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Article

E-Waste Management: An Analysis under the Perspective of Conflicts and Shared Responsibility

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Abstract: *Background*: The Brazilian National Solid Waste Policy establishes the shared responsibility of all actors involved in e-waste generation and management; however, some conflicts of interest need interventions and approaches for preventing them. *Objective*: This paper proposes using a graph model for conflict resolution (GMCR) decision support system to simulate the analysis and resolution of realistic e-waste management conflicts. *Method*: A systematic literature review focused on e-waste management, shared responsibility and conflict management was conducted, and a graph model for conflict resolution (GMCR) decision support system was applied to generate a framework to address this context. *Results*: The need for commitment agreements promoted by government institutions in partnerships with companies involved in the process is essential since the principle of shared responsibility requires educational actions, favoring efficiency in the reverse logistics recovery procedures for e-waste. Understanding the interconnected causes of conflicts and their facets is crucial for effective resolution and prevention, aiding comprehension, focused interventions, and evidence-based decision-making for transformative change amidst conflicting stakeholder objectives in the case of WEEE management. These results can be helpful for academics and practitioners working in this area.

Keywords: electronic waste; reverse logistic; systematic literature review; conflict; GMCR

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1. Introduction

Due to technological advances worldwide, producing electrical equipment and electronics (EEE) has emerged as one of the fastest-growing industrial sectors [1]. However, this growth significantly altered modern societies' consumption patterns, leading to a greater penetration of EEE in life consumers' everyday lives and subsequently to the rapid increase in quantities of waste electrical and electronic equipment (WEEE) [2].

As the amounts of WEEE are growing every year around the world, this has been recognized as problematic from an environmental point of view [3], and its management has become a challenging task for all stakeholders [4]. Despite this, several measures are being taken to alleviate them by introducing laws and management instruments at the national and universal levels.

Recently approved in Brazil, the Brazilian National Solid Waste Policy (BNSWP) establishes the implementation of reverse logistics networks for various types of waste, based on the shared responsibility principle, as an example of the category of e-waste. The principle of "shared responsibility" is one of the main points of this legislation, establishing that all actors in a supply chain are responsible for reverse logistics, such as manufacturers, distributors, importers, retailers, government, and the final consumer. The principle is carried out by means of sectoral agreements, which is an instrument of legislation. Thus, this situation emphasizes the need to aggregate different and often conflicting points of view [5].

A conflict is characterized by being a multicausal and multidimensional event and may result from a combination of political and institutional, socioeconomic and environmental factors [6]. Due to such characteristics, it is necessary to identify and understand the interactions between the various causes and dimensions in the context in which the conflict arises, to determine possible areas of intervention, and design appropriate approaches and 47 methods for conflict prevention, resolution, and transformation. In fact, the socio-environmental conflicts of modern society result from multiple causes, and responding to them is a complex and multidisciplinary task. Furthermore, according to [7] in e-waste management, several criteria are partially or completely in conflict.

However, according to Kua [8] the strategies formulated to deal with complex and ill-structured problems like this do not explicitly address possible conflicts between different policies. Still, strategically analyzing due conflicts provides a reliable diagnosis of the situation and can help decision makers make future decisions and provide guidelines for improved planning.

For this purpose, many tools in operations research have been used in the analysis of conflict strategies and, among them, formal methodologies such as game theory [9], metagame analysis [10] and conflict analysis [11]. In addition to these, we can highlight the graph model for resolution (graph model for conflict resolution—GMCR), which can use other techniques for analyzing and managing disagreements [12,13].

Studying the interplay amongst various factors leading to conflicts and their respective facets is of the utmost importance for achieving efficacious conflict resolution and prevention. In the context of shared responsibility, stakeholders have conflicting objectives. Thus, an approach facilitates an all-encompassing comprehension of conflicts, enabling targeted interventions and the judicious allocation of resources. By recognizing intricate patterns and engaging diverse stakeholders, this research ensures decision making grounded in empirical evidence and transforms conflicts into constructive change. The research gap reported in this paper is related to the use of formal methodologies to manage the disagreements between the stakeholders involved in a decision context, trying to find a compromise solution. This research gap drives the research question addressed in this paper. RQ1: How to deal with the disagreements between the stakeholders involved in the shared responsibility principle from the Brazilian National Solid Waste Policy (BNSWP)? RQ2: Which actions can be proposed to improve decision making for preventing conflicts?

In this context, this paper aims to analyze the resulting conflicts referring to one of the main points of the Brazilian National Solid Waste Policy (BNSWP), which deals with the shared responsibility principle in the context of e-waste management and consequently, proposes actions to improve the decision-making process, preventing conflicts. To reach this objective, primarily, a systematic literature review was conducted focusing on e-waste management, shared responsibility, and conflict management. Posteriorly, we used a graph model for conflict resolution (GMCR) decision support system.

