the previously mentioned damages, one of them is related to the global annual production of solid urban waste, which has an impact in three dimensions and is currently equivalent to more than 2 billion tons (Shah et al., 2021), and possibly will double to about of 4 billion by 2100 (Ebrahimian & Karimi, 2020).

In this way, in search of mitigating strategies for environmental impacts, sustainability assessments require the management of a variety of information, parameters, and uncertainties, due to this, the use of Multiple Criteria Decision-Making (MCDM) methods is considered appropriate, having because of its flexibility and the possibility of facilitating dialogue between stakeholders, analysts, and scientists, taking into account the opinion of the decision maker (DM) (Cinelli et al., 2014). With this, we can highlight the study by Cobos-Mora et al. (2022) who used an MCDM method called Analytical Hierarchical Process (AHP) to help choose the geographically optimal areas to locate transfer stations as an alternative to improve the quality of urban solid waste management in municipalities that generate little of this waste. And have long transport distances. Oliveira et al. (2022) proposed the integration of a Balanced Scorecard (BSC) and the FITradeoff multicriteria method to assess, monitor and improve corporate sustainability.

MCDM methods are intended to offer support as mathematical/axiomatic tools, effective in solving problems where conflicting criteria occur (Brans & Mareschal, 2005). According to Vincke (1992), the advantage of using multicriteria methods happens because, in general, there are no decisions that are simultaneously optimal in all aspects (criteria) of analysis, so the “best” option is selected. There are several MCDM methods, among which we highlight: AHP (Saaty, 1990), TOPSIS (Hwang et al., 1993), MACBETH (Bana et al., 1995), THOR (Gomes, 1999), among others.

We can also find numerous combinations between methods and even evolutions of the original method, which aim to improve or remedy some gaps found in the original method. Maêda et al. (2021) applied the hybrid multicriteria method AHP-TOPSIS-2N, composed of the Analytic Hierarchy Process (AHP), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), and two normalization procedures (2N), in the selection of aircraft for the Brazilian Navy. Recently Vitorino et al. (2022) proposed the new hybrid multicriteria method SAPEVO-WASPAS-2N, composed of the SAPEVO-M (Simple Aggregation of Preferences Expressed by Ordinal Vectors – Multi Decision Makers) methods and WASPAS-2N (Weighted Aggregated Sum Product Assessment) with two normalization techniques. Logullo et al. (2022) used a prioritization approach based on the combination of VFT, for structuring the problem, and the AHP method for ranking the alternatives.

Among the methods that are an evolution of the original method, this study addresses the THOR 2 method (Tenório, 2020), considered an evolution of the original THOR method, as it is a method where all the uncertainty present in assigning the classifications of alternatives and weights is quantified (Tenório, 2020). The term stands for Multicriteria Decision Aiding Hybrid Algorithm for Decision-Making Processes with Discrete Alternatives (THOR). Since its inception, the THOR method has been applied in various contexts, such as: demand Prioritization on Supply Chain (Esteves et al., 2022); strategy Analysis for project portfolio evaluation in a technology consulting company (Santos et al., 2022); military ship selection (Tenório et al., 2020; Costa et al., 2020); choice of electronic payment models for credit cards (Gomes & Maia, 2013); technology selection, with its results compared to the TODIM method (Gomes et al., 2021); and notably, in sustainable issues applied to waste recycling (Gomes et al., 2008).

With this, this paper aims to compare the results of the THOR2 Method, in comparison to the original THOR method, and to analyze possible rank changes between the methods, to support decision-making in the evolutionary process of waste recycling in Brazil, using THORWeb. It also analyses the possible rank changes between the methods, applied in the study by Gomes et al. (2008) in a way to support decision-making in the evolutionary process of waste recycling in Brazil. As a result of comparing the results of one of the first and most cited articles on the initial method with the results of its evolution, this work is original and timely.

The work is organized into five sections defined as 1- Introduction, 2- Theoretical Foundation, 3- Methodology, 4- Results and Discussion, and 5- Conclusion. The next section, Theoretical Foundations, presents the technique used and some important concepts. Then the section, Methodology, describes the methods used in the research. In section 4, you can find the research results and the discussion linked to these results. Subsequently, in section 5, the conclusion of the article is made.

