

Article

Reverse Logistics and the Circular Economy: A Study before and after the Implementation of the National Solid Waste Policy in Brazil

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Abstract: This article analyzes Reverse Logistics (RL) practices associated with the concept of Circular Economy (CE), comparing studies conducted before and after the implementation of the National Solid Waste Policy (NSWP) in Brazil. Data from companies in the Sul Fluminense region were analyzed using the Analytic Hierarchy Process to prioritize RL practices and identify those related to CE. The research included companies from nine Brazilian economic sectors that engage in some form of RL. The comparison of results aimed to evaluate the influence of the NSWP on these practices, with data analyzed using the Super Decisions software (version 3.2) to establish priorities and aggregate them using the Aggregating Individual Priorities method. It was observed that the implementation of the NSWP in 2010 emphasized the importance of sustainability. Although the concept of CE is recent, its operationalization is based on consolidated RL practices such as recycling, remanufacturing, and material reuse. The study provides insights to optimize and expand these practices, facilitating the transition from a linear economy to a circular one.

Keywords: Circular Economy; Reverse Logistics; National Solid Waste Policy



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1. Introduction

The global economy has been undergoing a process of intensified globalization driven by various agents, which increases awareness of sustainability issues. This results in greater environmental consciousness within society, stricter legislation, and products with shorter life cycles [1].

In this context, the concepts of Reverse Logistics (RL) and Circular Economy (CE) have gained prominence in both academic and business spheres. Numerous studies have been conducted on definitions, importance, barriers, motivators, and applications [2–11].

There are several definitions of CE, with the most widely accepted being provided by the Ellen MacArthur Foundation (EMF) [12] in 2015, which defines CE as an intentionally restorative and regenerative system. Other definitions compare CE with the linear economy [5,7], highlighting the inefficiency of the “take, make, dispose” model of the linear economy concerning sustainability principles. Figge et al. [13] analyzed 4000 scientific publications on CE in 2022 and established criteria that should be integrated into its definition, including closing resource loops, optimizing resource flows rather than minimizing them, and distinguishing between an ideal CE and a realistic CE that promotes sustainability combined with other approaches.

Although the concept of circularity is relatively new, its integration into the context of Industry 4.0 can be observed. Rosa et al. [14], Pizzi et al. [15], and Yu et al. [16] provide

examples of overlaps between these themes, highlighting that Industry 4.0 contributes to the implementation of CE practices. Many applications focus on logistics, sustainable supply chains, and RL [17].

In this scenario, several studies highlight how internal and external pressures influence the implementation of sustainable aspects in organizations, emphasizing RL as one of the main components of the CE [18–24].

In Brazil, the milestone in the CE occurred in 2010 with the implementation of the National Solid Waste Policy (NSWP), which mandates various productive sectors to implement waste management programs based on sustainability. This policy highlights important points, such as shared responsibility, which stipulates that the responsibility for post-consumer waste lies with the manufacturers, not only with consumers or the government [25–27]. Some applications of CE principles can be observed today in Brazilian industries and economic sectors, such as in the construction industry [28], the sugar-alcohol sector [29], and in rural properties that adopt sustainable practices [30], among others.

According to Dev et al. [17], RL has aspects similar to the CE, as both concepts are concerned with environmental, social, and economic dimensions. Other authors, such as Agrawal and Singh [31], assert that RL plays a fundamental role in implementing CE concepts in supply chains. However, there are differences between the two concepts, with CE being more comprehensive, as it does not solely encompass the reverse aspect of products.

In this new scenario, it is evident that RL, a concept that has been discussed for decades, is connected with the circularity of the economy, a more contemporary concept. RL is one of its principles, and its relevance increases as it conceptualizes and clarifies the management of product returns [32].

Table 1 summarizes some of the motivators that promote the practice of RL according to the opinions of various authors.

Table 1. Drivers of RL.