Exploring the interplay of various factors and their dimensions in conflicts provides significant advantages to practitioners and researchers. For practitioners, this comprehension provides them with sophisticated insights into the dynamics of conflicts, enabling them to carry out more targeted and effective interventions. Thus, practitioners can devise strategies that tackle the root issues, thereby preventing conflicts from escalating and promoting sustainable resolutions in the decision making related to WEEE management and reverse logistics. Policymakers can use the insight generated in this paper to improve the existing policies related to waste management and create new ones, addressing the points of conflict, such as the population's awareness and the financial support to companies. Additionally, researchers acquire a deeper understanding of the complex relationships among conflict drivers, thereby contributing to the creation of evidence-based frameworks and models. This knowledge empowers researchers to guide practitioners by providing informed recommendations, bridging the gap between theory and practical application.

2. Systematic Literature Review

The focus of this paper is to illustrate the systematic review of e-waste and conflict resolution, including circular economy and shared responsibility. Therefore, for more details about reverse logistics and e-waste, we encourage the readers to analyze [14], in which the authors developed a systematic literature review of reverse logistics for e-waste.

The literature review considered the Methodi Ordinatio [15] protocol as the basis for the bibliographic research methodology. This method is based on the multicriteria methodology decision-making process (multi-criteria decision aid—MCDA) [15], since it includes a multi-criteria approach to select and filter the relevant publications in the literature, classifying the papers according to their scientific relevance, by the Index Ordinatio (IO).

In this intervention method, the impact factor of the journal where the paper is published is considered, as is the number of citations and the difference between the year of publication and the year of research elaboration. Therefore, this is the differential of this methodology in relation to the other methods of systematic review.

The Methodi Ordinatio includes nine stages of investigation, according to Figure 1.

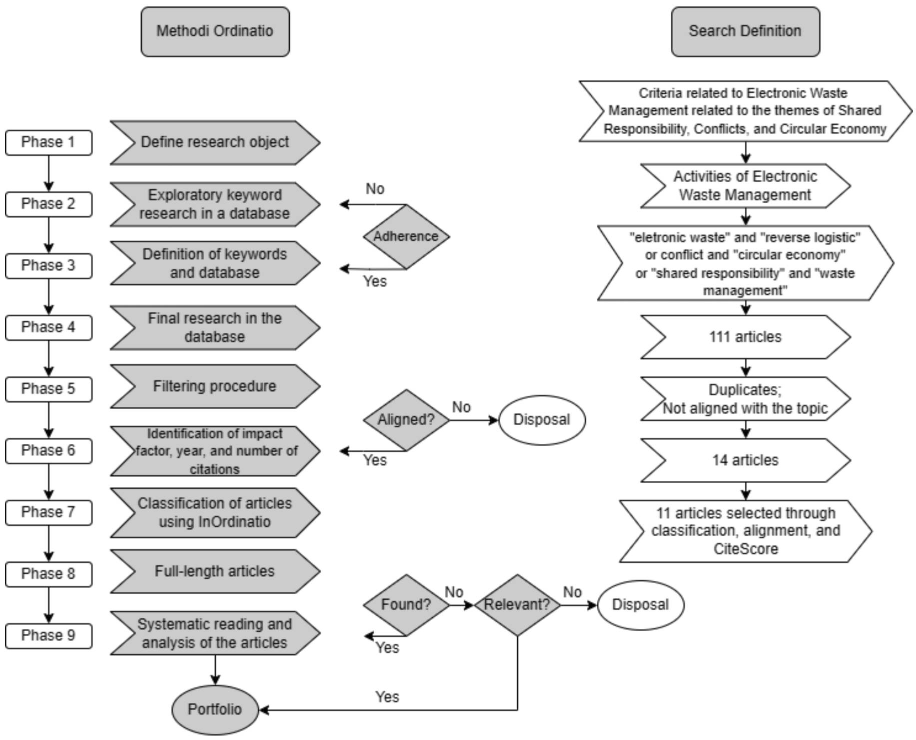

Figure 1. Flowchart of SLR protocol. Adapted from [15].

In a more didactic way, steps 1, 2, 3, and 9 require information and communication technologies with Internet access and a word processor. Steps 4, 5, 6, 7, and 8 require, in addition to the previous requirements, a reference manager software or app (the reference manager software used in this research for data collection was Mendeley Reference Manager v2.100.0), an electronic spreadsheet and a word processor. In step 6, we incorporated JabRef, which allows the transfer of data from conventional reference managers to an electronic spreadsheet format. This tool significantly facilitates the data collection carried out at this stage, which was one of the main reasons for the demand for research time in the first version of the Methodi Ordinatio. Step 7 is based on applying the Index Ordinatio (InOrdinatio) equation that uses three criteria: impact factor, year of publication, and number of citations. The purpose is to generate the InOrdinatio ranking, to determine the scientific relevance of a scientific paper [15].

Therefore, this research used a methodology based on a survey of secondary data from scientific articles. First, the theme of the research sought to identify the main criteria related to e-waste considering the themes of Shared Responsibility, Conflicts, and Circular Economy. Then, an analysis of the information obtained was carried out to, finally, make a correlation between the themes.