2. Theoretical basis

2.1. Plastic waste in Brazil

Plastic began to be used more in the 1950s. In 1950, 2 million tons were produced, and in 2015, 380 million tons were produced. Added all production within these years, the total is approximately 8.3 billion tons of plastics, of which only 9% are recycled (Mazhandu et al., 2020). It is estimated that in 2022 plastic production will reach 400 million tons.

Plastic waste threatens the entire environment, including marine and coastal ecosystems which are considered one of the most critical and productive in existence (Chatterjee & Sharma, 2019; Bhuyan et al., 2021). The study by Mentis et al. (2022) points out that citizens are relatively aware of plastics’ environmental damage. However, environmental education also has shortcomings, which can hinder this knowledge from becoming a behaviour. The work also indicates the population’s view that the state and local authorities are primarily responsible for implementing waste management actions.

In the Brazilian National Solid Waste Policy, guidelines can be found regarding waste, its better management, and integrated management (Brasil, 2010). It is also mentioned that waste generation is a shared responsibility (Brasil, 2010). However, in Brazil, the number of incorrect discards has been increasing, even though legislation has been created to improve practice in this regard. According to the Brazilian Association of Public Cleaning and Special Waste Companies (ABRELPE), in 2020, an annual value of almost 82 million tons of Urban Solid Waste (RSU) will be known in the country, with an amount collected of 76 million tons. This is, approximately 6 million tons of waste were not collected and, consequently, had an improper destination.

Plastics have a higher calorific value than glass, paper, and metals, second only to aluminium, with polymer energy ranging from 62 to 108 MJ/kg (Rafey & Siddiqui, 2021). Of these, 76 thousand tons of plastic were collected by associations and cooperatives in 2019 and recovered (ABRELPE, 2021).

There are some sources of this waste, but the largest arise from the post-consumer market. Because of this, these wastes need to be washed and properly separated for recycling (Rafey & Siddiqui 2021). Shanker et al. (2023) present a review where they suggest technological options for recycling and illustrate clusters of them, such as mechanical recycling, chemical recycling, approaches from waste to energy and bio-based polymers and even reprocessing infrastructure for these recycling of plastic waste.

2.2. Construction and Demolition Waste (CDW) in Brazil

The construction industry produces some environmental pollutants, such as noise, air pollution, solid and liquid pollutants, waste, and water pollution, among others (Adnan et al., 2014). This sector is the world's largest consumer of raw materials, consumes the most energy, and is one of the largest emitters of CO2. It emits 39% of total global emissions, where 11% is generated from construction materials and products manufacture., among others, and 28% is generated by the buildings themselves (GlobalABC, 2019).

CDW in urban regions is classified by its characteristics and derivation. Construction, renovations, and demolitions generate waste. The incorrect disposal of this waste causes damage to the environment, such as visual and environmental pollution, and can also cause public health problems, as it contains organic materials, chemicals, and packaging, presenting the possibility of insect proliferation, and bringing harm to society and its surroundings (Brasileiro & Matos, 2015).

In Brazil, approximately 47 million tons of CDW were collected by municipalities in 2020, representing 5.5% (ABRELPE, 2021). Due to the impacts caused, the application of a circular economy (CE) to the construction industry is critical for defining CDW management strategies. Despite national policies, CE promotion in building materials is also linked to local government bodies (Oliveira et al., 2021).

Currently, the most used method of disposal is still the landfill, Alsheyab (2022) proposes the recycling of waste as an alternative for sustainable management, where he shows that this can be an option for reducing the risk of landslides, energy consumption, compensation for greenhouse gas emissions, recovering value-added materials, creating jobs, and protecting the Earth's natural resources. CDW management strategies were described and validated. These strategies included reuse and recycling, reinforcement of training and surveillance practices, and changes to municipal policies for CDW disposal in public landfills (Oliveira et al., 2021).

2.3. Literature analysis

Initially, a literature analysis was carried out in the Scopus, Web of Science, ScienceDirect, and Scielo Brasil databases, with the objective of identifying the state of the art of all articles that used the THOR and/or THOR 2 method, and at the end selecting the most cited article for an evolutionary comparison between the methods.

According to Soós et al. (2018), analysing the literature enables the development of intellectual understanding and synthesis, on a specific topic and its presentation. This helps to develop and improve academic and professional practices.

Thus, the following sequence of words was proposed, for investigation through each of the databases, accessed from the Capes portal (www.capes.gov.br), in September 2022: TITLE-ABS-KEY ("THOR Method" OR "THOR 2 Method" AND multi-criteria OR multi-criteria).