Drivers of RL	Authors
Financial factors, customer needs, sustainability, competitiveness and survival in the market, and stricter legislation.	[33]
Economic, legal, and corporate citizenship factors.	[2]
Economic (value recapture), image (to promote companies), and customer service factors.	[25]
Legal and image factors.	[34]
Economic, customer service, legal, corporate citizenship, and corporate image factors ¹ .	[35–37]
Legislation and standardization, tax and financial aspects, government control, and public participation.	[38]
Economic factors, legal aspects, and image considerations.	[39–41]

¹ This article used the criteria of Leite [35], Hernández [36], and Govindan et al. [37].

Independent of the motivators, RL encompasses activities such as product returns, recycling, remanufacturing, and disposal, aimed at extracting value from discarded products while minimizing environmental impact [42]. In analyzing RL practices and their relationship with CE, the National Industry Confederation (NIC) [43] conducted a study identifying CE practices implemented in Brazilian companies, including process optimization, circular inputs, resource recovery, product life extension, virtualization, and sharing. Additionally, Zhu et al. [44] categorize RL practices into green purchasing, customer cooperation on environmental issues, internal environmental management, ecodesign, and investment recovery.

While the concept of a CE is more comprehensive than that of RL, the implementation of CE principles in supply chains can be exemplified by RL activities [31]. Table 2 presents examples of RL activities that fall within the CE framework.

Table 2. Classification of RL practices according to their circularity.

RL Practices	Relationship with CE Concept
Materials returned to the production process.	Classified as circular and falling under the category of investment recovery, it aims to collect and recycle end-of-life products and materials, often reintegrating them into the production process [44]. According to CNI [43], this category includes circular inputs derived from repairs, refurbishment, remanufacturing, recycling, and/or renewable sources.
Reuse of packaging and sale as raw material for other processes.	According to Zhu et al. [44], this activity is circular and falls within the investment recovery group, including the sale of scrap, used materials, and surplus capital equipment.
Resale of products in secondary markets.	Circular activity that fits into the investment recovery (sale) of excess inventory/materials [44].
Recycling	This is one of the primary circular activities when establishing a recycling system to utilize defective or non-defective products [44].
Existence of records of costs generated by returns.	Circular activity within the investment recovery group, as per Zhu et al. [44].
Expenditure on social and environmental actions.	Activity classified as circular, according to CNI [43] and Zhu et al. [44], used to enhance the company's image through campaigns that address environmental, social, and economic concerns.
Expenses on employee training.	Within the internal environmental management group, this activity is classified as circular, such as specialized training for workers on environmental issues.
Operating the reverse channel (costs of collection, sorting, transportation, storage).	It is classified as investment recovery for the reverse channel in general, from collection to storage, as per Zhu et al. [44]; it is an activity of CE.
Developing new technologies for recycling or recovery (costs to develop new technologies).	This activity is circular, according to Zhu et al. [44], and also falls within investment recovery.
Proper disposal of waste.	This activity falls within the concept of CE, as it classifies waste according to its reuse, recycling, recovery of parts and components, and proper end-of-life disposal.
Partnerships with stakeholders.	According to Zhu et al. [44], cooperation among the various agents involved in the processes is one of the key factors in pursuing circularity. The authors emphasize cooperation among suppliers, customers, managers, and all stakeholders.
Liberal return policies.	This activity is classified as circular, as Zhu et al. [44] advocate for the creation of a recycling system that facilitates product return.
Well-defined returns.	Returns should be integrated into a well-defined system of collection, return, and recycling, fundamental concepts of CE [44].
Corporate responsibility for the proper disposal of their products at the end of their lifecycle.	CNI [43] and Zhu et al. [44] define this activity as one of the most important, as they seek to establish circular inputs, process optimization, and shared responsibility in handling end-of-life products.

Adapted from Bitencourt [45] based on NIC [43]; Zhu et al. [44].

All RL activities shown in Table 2 are included by the authors as part of the CE concept. However, there is a set of other practices that organizations consider within RL-related activities but are not regarded as part of CE. Among these, they may include job creation in the reverse channel; advertising as a responsible company for its products and processes;

acceptance of returns for customer satisfaction reasons; the establishment of minimum recovery levels to be met by companies, among others.