In the next step, searches were carried out on the Web of Science platform—Main Collection (Clarivate Analytics). The terms used were: "electronic waste" and "reverse logistical" or conflict and "circular economy" or "shared responsibility" and "waste management". It is noteworthy that the sample space used in the searches corresponded to the period from 2016 to 2020, reaching a result of 111 files.

Considering the subjects of excluding papers, some of them deal with: the packaging industry; pharmaceutical sector; food industry; integrated configuration system of vehicles; green supply chain management; eco-efficient supply chains; supplier development; construction industry; sustainable chain management supplies; and quality innovation in health.

The papers directed to the technical approach of the recycling and treatment of e-waste focused on the elements present in the composition of the device were also discarded, as well as those that did not present any conflict in the management of WEEE or did not deal with WEEE, as well as files that were not intended for the reverse logistics area.

Considering the choice of Methodi Ordinatio [15], only journals with factors of impact were mentioned in the systematic literature review. Also, the impact factor chosen was the CiteScore, which is part of Scopus's basket of journal metrics; Elsevier database, which includes SNIP (Source Normalized Impact per Paper), SJR (SCImago Journal Rank), citation and document counts, and percentages cited, which establishes the impact of the number of citations/CI in journals. Through Google Scholar, we identified the number of citations of each article. The last step consists of defining the InOrdinatio index, according to (1), which can make it possible to obtain a ranking of papers, organized from best to worst. In this way, papers can be classified according to their scientific relevance.

$$InOrdinatio = \left(\frac{IF}{1000}\right) + \alpha^{*}[10 - (YearResearch - YearPublication)] + \left(\sum C_i\right) \quad (1)$$

where:

- **IF** is the impact factor, which is divided by 1000 (one thousand), aiming to normalize its value in relation to other criteria;
- $\boldsymbol{\alpha}$ is a weighting factor ranging from 1 to 10, to be assigned by the researcher. The closer the number is to one, the less importance has, the researcher will attribute to the criterion year, while the closer to 10, the greater the importance will be;
- **YearResearch** is the year in which the survey was developed;
- **YearPublication** is the year the article was published;
- $\sum \boldsymbol{C_i}$ sum of citations from the article [15].

Values used in the study:

- **IF** = journals' CiteScore;
- $\boldsymbol{\alpha}$ = 1 1 (one) common to all;
- **YearResearch** = the year 2021 was used;
- **YearPublication** = year of publication of the article;
- $\sum \boldsymbol{C_i}$ = citations (scholar.google.com).

As already mentioned, the eleven articles met all inclusion criteria previously defined in the systematic literature review protocol. After calculating the IO, it was decided by the researchers not to establish a cut-off level, since the number of resulting files was low. According to [15], this level cut-off must be defined according to the experience of the researcher and sensitivity in relation to the subject researched.

2.1. Bibliometric Analysis

Data collection for analysis was performed with the aid of Bibliometrics, an open source tool assigned to quantitative research in bibliometrics and sensitometry that encompasses all relevant bibliometric analysis methods. Its main function boils down to the statistical analysis of the content on keywords, title and abstract, term extraction, match and merge duplication, matrix construction, and similarity normalization for network analysis [16]. We started the bibliometric analysis by examining the papers from the "WordCloud", providing an image with the most frequent words in the search database. Its dimensions in the cloud represent the amplitude of its repetitions in the selected articles. Therefore, in Figure 2, it is noticeable, due to that which is highlighted in the center of the bank of words, the most used was "Model", followed by "WEEE", both in English and, respectively, mean model and e-waste.

Figure 2. Most frequent words in the search database.

As previously mentioned, the time horizon of this study was from 2016 to 2020. In Figure 3, the peak of the subject was concentrated in 2018, but since 2017, the subject has drawn the attention of researchers. Because, with the advancement of technology and the reduction in the useful life of products, the amount of electronic waste increases in a considerable way [17]. Thus, there is a greater need for a strategy for managing these devices.

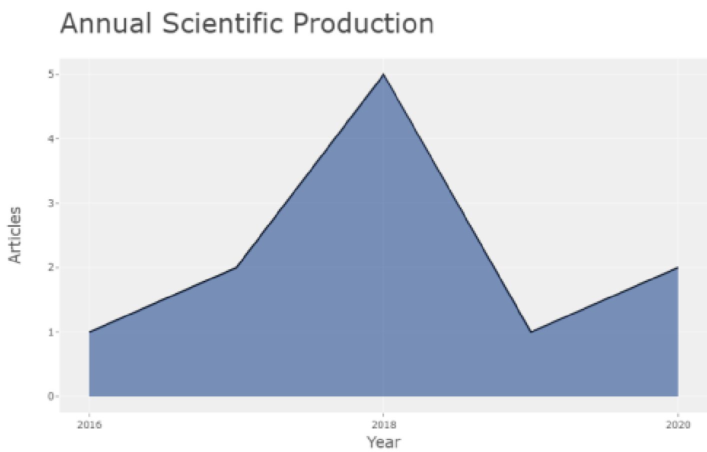

Figure 3. Distribution of papers about e-waste by year.