Table 1 presents all articles, Journals, citations, and the mentioned databases related to the THOR method.

The results present 14 articles, published in eight different journals, with two articles found in two identical databases.

Table 1. Article with application of THOR in databases.

Title	Authors and year	Journal	Citation	Data base
Strategy Analysis for project portfolio evaluation in a technology consulting company by the hybrid method THOR	Santos et al. (2022)	Procedia Computer Science, v. 199, p. 134-141, 2022.	1	Scopus
Demand Prioritization on Supply Chain by the Integration of Value-Focused Thinking Approach and THOR 2 Method	Esteves et al. (2022)	Procedia Computer Science, v. 214, p. 248-256, 2022.	1	Scopus
A fuzzy scale approach to the THOR algorithm	Elacoste et al. (2022)	Pesquisa Operacional 42: e261547 p.1-25	0	Scielo Brazil
THOR 2 Method: An Efficient Instrument in Situations Where There Is Uncertainty or Lack of Data	Tenório et al. (2021)	IEEE Access 9, pp. 161794-161805	2	Scopus and Web of Science
Ballast water management: technology choice comparing TODIM and THOR 2	Gomes et al. (2021)	Independent Journal of Management & Production 12 (8), pp.2140-2160	1	Web of Science
Navy Warship Selection and Multicriteria Analysis: The THOR Method Supporting Decision Making	Tenório et al. (2020)	Springer Proceedings in Mathematics and Statistics 337, pp. 27-39	17	Scopus
Choosing a hospital assistance ship to fight the covid-19 pandemic	Costa et al. (2020)	Revista de Saúde Pública 2020;54-79	20	Scielo Brazil
Application of multicriteria methods to the problem of choice models of electronic payment by credit card	Gomes & Costa (2013)	Production v. 25, n. 1, p. 54-68	12	Scielo Brazil
Using multicriteria decision support in a biomass alternatives ordination problem	Gomes & Maia (2013)	Production v. 25, n. 1, p. 54-69	2	Scielo Brazil
Decision analysis for the exploration of gas reserves: merging Todim and Thor	Gomes et al. (2010)	Pesquisa Operacional v.30, n.3, p.601-617	20	Scielo Brazil
Uso de SAD no apoio à decisão na destinação de resíduos plásticos e gestão de materiais	Cardoso et al. (2009)	Pesquisa Operacional v.29, n.1, p.67-95	27	Scielo Brazil
Multicriteria decision making applied to waste recycling in Brazil	Gomes et al. (2008)	Omega Volume 36, Issue 3, June 2008, Pages 395-404	83	SciencDirect
Modelagem analítica aplicada à negociação e decisão em grupo	Gomes (2006)	Pesquisa Operacional v.26, n.3, p.537-566	2	Scielo Brazil
Using MCDA methods THOR in an application for outranking the ballast water management options	Gomes (2005)	Pesquisa Operacional v.25, n.1, p.11-28	22	Scielo Brazil

We can identify that the theme of sustainability is found in some scientific productions applied with the THOR method (Gomes, 2005; Gomes et al., 2008, 2021; Cardoso et al., 2009; Gomes & Maia, 2013), where the article with the highest number of citations (83 citations), Gomes et al. (2008) published in “Omega”, presents the use of THOR as an environmental decision support system in two case studies. The first evaluates different ways of disposing of plastic waste, while the second, waste recycling facilities’ construction and demolition (C&D) operations are subject to a performance assessment. This study was chosen as a basis for an evolutionary comparison between the THOR and THOR 2 methods, presented in this article.

3. Methodology

The decision-making process generally involves a choice between several alternatives. Multicriteria methods are very useful to support the decision-making process in these cases because they consider value judgments and not only technical issues, to evaluate alternatives to solve real problems, presenting a highly multidisciplinary (Mellem et al., 2022). Complex environments, conflicting criteria, uncertainties, and inaccurate information are characteristic of many decision problems that are present in the real world. Multicriteria methodology contributes to making the decision-making process more rational and efficient. An important feature to emphasize is that multicriteria methods are not designed to search for the best alternative concerning all criteria. The difficulty of the problem originates from the presence of more than one criterion (Costa et al., 2022). This article makes a first application of THOR 2 in this new problem, allowing a comparison of methods to give greater security to the decision maker.