To analyze the practices of RL and CE implemented in various countries, it is necessary to highlight the existence of laws and regulations as the main motivation. In China, the CE Law was enacted in 2008 [46,47]. Sousa et al. [48] mention other countries with specific regulations regarding environmental indicators, such as the United States with the Resource Conservation and Recovery Act (RCRA), and the European Union with Directive 2008/98/EU, which guides waste management. In Brazil, RL and the RCRA gained prominence with the NSWP, sanctioned in 2010 under Law No. 12305, marking the management of solid waste in the Brazilian scenario [39].

The NSWP addresses some important concepts, highlighting shared responsibility for the product life cycle, sectoral agreements, RL, operational and financial sustainability, and the adoption of sustainable production and consumption standards. In this context, one of the main instruments for implementing shared responsibility is RL, directly linked to the economic value recovery of waste, prioritizing recycling and the proper disposal of residuals.

However, there are divergences regarding the effectiveness of implementing the NSWP. Cetrulo et al. [49] tested some hypotheses about the effectiveness of the NSWP, concluding that the rate of recovery of recyclable materials did not significantly increase and the overall proportion of environmentally adequate landfills did not increase significantly. Among the challenges for implementing the NSWP are lack of government funding, insufficient technical and administrative capacity, lack of public awareness about waste generation, deficiencies in the federal government's decentralization strategy for agenda implementation, and lack of integration with other policies [49].

The differences in the Brazilian landscape before and after the NSWP can also be observed in academic production before and after 2010. Prior to 2010, there was a lack of a policy regulating and standardizing end-of-life strategies for products [50]. With the implementation of the NSWP, RL is treated as a development tool characterized by a set of actions, procedures, and means aimed at enabling the collection and return of solid waste to the business sector for reuse in its own or other production cycles, or for another environmentally sound final disposal.

In this context, there are studies emphasizing the need for integration in the production chain to comply with legislation, placing importance on RL practices [25]. Similarly, Souza et al. [51] present a new perspective previously underexplored: the social and environmental aspects of a recycling cooperative in post-consumer reverse channels.

More recently, the term 'voluntary RL' has emerged, adopted voluntarily by supply chain agents without legal or regulatory imposition, for economic or strategic reasons [3]. Examples of this type of logistics include the 'Reciclus' program, a nonprofit association formed by manufacturers and importers of fluorescent lamps responsible for their collection and recycling; the Sistema Campo Limpo for collecting agricultural pesticide packaging and the Instituto Jogue Limpo, which has signed 13 Commitment Terms with Environmental Secretariats for the proper disposal of lubricant oil packaging [52,53].

In this way, it is noted that both concepts (RL and CE) are associated with reverse flow management, which is a critical part of organizational management. The importance of regulations that compel companies to implement these practices is also highlighted, aiming to achieve sustainability by reducing waste, efficiently using resources, and meeting the growing demand for environmentally responsible business practices.

Thus, the objective of this article is to analyze the importance or priority of RL practices associated with the concept of CE, comparing studies conducted by different authors and using the implementation of the NSWP in Brazil as a benchmark. The Analytic Hierarchy Process (AHP) will be the decision support method used in the study to establish 'measurements or importances' of these practices, and thereby measure the influence of the NSWP by comparing both studies.

Integrating the concepts of RL and CE to understand characteristics, interrelationships, and barriers can be an innovative theme, where CE can be seen as an emerging and relatively new topic under development. However, integrating these two concepts can help minimize negative environmental impacts associated with the production and disposal of products, contributing to ecosystem conservation and a reduction in carbon emissions. It can also support the understanding and implementation of regulations such as the NSWP, thereby helping governments and companies align their sustainability strategies.

To achieve the objective, it was necessary to analyze the priority of RL programs and activities, using studies conducted before and after the implementation of the NSWP as a basis. In this context, RL practices were linked to the new concept of CE, and the research data were processed to demonstrate this interrelationship. However, the study is geographically limited, focusing solely on companies from a specific region, the South Fluminense Region.

The article is structured into five sections: Section 1 provides the introduction and background of the research, highlighting concepts. Section 2 focuses on the methods, including data collection and processing. Section 3 presents the results. Section 4 discusses the findings and the study's relevance, emphasizing novelty. Finally, Section 5 presents the conclusions.