Table 1 shows the most relevant authors from the research database. In the first place was "Xavier, L. H." with two articles used in the study. In addition, the authors' productivity was quantified using the h factor, in the Scopus database. The h-index was devised by Jorge Hirsch in 2005 with the aim of objectively measuring the impact and relevance of the authors' scientific production, based on the number of publications and citations, that is, if a researcher has H = 5, this means that they had five articles that received five or more citations equally.

Table 1. Most relevant authors for the research and their respective H-factors.

Author	Nº Relevant Papers in Research	H Index
Xavier, L.H.	2	4
Alves, D.S.	1	17
Bastos do Valle, R.A.	1	1
Bundgaard, A.M.	1	5
Chaves, G.L.D.	1	4
Chen, Y.	1	20
De Souza, R.G.	1	4
Dias, P.	1	66
Dorrian, J.	1	35
Farina, M.C.	1	18
Ghisolfi, V.	1	2
Goncalves Quelhas, O.L.	1	15
Huda, N.	1	35
Isernia, R.	1	4
Islam, M.T.	1	32
Jayaprakash, J.	1	14
Kagawa, S.	1	77
Litchfield, C.A.	1	13
Lowry, R.	1	79
Mosgaard, M.A.	1	8

Source: Web of Science (2022) and Aria and Cuccurullo (2017).

Finally, in Table 2, we have the most relevant sources. The journal "*Resources Conservation and Recycling*" is in first place, with four documents, followed by the journal "*Waste Management*" with two documents. In the same table, through the Journal Citation Reports (JCR) base, which promotes a perspective for evaluating and comparing journals by counting citations and articles from almost all specialties in the fields of science, the impact factors of the journals in the database are shown.

Table 2. Journals' evaluation and comparison.

Journal	Impact Factor	Nº Relevant Paper in
Resources Conservation and Recycling	10.204	4
Waste Management	7.145	2
European Business Review	8.081	1
FME Transactions	1.769	1
Journal of Cleaner Production	9.297	1
Plos One	3.240	1
Sustainability	3.251	1

Source: Impact Factor (2022) and Aria and Cuccurullo (2017).

The key point of this paper was to identify gaps found in the papers analyzed in the systematic review of the literature. The main one, in particular, was the lack of guidance for resolving existing conflicts in electronic waste management. In the following sections, we present some conflicts found in the review and, finally, a proposal for managing these conflicts.

2.2. Conflict Analysis

For the management and treatment of conflicts involving e-waste, we elaborated Table 3, identifying the papers, authors, the InOrdination index, the conflicts, and the actors involved in these conflicts.

Table 3. Conflicts and their actors.

Title	Authors	InOrdinatio	Conflicts	Actors
Reverse logistics and closed-loop supply chain of Waste Electrical and Electronic Equipment (WEEE)/E -waste: A comprehensive literature	Islam, M. T. and Huda, N.	178.0147	Integrate reverse logistics and closed-loop supply chain to WEEE.	Consumers, government, institutions, companies, stakeholders, and manufacturers
Multi period disassembly-to-order of end of life product based on scheduling to maximize the profit in reverse logistic operation	Sathish, T., Jayaprakash, J., Senthil, P.V., and Saravanan, R.	163.0027	The creation of new electronics is increasing, which leads to massive junk mail. Generating the need of current items being discarded or dismantled.	Consumers, government.
Sustainability assessment and prioritisation of e-waste management options in Brazil	de Souza, R.G., Clímaco, J.C.N., Sant'Anna, A.P., Rocha, T.B., do Valle, R.D.A.B., and Quelhas, O.L.G.	107.0115	Implementation of reverse logistics systems under the shared responsibility of consumers, companies, and the government.	Private companies, cooperatives, and social enterprises.
System dynamics applied to closed loop supply chains of desktops and laptops in Brazil: A perspective for social inclusion of waste pickers	Ghisolfi, V., Diniz Chaves, G.D.L., Ribeiro Siman, R., Xavier, L.H.	100.0115	Formalization of waste pickers, given the importance of guaranteeing that cooperatives of waste pickers have access to a minimum value.	Waste pickers and companies.
Towards an inclusive circular economy: Quantifying the spatial flows of e-waste through the informal sector in China	Tong, X., Wang, T., Chen, Y., and Wang, Y.	59.0147	Recycling system of electronic waste	Chinese government, recycling plants, and informal waste transport sector electronic
The reverse supply chain of the e-waste management processes in a circular economy framework: Evidence from Italy	Isernia, R. Passaro, R. Quinto, I. Thomas, A.	43.0039	Adoption of approaches of circular economy with a specific focus on collection centers.	Italian organization of system of WEEE management and government
A circular approach to the e-waste valorization through urban mining in Rio de Janeiro, Brazil	Ottoni, M. Dias, P. Xavier, L.H.	41.0131	Absence of an adequate system of reverse logistics of e-waste.	Consumers, recycling companies, and stakeholders
Constraints and opportunitiesfor integrating preparation for reuse in the Danish WEEE management system	Zacho, K. O. Bundgaard, A. M. Mosgaard, M. A.	25.0147	Integrate reuse as a management option within the current system.	Stakeholders and municipal waste authorities.