As previously presented, for the methodological development of this research, the article by Gomes et al. (2008), and the original fingers featured therein. The article talks about sustainability and uses the multicriteria method for decision-making in two situations.

In the article by Gomes et al. (2008) the THOR method was used and in this one, we will start with the same data, as already mentioned, but we will use the THOR 2 multicriteria method for comparison. The authors presented two cases in which there were different preferences in the decisions that the decision-makers chose.

In the first case, different forms of disposal of plastic waste are evaluated. In the second case, the choice was made for construction and demolition waste recycling facilities.

Criteria for the 1st case:

- Investments (euros/kg d): It is the sum of the costs of acquisition, assembly of the equipment, and construction of the necessary infrastructure for the operation.
- Operating costs (euros/kg): It is the sum of the fixed and variable costs of the production process. Remuneration, maintenance of machines and vehicles, transport (collection and transport), energy (electricity and fuel), machine and vehicle depreciation, and others were considered.
- Disposal/treatment costs (euros/kg): These are the costs related to the disposal of waste generated by the new process elsewhere.
- CO_2 Emissions (kg/kg): Total CO_2 emitted in the production and transport process.
- Benefits (euros/kg): Value of the sale of the transformed product: production of pallets, added to the benefit of not using landfills (mechanical recycling); production of fuel oil, added to the non-use of landfills (chemical recycling); steam production, in addition to not using landfills (thermal recycling); the benefit of not using a landfill (reuse and incineration); and no benefit obtained (using the landfill).
- Corporate image (qualitative assessment): Considers the elimination or not of waste and the amount of energy consumed. Some processes tend to favour the corporate image, such as reuse and recycling by using fewer natural resources.

Four types of decision makers (DM) were considered in the first case:

- Government: Decisions based on laws, rules, and regulations with a focus on benefits for society and the environment.
- Manager: Decisions related to the business.
- Consumer preferences are generally price oriented. However, environmental concerns are growing and becoming part of some people's lifestyles.
- Integrated: It is the balance point of the 3 previous evaluators.

An uncertainty (relevance index) of 0.8 was adopted for the mechanical recycling criteria weights and for CO2 emissions. And the same value was given to the uncertainty of the alternatives and criteria.

The THOR 2 method, developed by Tenório (2020), consists of the axiomatic evolution of the THOR method by Gomes (1999). The originally developed method combines Rough Set Theory, Fuzzy Set Theory and Preference Theory (Gomes et al., 2008, 2021; Costa et al., 2020).

According to Gomes (1999), three scenarios must be considered, given alternatives a and b, when using the THOR method, so that an alternative is perceived as better: S1, S2 and S3. For the analysis of each scenario, it is necessary to use the equations of the preference relationships (1) (2) and (3) (Tenório, 2020; Esteves et al., 2022):

$$aPb \leftrightarrow g(a) - g(b) > +p \tag{1}$$

$$aIb \leftrightarrow -q \leq \left| g(a) - g(b) \right| \leq +q \tag{2}$$

$$aQb \leftrightarrow q < \left| g(a) - g(b) \right| \leq p \tag{3}$$

Equations 1, 2 and 3 present the preference thresholds, where Equation 1 illustrates a strict preference relation (P) of one alternative over the other. Equation 2 presents an indifference relation of one alternative over another (I). Equation 3 exposes a weak preference relation (Q) of one alternative compared to another, whereas the relation g(.) designates a criterion.

To quantify the alternatives, we will use Equations 4, 5 and 6 for each of the scenarios (S1, S2 and S3) (Tenório, 2020; Esteves et al., 2022).

$$S1:\sum_{j=1}^{n}(w_j|aP_jb) > \sum_{j=1}^{n}(w_j|aQ_jb + aI_jb + aR_jb + bQ_ja + bP_ja) \quad (4)$$

$$S2:\sum_{j=1}^{n}(w_j|aP_jb + aQ_jb) > \sum_{j=1}^{n}(w_j|aI_jb + aR_jb + bQ_ja + bP_ja) \quad (5)$$

$$S3:\sum_{j=1}^{n}(w_j|aP_jb + aQ_jb + aI_jb) > \sum_{j=1}^{n}(w_j|aR_jb + bQ_ja + bP_ja) \quad (6)$$

In scenario S1 (4), the sum of the weights of criteria “j” such that “a” is strongly preferred to “b” is greater than the sum of the weights of criteria “j” such that a is weakly preferred to “b” plus the sum of the weights of the criteria “j” such that “a” is indifferent to “b” plus the sum of the weights of the criteria “j” such that “a” is not comparable with “b” not plus the sum of the weights of the criteria “j” such that “b” is weakly preferable to “a” any plus the sum of the weights of criteria “j” such that “b” is strongly preferred to “a” (Gomes et al., 2021). Thus, the alternatives will only have their attractiveness scored in cases where Equation 1, aPb, occurs.