2. Materials and Methods

The present research is classified as follows:

- **Applied nature:** as it examines the RL practices in a sample of companies from the South Fluminense region before and after the implementation of NSWP.
- **Exploratory:** The literature review focused on interrelating concepts of CE and RL linked to the NSWP. Subsequently, qualitative and quantitative data collected by Hernández [36] and Bitencourt [54] were processed and organized to analyze the relationship between RL and CE and to determine if there were changes after the implementation of the NSWP. Although two cases were selected for the study, the research is not considered a multiple case study because there is no in-depth investigation, which, according to Miguel [55], is characteristic of longitudinal research with more extensive temporal analysis, something that is not the aim of the present study.
- **Mixed Method:** With a sequential exploratory strategy, prioritizing initially collected qualitative data [56]. In this approach, quantitative data are used to assist in interpretation and to corroborate qualitative results. The qualitative strategy poses a broad question for the research, identified from establishing the relationship between RL and CE concepts. Both qualitative and quantitative strategies coexist from the definition of objectives, which were expressed by verbs that keep the investigation open, such as “analyze”, and phrases like “measurement of importance”. According to authors Günther [57] and Creswell and Creswell [56], as research questions are multifaceted, they accommodate more than one method.

To carry out this article, the following steps shown in Figure 1 were followed:

The result of the first stage allowed for a deeper exploration of specific aspects to initiate the exploratory and empirical research of the methodological solution. It was observed that sustainability themes, in general, began in the 1970s, with significant values emerging from 1974 onwards. Since then, the trend of academic research growth has continued, incorporating new themes related to this subject. This literature review provided the basis for establishing RL practices to be researched and the criteria to follow in the empirical study.

To fulfill the second stage, the characteristics of the sample of companies were verified to establish comparison criteria for both analyzed studies. The sample included companies representing nine sectors of the economy engaged in some form of RL practices, including metallurgy, paper, publishing, automotive, hygiene, information technology, cleaning, construction, and pharmaceutical sectors. It was a convenience sample, chosen for ease of data collection, located in the South Fluminense region of Rio de Janeiro State, Brazil. Disad-

vantages of this sampling method may include biases in responses, as the components are not representative of a population, and therefore, generalizations cannot be made. For this reason, literature was reviewed on RL programs and activities and their relationship with CE to initiate field data collection and make appropriate comparisons. Data were collected at two points in time (before and after the implementation of the NSW). According to Creswell and Creswell [56], this type of analysis is referred to as a cross-sectional study.

Step 1	Literature review. • Circular Economy (CE) • Reverse Logistics (RL) • Interrelation between the concepts of CE and LR. • Solid Waste National Policy (SWNP)
Step 2	Verification of the sample of companies. • Sample size. • Type and sector of the companies. • Timeline of the collected data.
Step 3	Grouping and analysis of collected data. • Processing and organization of the data from the studies by Hernández (2011) and Bitencourt (2021). • Use of RL categories related to CE (See Table 2).
Step 4	Results of the decision support method application. • Use of the Analytic Hierarchy Process in both studies.
Step 5	Discussion of results. • What are the most common RL practices? • Interrelation of RL practices with the concepts of CE.

Figure 1. Research steps [36,45].

In the third stage, the original data from the studies by Hernández [36] (data collected between 2008 and 2010) and Bitencourt [54] (data collected between 2019 and 2021) were grouped and organized to maintain the names of RL practices, as shown in Table 2, and thus to be able to relate RL activities to CE activities. Regarding the motivators or objectives of the RL programs practiced by industries, the criteria of Leite [35], Hernández [36], and Govindan et al. [37] were maintained, as shown in Table 1.

In the fourth stage, after grouping the practices (programs and activities) of RL, the results of applying the AHP method in both studies were verified. Both authors, Hernández [36] and Bitencourt [45] decided to use the method developed by Saaty [58] due to its widespread use both individually and in combination with other decision support methods [9,47,59–62]. When the qualitative data collection was completed, it was observed that AHP was suitable for the study's needs, and the RL activities reported by the companies did not exceed the nine elements considered appropriate for comparison by the method. This method operates based on experts who have experience in the study subject, which is why logistics experts from each company participated in the survey and responded to the questionnaire. In Hernández's study [36], 33 experts participated, including general managers with a strategic view of the organization, and in all cases of the nine companies analyzed, logistics managers with over 10 years of experience in the role were included. In Bitencourt's study [45], all nine interviewed experts belonged to the logistics and purchasing area, with a prerequisite that their tenure in the role was equal to or greater than 10 years, for comparability with Hernández's study [36]. Within this group of experts, some had participated in RL projects focused on recycling and resource reuse.