Table 3. *Cont.*

Title	Authors	Inordinatio	Conflicts	Actors
Recycling 115,369 mobile phones for gorilla conservation over a six-year period (2009–2014) at Zoos Victoria: A case study of 'points of influence' and mobile phone donations	Litchfield, Carla A. Lowry, Rachel Dorrian, Jill	19.0053	A major barrier to a sustainable circular economy tempting for cell phones is the hoarding of their retired phones.	Consumers, stakeholders.
Disposal and reuse of the information technology waste: a case study in a Brazilian university	Alves, D.S. Farina, M.C.	14.0006	Collection and recycling of computer equipment in universities and organizations.	Waste disposal and reuse center of IT in a Brazilian university, users and stakeholder.
Conflicting consequences of price-induced product lifetime extension in circular economy: The impact on metals, greenhouse gas, and sales of air conditioners	Nishijima, Daisuke Nansai, Keisuke Kagawa, Shigemi Oguchi, Masahiro	9.0147	Product sales (air conditioning) through changes in consumers' product substitution decisions.	Consumers and producers.

In general, as seen in [18], the sources of conflicts regarding e-waste include disagreements concerning objectives, knowledge, ethical values, and a culture of sustainability.

Many tools in operations research have been used in the strategic analysis of conflicts. In this study, we proposed using the graph model for conflict resolution (GMCR) based on graph theory and game theory. The GMCR was selected because it is a flexible method for conflict resolution, with solid and realistic mathematical principles, allowing the modeling of strategic decisions, anticipating solutions, and contributing to assessing contexts' political, economic, environmental, and social viability [19]. In the case of social evaluation, we suggest [20].

3. GMCR Application

The GMCR is a conflict analysis method that finds decisions to be taken by each decision maker (DM) based on stability evaluation in an established set of moves based on the preferences of each player. The evaluation depends on the kind of information obtained in the process, which can be more restricted as in a crisp set (binary relation between states) or presented in fuzzy degrees (each pair of states has a value between 0 and 1). Both are commonly used in qualitative comparative analysis [21]. A crisp set can be regarded as a particular case of fuzzy sets in which the membership function is restricted to the extreme points [22].

The GMCR method comprises two phases: modeling and analysis. Modeling is the stage in which: (i) the players/decision makers, or stakeholders involved in the conflict; (ii) the options that each decision maker can control; (iii) the states, or rather, the set of all likely combinations of decision makers options, with the elimination of states considered unfeasible; and (iv) individual preferences regarding each of the options. Then, the stability analysis of each state to identify the equilibria for each player. Finally, the sensitivity analysis estimates solutions' robustness [13]. Sensitivity analysis is instrumental when studying an electric current conflict to avoid possibly facing unforeseen events.

When performing stability analysis, the graph model is ideally designed to accurately track possible movements between conflicting states. In the broadest conceptual framework, a state is stable with regard to a specific decision maker if deviating from the said state through the autonomous modification of strategic choice does not yield favorable outcomes. A solution concept entails a meticulously formulated mathematical explication of how stability can be quantified. Consequently, it constitutes an explanation of conceivable human or sociological conduct within a context of conflict. Given the diverse array of potential human responses within a contentious scenario, many solution concepts have been established to model the spectrum of feasible human behaviors.

In order to improve the understanding of the solution concepts, Table 4 presents the stability analysis and equilibria using the following solution concepts: Nash stability (Nash), general meta-rationality (GMR), symmetric meta-rationality (SMR), sequential stability (SEQ), and simultaneous stability (SIM).

Table 4. Meaning of solution concepts.

Solution Concepts	Meaning
Nash stability (Nash)	It represents balance in a scenario in which, in a game with two or more players, no player can win if they unilaterally change their strategy.
General meta-rationality (GMR)	The player judges their moves carefully, considering all possible actions and ignoring their counteracting actions.
Symmetric meta-rationality (SMR)	Regarding the GMR, the player finds one more scenario and analyses their possible counteracting actions to possible opponent punishments.
Sequential stability (SEQ)	As in GMR, the player only analyzes their opponent's probable performances, ignoring their counter-performances. The difference is that, in SEQ, the player expects their opponent to consider their payoff role in making their decisions and, therefore, will not always respond by blocking their unilateral improvements.
Simultaneous stability (SIM)	Examines the strategic impact of two or more players moving together simultaneously in a given scenario so that a combination of moves can become a new and unexpected result.

3.1. GMCR in E-Waste Management Conflict Case

The section presents the application of the GMCR method within the delineated problem context of waste management conflicts in Brazil, focusing on e-waste management. The intricate web of interactions arising from diverse stakeholders' perspectives and preferences helps model a conflictual game and a systematic approach to conflict comprehension and resolution. In this regard, the GMCR method is pivotal as a quantitative and structured framework for dissecting the multifaceted dimensions of conflicts.

Applying the GMCR method to the described problem entails systematic steps. First, the stakeholders engaged in the waste management network are identified as in [12]. Subsequently, their individual preferences, priorities, and strategic choices are articulated and aligned with the tenets of the Brazilian National Solid Waste Policy, forming the basis for the subsequent analysis. The GMCR method will then facilitate the aggregation and the assessment of these preferences enabling the quantification of the underlying conflicts' dynamics.