In scenario S2 (5), more flexible than S1 (4) and stricter compared to S3 (6), the sum of the weights of criteria “j” such that “a” is strongly preferred to “b” and is weakly preferred “b” is greater than the sum of weights of criteria “j” such that “a” is weakly preferable to “b” plus the sum of weights of criteria “j” such that “a” is indifferent to “b” plus the sum of the weights of the criteria “j” such that “a” is not comparable with “b” plus the sum of the weights of the criteria “j” such that “b” is weakly preferable to “a” any plus the sum of the weights of criteria “j” such that “b” is strongly preferable to “a” (Gomes et al., 2021). Thus, the alternatives will only present punctuated attractiveness where Equations 1 and 3, aPb and aQb occur.

In the last scenario S3, which is the least rigorous compared to those mentioned above, it includes all equations aPb (1), aIb (2), and aQb (3).

According to Tenório (2020), the main differences between the THOR 2 method and the original THOR are related to the attribution of weights. If indifference is attributed to half the weight of the criterion. When the preference is weak, a proportion is established between half of the criterion weight and the value of the total weight. Additionally, a fuzzy-rough fact is multiplied by the criterion weight.

For the calculation of both methods, Web software was developed that is available free of charge through access to the THOR Web platform (http://www.thor-web.com/), developed at the Instituto Militar de Engenharia (IME) located in Rio de Janeiro, Brazil (Almeida et al., 2020).

Since the creation of THOR by Gomes in 1999, and mainly with the creation of its computational platform, the method has been applied to solve several problems involving multicriteria analysis.

The analysis is carried out in four steps and begins with the application of THOR, followed by the application of THOR 2, for subsequent sensitivity analysis comparing the two results and thus the conclusion.

4. Results and discussion

The criteria already mentioned, alternatives, weights and other data used in this first moment, can be found in Table 2 below.

In a second moment, we took the data still used by Gomes et al. (2008) regarding the choice of CDW recycling facilities, where 13 alternatives were placed, and the criteria are as follows.

- Total operating time (years): This is the installation time excluding long periods of downtime (over one month).
- Installed capacity (ton/h): Total capacity of equipment to process RCD.
- Current production (ton/d): It is the unit’s average production over the last 12 months. With the facility closed, refers to the average over the 12 months prior to the outage.
- Initial investment costs (103 US$): Initial structure cost for operation.
- Current status: there are two options: off or in operation.

The decision makers were the same as in the first case, but they presented an “ideal” point of view.

Table 3 below shows the data used.

The values of their weights, preferences, indifferences and disagreements were placed in the THOR WEB software and used for the analysis of the comparison of methods.

In this section you can find the results and discussion of the research. And as Cinelli et al. (2014) mention, sustainability assessments require the management of a variety of information, parameters, and uncertainties, hence the use of MCDM in decision making.

In Table 4 it is possible to find the result of the first case found by Gomes et al. (2008) using the THOR method.

In Table 5 below, the result of the first case can be identified, now using the THOR 2 method.

In this first case, the THOR method (Table 4) shows a preference for reuse and mechanical recycling by all decision-makers (S1, S2, and S3). Reuse was the best in integrated.

Table 2. Criteria, weights, and alternatives for plastic waste disposal.