To apply AHP, the method's steps described below were followed:

1. **Hierarchy Representation:** The defined objective was to prioritize RL practices, including criteria (RL programs) and alternatives (RL activities). This hierarchy was specific to each company and later grouped according to the study objectives;
2. **Judgment of criteria and alternatives:** This judgment was carried out through pairwise comparison of all criteria and alternatives using Saaty's Fundamental Scale, where numbers range from 1 (equal importance) to 9 (absolute importance) [58];
3. **Eigenvalue calculation:** Estimation of the relative weights of decision elements at each level using hierarchical synthesis. Subsequently, pairwise comparison consistency is assessed. This consistency must remain less than or equal to 10% for the judgments to be considered valid and is calculated by Equation (1):

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (1)$$

where:

CI : Consistency Index

λ_{max} : Maximum Eigenvalue

n : Number of Criteria

4. **Aggregation of priorities and determination of global priority:** Aggregation of relative priorities was performed to evaluate the outcome achieved concerning the objective. Priorities were calculated for each interviewed expert; since the companies belong to different sectors, their objectives also varied. To aggregate the results, the Aggregating Individual Priorities (AIP) method using arithmetic mean was employed. This aggregation method is used when decision vectors from individuals, with different perspectives on values and objectives, are combined to form an overall priority vector, as occurred in this case.

Table 3 presents the programs and activities that were used to gather information on the RL activities carried out by the company.

Table 3. Programs and Activities of RL.

RL Programs (Based on Objectives or Motivators)	RL Activities (Literature)	RL Activities (Reported by Companies)
Economic Programs (EP)	Materials returned to the production process. Reuse of packaging and sale as raw material for other processes. Resale of products in secondary markets. Recycling	Recycling
	Existence of records of costs generated by returns. Expenditure on social and environmental actions. Expenses for employee training. Costs to operate the reverse channel (collection, sorting, transportation, and storage). Costs for developing new technologies.	Costs to operate the reverse channel. Expenditure on social actions.
Image Programs (IP)	Advertisement as a responsible company regarding its products and processes. Development of new technologies to utilize recycled materials.	Development of new technologies.
	Proper disposal of waste.	Proper disposal of waste.
Corporate Citizenship Programs (CCP)	Social projects. Educational projects. Employment creation to operate the reverse channel.	Projects/Advertising ¹

Table 3. Cont.

RL Programs (Based on Objectives or Motivators)	RL Activities (Literature)	RL Activities (Reported by Companies)
Customer Service Programs (CSP)	Partnerships with stakeholders. Liberal return policies.	Partnerships with stakeholders.
	Customer retention. Well-defined returns.	Customer retention ¹ .
Legal Programs (LP)	Corporate responsibility for properly disposing of their products at the end of their useful life.	Corporate responsibility for proper disposal.
	Establishment of minimum recovery levels to be met by companies.	Minimum recovery levels ² .

¹ For the final result, the marked items will be summarized under ‘other activities’ as they were not identified as CE practices. ² Minimum recovery levels were only marked by one of the companies, and when further discussed with the experts, the understanding was compliance or responsibility for proper disposal. Therefore, it was considered only one activity within the LP.

As can be seen in Table 3, out of the 21 RL activities surveyed in the companies, only nine appeared, thus making it feasible to use the AHP.

Finally, in the fifth stage, the results are analyzed, both quantitatively through the comparison of priorities, as well as qualitatively to identify which RL activities the companies are carrying out and their relationship with the concept of CE.

3. Results

As previously mentioned, data collection was conducted in nine companies from various sectors engaged in RL activities. This survey corresponds to two different points in the timeline, identified in the present study, based on the results of Hernández [36] and Bitencourt [45].