3.1.1. GMCR Modeling Process

Following flowchart, we start this process of defining the decision makers: According to [18] actors of all segments, as government, civil society, industry, and the third sector may be involved in this process. However, due to the number of actors, we cite as main decision makers: consumers (DM1), governments (municipal, state, and federal) (DM2), and companies (manufacturers/recyclers/distributors) (DM3). Table 5 shows the decision-makers and their options (actions) corresponding to each alternative that each decision maker would have under their control.

Table 5. Decision-makers and options.

DM1	O1	Separate common waste from WEEE and send to an eco point for proper treatment.
	O2	Pay for the correct disposal of WEEE.
DM2	O3	Provide incentives to national companies to carry out the correct disposal of WEEE.
	O4	Supervise and sanction the rules established for the collection and proper disposal of WEEE.
	O5	Raise awareness and educate the population about the damage caused to the environment and human health by the incorrect disposal of WEEE.
	O6	Inclusion of the category of collectors of recyclable materials through cooperatives.
DM3	O7	Provide eco points for receiving WEEE.
	O8	Appropriately dispose of WEEE to third parties through sale or donation.
	O9	Return/reuse of products (WEEE) received in the production cycle.
	O10	Discussion of the circular economy with a focus on recycling.
	O11	Carry out/encourage collection and recycling of computer equipment ethics in universities and society in general.

The table exemplifies the options that are available to each decision maker, with the possibility of selecting an option or not. For DM1, called consumers, the options are: separating common waste from WEEE and sending it to an eco-point for proper treatment, and/or paying for the correct disposal of WEEE. For governments, DM2, four options are available: provide incentives for national companies to correctly dispose of WEEE; inspect and sanction the rules established for the proper collection and disposal of WEEE; raise awareness and educate the population about the damage caused to the environment and human health by the incorrect disposal of WEEE; and/or the inclusion of the category of waste pickers of recyclable materials through cooperatives. For DM3, companies, there are five available options to be selected, they are: make eco-points available for receiving WEEE; properly allocate WEEE to third parties through sale or donation; the return/reuse of products (WEEE) received to the production cycle; discussion of the circular economy with a focus on recycling; and/or carry out/encourage collection and recycling of computer equipment in universities and society in general.

A state is a vector formed by "*Y*" (*yes*) or "N" (*no*), where "Y" means that the corresponding option is selected and "*N*" is the opposite. The number of states (k) is calculated according to the number of options: $k = 2^m$, where m is the number of options available for decision makers. For this conflict, a set of 2048 states were obtained.

An analysis evaluated the alternatives and pointed to the states considered unviable: the states where options 02 and 11 are selected at the same time. (Y———Y) were considered mutually exclusive, as it makes no sense for DM1 to pay for collection and appropriate destination, for example, hiring a company specialized in LR, when the DM3 already does it (in a way the consumer already pays, as it is already included in the composition product price). Likewise, it makes no sense for options 8 and 9 (——-YY–) to be selected simultaneously, once the DM3 or performs the appropriate destination to third parties or it returns/reuses the WEEE; moreover, it does not make sense for options 2 and 3 (-YY———) to be selected simultaneously, given that if DM1 pays for correct disposal, it makes no sense for DM2 to provide incentives for companies to do. Also, states where such options were no selected simultaneously, (-N———N), (——-NN–), (-NN———), were removed, leaving 256 viable states.

The prioritization of each decision maker in relation to each of the options was estimated based on the experience of a specialist with a Ph.D. in production engineering, 44 years and teaching in the area of reverse logistics, and supply chain management, in addition to having knowledge and experience in WEEE management conflicts for 20 years. These preferences are summarized in Table 6. Options with a negative sign indicate that a particular option was not selected (N); the sign '/' represents 'or'. The "if" means that the decision maker would choose option A and not B; and “iff” is used in the sense of ‘if only if’.

Table 6. Preference ranking.

DM1	DM2	DM3
1iff5	1	1iff9
−2	2	2iff9
3	3iff4	3
4	4/3	−4
5iff7	5iff7	5iff7
6iff8	6iff9	6iff9
7	7iff8	7if8
8iff7	8	8iff9
9if8	9	9if8
10iff9	10if9	10if9
11iff5	11iff5	11iff9

3.1.2. GMCR Analysis Process

With the inputs of the first phase, we evaluated the results based on the concepts of Table 4. This paper considers all reasonable matches of the universe of 2048 combinations to find the more stable combinations.

In Table 7, the check mark indicates that these states are in equilibrium under this solution concept. Table 7 also suggests a selection of states whose composition has more solutions among the 256 states of the problem.

Table 7. States and their respective balances.