	Criteria					
	Investments (euros/kg d)	Operational costs (euros/kg)	Disposal/treatment costs (euros/kg)	CO_2 emissions (kg/kg)	Corporate image	Benefits (euros/kg)
			Criteria weights			
Government	4	1	3	5	2	6
Manager	3	5	4	1	2	6
Consumer	3	1	2	4	6	5
Integrated	3	2	3	3	3	5
			Alternatives			
p	4	0.02	0	0.02	0	0
q	2	0.01	0	0.01	0	0
Veto	300	0.4	0.2	3.2	10	0.3
Reuse	-5	−0.2625	−0.00561	−0.062	11	+ 0.181
Landfill	−0.038	−0.1810	0	−0.014	3	0
Thermal recycling	-254	−0.1701	−0.00360	−3.116	7	+ 0.014
Chemical recycling	-454	−0.2977	−0.00228	−0.533	5	+ 0.255
Mechanical recycling	-10	−0.2917	−0.00623	−0.069	9	+ 0.280
Incineration	-231	−0.1547	−0.00327	−2.833	1	+ 0.181

Source: Gomes et al. (2008).

Table 3. Data for choosing RCD recycling facility.

	Operation time (years)	Installed capacity (ton/h)	Present production (ton/d)	Initial investment cost (10^3 US$)	Present status
Weight	1	1	1.2	1.2	1.2
Membership function	1	1	1	1	1
			Facilities		
p	0.5	2	4	3	0.4
q	0.2	1	2	2	0.2
Veto	9	93	200	200	5
A	7	100	230	1000	Stopped
B	6	30	80	210	Stopped
C	1	40	60	83	Stopped
D	1	20	170	159	Operating
E	3	10	10	36	Operating
F	1	25	30	100	Operating
G	0.3	15	45	67	Operating
H	9	40	210	150	Operating
I	8	40	210	183	Operating
J	7	15	80	109	Stopped
K	3	30	100	80	Operating
L	0.5	30	1	85	Stopped
M	4	35	32	115	Operating

Source: Gomes et al. (2008).

This does not occur with method THOR 2 (Table 5), which obtains the same preference only from the consumer. Showing a different result for other decision-makers. Landfill (Integrated and Government in S1) was the first option in the THOR 2 method, while it was the last option in THOR. Landfill was the fiesta option in Government S2 and integrated in THOR 2. It was the same in S3.

With the THOR method, the first option was reuse, followed by mechanical recycling, then chemical, fourth thermal, fifth incineration, and finally landfill for all decision-makers.

Table 4. Plastic waste - the decision maker's point of view (S1, S2 and S3).

Alternative	Consumer	Government	Organization	Integrated
		S1 Score		
Reuse	3.38	2.98	2.79	2.97
Mechanical recycling	3.24	3.5	2.24	2.79
Chemical recycling	2.00	2.0	1.67	1.90
Thermal recycling	0.67	0.57	0.53	0.58
Incineration	0.67	1.38	1.84	1.77
Landfill	0.57	0	0	0
		S2 Score		
Reuse	3.38	2.98	2.79	2.97
Mechanical recycling	3.24	3.5	2.24	2.79
Chemical recycling	2.00	2.0	1.67	1.89
Thermal recycling	0.71	0.62	0.76	0.68
Incineration	1.21	1.43	2.07	1.87
Landfill	0.5	0	0	0
		S3 Score		
Reuse	3.81	3.48	2.83	3.37
Mechanical recycling	3.29	3.57	2.48	2.89
Chemical recycling	2.00	2.0	1.67	1.89
Thermal recycling	0.71	0.62	0.76	0.68
Incineration	1.21	1.43	2.07	1.89
Landfill	0.5	0	0	0

Source: Gomes et al. (2008).

Table 5. Plastic waste - the decision maker's point of view (S1, S2 and S3) in THOR 2.

Alternative	Consumer	Government	Organization	Integrated
		S1 Score		
Reuse	3.374	2.494	2.263	2.458
Mechanical recycling	3.119	2.429	1.773	2.232
Chemical recycling	1.839	1.439	1.153	1.324
Thermal recycling	0.55	0.0	0.5	0.5
Incineration	0.665	0.862	1.733	0.749
Landfill	1.207	3.043	2.339	2.826
		S2 Score		
Reuse	3.374	2.494	2.263	2.458
Mechanical recycling	3.119	2.429	1.773	2.232
Chemical recycling	1.839	1.439	1.153	1.324
Thermal recycling	0.577	0.0	0.582	0.516
Incineration	0.703	0.9	1.93	0.834
Landfill	1.207	3.043	1.839	2.326
		S3 Score		
Reuse	3.613	2.796	2.285	2.695
Mechanical recycling	3.144	2.455	1.91	2.289
Chemical recycling	1.839	1.439	1.153	1.324
Thermal recycling	0.577	0.0	0.582	0.516
Incineration	0.703	0.9	1.93	0.834
Landfill	1.207	3.043	1.839	2.326

With the THOR 2 method, for consumer preference, the first option was reuse, followed by mechanical recycling, the third was chemical, followed by landfill, soon after incineration, and finally thermal recycling.