To avoid unnecessary repetitions, we initially address the study by Hernández [36], covering all steps of the AHP. It is important to highlight that the data collected in Hernández’s research [36] spans the period from 2008 to 2010, prior to the enactment of the NSWP.

To exemplify the study, the application of the AHP method for both case studies will be presented below.

- (a) **Hierarchy Structure:** Figure 2 depicts the hierarchical tree representing the RL practices identified in the surveyed companies (categories from Table 3). For applying the AHP, the levels of the hierarchical structure are represented by objectives or goals, programs, and activities. Therefore, in the models that will be analyzed, RL programs or drivers represent the criteria, and RL activities represent the alternatives of the method.

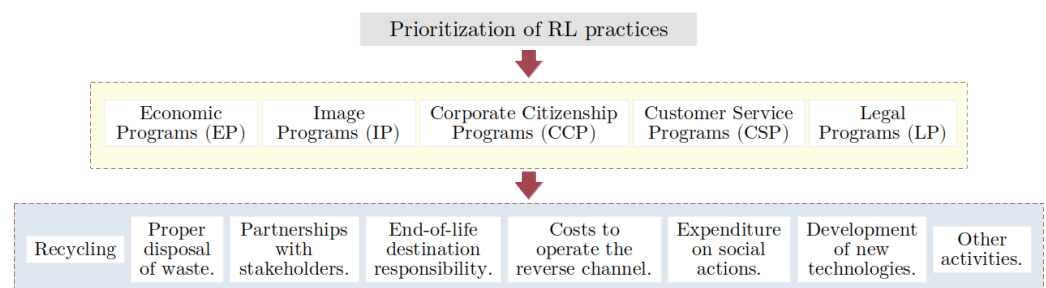


Figure 2. Hierarchical tree with the RL activities in the surveyed companies.

Figure 2 depicts the generalized hierarchical tree for the two case studies. It was constructed using and grouping the data collected from the two analyzed cases. In Hernández's study [36], the term "recycling" did not appear; instead, the terms "materials returned to the production process", "reuse of packaging and sale as raw material for other processes", and "resale of products in secondary markets" were mentioned. Referring to Table 2, according to the definitions by Zhu et al. [44] and NIC [43], these terms signify value recovery, investments, and achieving some form of savings through recycling. Therefore, it was decided to use the term "recycling" and aggregate therein the weights of the other mentioned categories.

Other activities not identified in Hernandez's model [36] included: end-of-life product disposal responsibility; costs of operating reverse channels; disbursements for social actions. Nevertheless, these latter two elements were diluted within advertising and social projects activities (considered in other activities) and in the development of new technologies, as greater importance was given to those technologies that entailed higher expenses.

In Bitencourt's study [45], all activities from the hierarchical structure in Figure 2 are included. Regarding the level that includes RL programs, there was no difference between the two studies (all 5 RL programs are included, although not all companies have identified each one). Nevertheless, as the data will be aggregated, those unidentified programs will decrease in their weight or importance in the overall result that the method reveals.

- (b) **Judgment Execution and Global Priority Determination:** To continue with the application of the AHP method, 6 judgment matrices were developed (one matrix for evaluating the criteria/programs and five matrices for analyzing the importance of each RL alternative/activity compared to each program). The pairwise comparison of judgments was conducted using the Saaty Fundamental Scale (values ranging from 1 to 9) [58]. Lastly, the global priority of each program and alternatives was determined, as shown below in each particular case.

CASE A: Study by Hernandez [36]

By way of example, Table 4 displays the judgment matrix and the priorities of criteria (RL programs) identified by one of the experts in one of the surveyed companies.

Table 4. The judgment matrix and the priorities of criteria (RL programs).

Criteria/Programs	CSP IP		CCP	EP	Priorities of RL Programs
Customer Service Programs (CSP)	1	3	6	3	0.52740
Image Programs (IP)		1	3	1	0.19791
Corporate Citizenship Programs (CCP)			1	1/3	0.07553
Economic Programs (EP)				1	0.19916
Legal Programs (LP)	-	-	-	-	-

Adapted from Hernández [36].