State\Balance	**Nash**	**GMR**	**SEQ**	**SIM**	**SEQ** and **SIM**	**SMR**
130	✓	✓	✓	✓	✓	✓
642	✓	✓	✓	✓	✓	✓
883	✓	✓	✓	✓	✓	✓
1164	✓	✓	✓	✓	✓	✓
1676	✓	✓	✓	✓	✓	✓
1917	✓	✓	✓	✓	✓	✓

The six states presented in Table 7 are in equilibrium in all stability criteria. In fact, as described in [23], this model tries to ensure that all aspects from different decision makers should be equally considered. All states indicate that: DM2 will carry out campaigns to raise awareness and educate the population about the damage caused to the environment and human health by the incorrect disposal of WEEE, allowing DM1 to separate common waste from WEEE and send it to an eco-point for proper treatment, while DM3 will carry out the return/reuse of products (WEEE) received in the production cycle.

Also, according to the preference ranking, states 883 and 1917 are preferred. For DM2 and DM3, states where DM1 chooses to pay to properly dispose of WEEE to third parties are preferable to states that do not select that option. Therefore, the conflict analysis indicates that state 883 is the best solution likely to conflict. Status 883 means that the consumer population will either be able to separate common waste from WEEE and send it to an eco-point for proper treatment or how much they can pay for the correct disposal of WEEE. The government, along with its sphere of action, may choose to raise awareness and educate the population about the damage caused to the environment and human health by the incorrect disposal of WEEE, such as it may also carry out the inclusion of the category of collectors of recyclable materials for means of cooperatives. Companies may choose to make eco-points available for receiving WEEE; return/reuse of products (WEEE) received at the production cycle; and/or hold a discussion on a circular economy focusing on recycling.

Making a parallel to the literature review with the analysis of the obtained results, consumer action in shared responsibility is fundamental to the success of reverse logistics. In fact, according to [14], several studies indicate that the population needs to be aware of the issue of e-waste, and thus its consequences. Natume and Sant'Anna [24] observed in their research that consumers and companies, when companies dispose of their electrical and electronic equipment in the standard trash, do not have the understanding of the consequences of this act, in addition to not having the necessary information about e-waste recycling. In part, this is because, until recently, the area of technology was not traditionally seen as a polluting industry.

In [14], the authors listed a series of papers that address the main obstacles to the correct disposal of electronic waste: economic barriers [25], management barriers [26]. Additionally, there may be cultural, educational, or consciousness-related issues [18].

It is observed in this scenario that there is a need for commitment agreements articulated by government institutions in partnerships with companies linked to the process since the principle of shared responsibility for the lifecycle of products was established to determine educational actions, contributing to efficiency in the reverse logistics of WEEE recovery procedures, allowing everyone to do their part favoring different areas in the environmental and business scenarios.

At the present time, where information plays an increasingly important role, the Internet, network, multimedia and education for the population represent the viability of encouraging and sensitizing the community to engage in different forms of participation in quality of life protection. Thus, as can be seen in [18], cooperation between actors becomes one of the main goal for improving e-waste recycling network.

As a suggestion to comply with the principle of shared responsibility, we propose some actions such as reuse—unserviceable pieces of equipment are withdrawn and stored for future recovery of other equipment; rating for reuse of parts and equipment; storage until collection by re-credited cyclers or proper disposal; education for the population, improving the level of consumer awareness, in addition to investing in dissemination and expansion of collection points to facilitate disposal; and increased discussion in academia.

Legally, BNSWP includes all the necessary tools for the correct solid waste management, considering the characteristics and needs of the Brazilian reality. However, some cannot deny the innumerable challenges that pressure its execution, such as bureaucracy for access to financial resources and tax incentives granted by the union. In addition, the signing of sectoral agreements and the officialization of the BNSWP plans are of essential importance for the compliance and oversight of their instruments.

4. Implications of the Proposed Actions for the Decision-Making Context

The proposed measures for mitigating conflicts in the reverse logistics of e-waste have the potential to significantly reduce and prevent them. Adhering to the principle of shared responsibility, the recommended actions such as equipment reuse, rating for the reuse of parts and equipment, proper storage, consumer education, and expanding collection points offer practical steps to mitigate the negative impact of e-waste. Reusing unserviceable equipment conserves resources and reduces the need for new production, thereby cutting down on waste generation. The implementation of a rating system for reuse ensures the efficient utilization of viable components, thereby further minimizing waste. The proper storage and collection by accredited recyclers prevent haphazard disposal, thus reducing environmental pollution and health risks.

Educating the citizens on proper e-waste disposal raises consumer awareness and cultivates responsible habits, thereby decreasing the likelihood of improper disposal and contributing to the reduction in and prevention of conflicts. Thus, the companies (industries, retailers) will be able to propose strategies to collect an adequate amount of residues that justify the transportation costs. The expansion of collection points simplifies the disposal process, making it more accessible and convenient for individuals, consequently encouraging proper e-waste management and the feasibility of reverse logistics of WEEE.

Furthermore, fostering scholarly discussions promotes research and innovation in 396 e-waste management strategies, thereby enhancing the overall understanding of the challenges and solutions. While a legal framework such as Brazil's National Solid Waste Policy (BNSWP) provides a comprehensive foundation, these proposed actions address the practical hurdles and complexities of implementation. Overcoming challenges such as bureaucratic barriers and accessing financial resources can enhance the execution of the BNSWP. Sectoral agreements and official BNSWP plans' endorsement are pivotal in ensuring compliance and the effective oversight of waste management practices.