It is noteworthy that reuse, mechanical and chemical recycling, and incineration remain in the hands of the consumer as the decision-maker.

Still with THOR 2, the preference of the government and integrated had the same placement. Landfill ranked first, reuse second, mechanical recycling third, then chemical, followed by incineration, and finally thermal.

The organization's preference followed landfill in the first position, reuse in the second, incineration and mechanical recycling in the third position, chemical recycling in the fourth, and lastly, thermal recycling.

The most significant change regarding the positions was the landfill, which went from last to first, by three of the four decision-makers.

In Table 6, it is possible to visualize the result of the second case of the article by Gomes et al. (2008) using the THOR method.

In Table 7 below, it is possible to visualize the result of the second case using the THOR 2 method.

This article uses the THOR and THOR 2 methods with the purpose of doing a sensitivity analysis of the obtained results.

It can be noted that there is also a difference in the results with the use of the THOR method for THOR 2.

With the THOR method, the order from best option to worst option is installation K, I, H, D, M, E, C, B, G, F, J, L, and lastly, installation A.

With the THOR 2 method, the order from best option to worst option is installation I, A, H, B, M, D, K, J, F, C, G, L, and lastly, installation E.

Table 6. RCD installations: results S1, S2, S3 and S4 ("no weights").

Facilities	S_1	S_2	S_3	S_4 "no weights"
K	8.57	8.57	11.57	11.40
I	8.43	8.43	11.29	11.00
H	8.43	8.43	11.14	11.00
D	6.64	6.64	7.57	7.00
M	5.71	5.71	7.14	6.40
E	5.57	5.57	6.14	5.20
C	3.71	3.71	4.57	4.40
B	3.36	3.36	4.57	4.40
G	3.14	3.14	4.00	3.60
F	3.14	3.14	4.00	3.40
J	3.07	3.07	3.86	3.00
L	2.00	2.00	2.86	2.60
A	1.50	1.50	1.71	2.40

Source: Gomes et al. (2008).

Table 7. C&D facilities: S1, S2 and S3 results with THOR 2.

Facilities	S1	S2	S3
K	5.157	5.157	5.828
I	9.468	9.468	10.53
H	9.228	9.228	10.238
D	5.263	5.441	6.224
M	5.601	5.601	6.254
E	0.607	0.607	0.607
C	2.393	2.62	2.922
B	5.972	5.972	6.638
G	1.18	1.18	1.369
F	2.463	2.641	2.95
J	3.92	3.92	3.758
L	1.0	0.5	0.529
A	9.326	9.326	9.93

It is important to point out that among the first three placements in the THOR method, two were also present in the THOR 2 method, installations I and H.

It is also noteworthy that the last option included in THOR, ranked second in the THOR 2 method.

The installations that remained in the positions in both methods were installations H (3rd position), M (5th position) and L (11th or penultimate position).

As practical and managerial implications, the methods prove to be viable for aiding decision-making in the area of sustainability.

5. Conclusion

The objective of the article was achieved since it was possible to compare the methods' results. In real contexts, as is the case, it is interesting to use more than one method to compare the results found in each one. This is how it was done.

It is pertinent to emphasize that the result will not only depend on the selected method but also on the decision-makers.

It was found that there are differences in the ordering suggested by the two methods, thus showing that one method does not replace the other but complements the other.

In an academic review, studies like this provide a state-of-the-art review of the THOR method and THOR 2, which helps researchers identify all articles and areas of research published using the methods.

A limitation of the study refers to the article by Gomes et al. (2008), because it was carried out in a context, and currently the weight given to some criteria could not be the same, since with the more sustainable look of the present period, the last option would be the landfill, which ended up being the first option in THOR 2 for some decision makers.

The methodology used in this work can be replicated in other scenarios, for other organizations, using different databases.

The method proved easy to apply as well as versatile in many areas and situations.

As a suggestion for future work, it would be appropriate to compare the methods, but now with updated data as well as verifying the possibility of including new alternatives and/or criteria and verifying the need to include new decision makers. The application of a third multicriteria method to compare the result with THOR and THOR 2 would also be relevant.

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