Incorporating these solutions harmonizes the efforts of various stakeholders, including consumers, producers, retailers, recyclers, policymakers, and academics, aligning with the principle of shared responsibility, and ultimately contributing to the more sustainable and conflict-free reverse logistics of e-waste in Brazil.

The BNSWP is the Brazilian National Policy related to waste management, a policy that took 20 years to be approved in the National Congress. However, the lasting period of this policy drove the stakeholders to take action towards the reverse logistics of WEEE. This policy created several opportunities for businesses and new acting branches. We can note a significant development and understanding of reverse logistics from 2010 until now. However, some actions still need to be taken to improve the reverse flow of the WEEE. The actions proposed in this paper can be helpful to practitioners to propose strategies to be implemented by companies involved (producers, retailers, and recyclers) to improve the collection points to consumers, which can guarantee the involvement of the population and the increase in the return rates, making the reverse logistics system feasible. Surely, this policy can be improved, or still, new policies can be created addressing the specific points of conflict, such as the awareness of the population, the financial benefits from companies to invest in reverse logistics. This paper can be helpful for policy-makers to decide in which points to concentrate efforts.

5. Final Remarks

The GMCR decision support system was applied to simulate the analysis and resolution of a conflict involving e-waste, helping decision makers determine the most appropriate e-waste management option/alternatives. The description of the conflict was based on scientific papers published over the years and selected for this research. For this research, according to the report, the parties interested in the conflict are consumers, governments (federal, state, and municipal) and companies. From the options that each of these decision-makers would have, a set of 2048 states were reached possible, among which 1792 were non-feasible states. According to the GMCR, 127 states were considered equilibria in some stability criteria. Still, only six states were pointed out in all stability criteria, one being the most likely solution. However, the analysis of these solutions indicated that one is the most reasonable solution. With reverse logistics being a sustainable development model, continuing with the recent growth model is irrational. Faced with this reality, public power would be self-sufficient to punish or encourage organizations to take responsibility for the impact generated by their activities. And these must, through educational campaigns and marketing actions, promote standard changes as important means of correctly recycling and disposing of waste.

Among the numerous barriers, the one that stands out is the lack of publicity campaigns and awareness, since up to this moment, knowledge and culture in the country about the importance of separation and recycling foreseen in the BNSWP, the population still does not see economic potential in this waste and ends up discarding it in the standard trash. For example, consumers still have little information about the correct disposal of electronic waste, the existence of collection points, the harm that this waste can cause to health and the environment and, mainly, the responsibility within the reverse logistics policy is up to them.

As suggestions for measures to reduce conflicts, companies should provide more readily accessible collection points; governments must invest in educational campaigns via various media (radio, television, Internet); the application of policy that promotes environmental education already in elementary schools is essential, since, in this way, the new generations will be educated in the ethical principles of sustainability, making the implementation of public policies aimed at sustainably handling resources more viable. However, it is of essential importance that, in addition to education projects and environmental sustainability, contrary practices are penalized under the law. Table 8, exemplifies the above suggestions directed at companies and government officials.

Table 8. Suggestions for companies and governments.

DM	Suggested Measures
DM2 (governments)	Invest in educational campaigns via different media (radio, television, Internet). The application of a policy that promotes environmental education in elementary schools. Penalzse contrary practices (related to WEEE) as provided by law.
DM3 (companies)	Making more eco points available to facilitate the collection of materials.

This study has a limitation from the perspective of research management, given that due to the pandemic caused by SARS-CoV-2 (COVID-19), the modeling was carried out from the description of the conflict by third parties, without considering, in the modeling step, the involvement of identified decision makers. However, this fact does not compromise the attainment of study's objective, which was to verify whether the GMCR approach could be effectively used to support the management of electronic waste, particularly in the analysis and resolution of conflicts, which proved to be satisfactory. We obtained a result in conflict resolution.

We also did not consider all stakeholders' perceptions in this context. This paper also focused on interviews with third parties to obtain the perceptions of the conflicts in the shared responsibility, so we did not present a holistic view of the problem. Future studies can conduct a broad survey of the population and other stakeholders to gather more conflicts and disagreements to be addressed. Different approaches from operational research can also be used to model the study's variables, providing new insights into the decision making process.

This study has theoretical, methodological, and practical contributions. In terms of theoretical contributions, this paper points out the importance and co-responsibility of the consumer population, companies, and governments regarding the consequences of the remanufacturing, recycling, and appropriate environmental disposal of WEEE. In terms of methodological contribution, this study used the Bibliometrix and the Web of Science as a basis to systematically review the literature to obtain a solid and relevant database and carry out the application of the program GMCR. Finally, in terms of practical contributions, once we use the GMCR, we propose an actual application for conflict resolution in WEEE management.

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analysis of the results, writing, and supervision of the study. All authors have read and agreed to the published version of the manuscript.

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