As can be seen in Table 4, for this particular company, the legal program (PL) was not identified as an RL activity. This pattern was also observed in three other surveyed companies, which influenced the overall importance result of this RL program when all the data were aggregated.

Similarly, criteria and alternative judgments were conducted across all companies in the study, confirming that consistency ranged between 0 and 0.0624, indicating coherent judgments.

As previously explained, to aggregate priorities and present a single result, the AIP criterion was used, where the arithmetic mean of all priorities led to the final outcome. The consolidated global priorities for the nine surveyed companies can be seen in Table 5. Given the minimal divergence in RL practice results among the studied companies, it was preferred to maintain the grouping and analyze the outcomes from this perspective.

Table 5. Priorities of the RL programs and activities in the surveyed companies in Hernández [36].

Criteria/Programs	Priorities of RL Programs
Economic Programs (EP)	0.52882
Legal Programs (LP)	0.02285
Image Programs (IP)	0.24378
Customer Service Programs (CSP)	0.13185
Corporate Citizenship Programs (CCP)	0.07270
Alternatives/Activities	Priorities of RL Activities
Recycling	0.18862
Proper disposal of waste.	0.01585
Partnerships with stakeholders.	0.05301
Development of new technologies.	0.60199
Weight of all RL-CE activities (Total Value)	0.85948
Weight of other RL activities not related to CE (Total Value)	0.14052

Adapted from Hernández [36].

As observed in Table 5, the economic program (EP) has a higher priority compared to others, followed by the image program (IP). The program of least weight or importance was the legal program (LP). Regarding the importance of alternatives, the greatest weight is placed on the development of new technologies (clean technologies, development of components with recoverable materials). Second in priority is recycling, although the primary objective at this time was to extract economic value through recovery or reuse. In the category of “other activities”, the highest weights are found in marketing and advertising activities involving the community, such as job creation and social and educational projects. It is believed that for this reason, the second highest-scoring program is the image program.

Activities such as operating RL costs, disbursements for social actions, and companies’ responsibility for the correct disposal of their products at the end of their useful life still do not appear in the scenario of the surveyed companies.

CASE B: Study by Bitencourt [45]

To analyze this case, a higher degree of detail was provided regarding the priorities of RL programs and activities. It was observed that the implementation of the NSWP did not equally influence all analyzed companies and sectors. Table 6 presents the priorities of RL programs in each surveyed sector.

Table 6. Priorities of RL programs in the surveyed companies from Bitencourt [45].

Sectors	Reverse LP				
	EP	LP	IP	CSP	CCP
Metallurgical	0.51399	0.25758	0.06721	0.03793	0.12329
Civil construction	0.28084	0.28084	0.28084	0.10697	0.05051
Automotive	0.71706	0.21717	0.06577	-	-
Domestic appliance	0.19955	0.51281	0.19093	0.03334	0.06338
Hygiene	0.51281	0.26150	0.12898	0.06338	0.03334
Pharmaceutical	0.51281	0.23709	0.08778	0.03334	0.12898
Paper	0.51281	0.03334	0.12898	0.06338	0.26150
Computer	0.50564	0.06655	0.13034	0.03336	0.26411
Publishing	0.36209	0.36209	0.16069	0.03892	0.07620
Aggregated priorities	0.45751	0.24766	0.13795	0.05133	0.12516

Adapted from Bitencourt [45].

It is observed in Table 6 that not all programs are identified in every company. In the automotive industry, RL activities are only motivated by economic, legal, and image factors [54]. Another important observation is the significance or weight of each program in each sector. For example, in the household appliances sector, greater importance is

attributed to LP than EP. This could be explained by the fundamental legislation in this area, such as consumer protection laws that have allowed exchanges long before the implementation of the NSW. P.

The priorities were grouped using the AIP criterion, and the result is observed in the last row of Table 6. EP remains a priority in the implementation of RL practices, but there are significant changes that will be analyzed later. The priorities of RL activities are shown in Table 7.

Table 7. Priorities of RL activities in the surveyed companies from Bitencourt [45].

RL Activities Related to CE	Priority of Activities
Recycling	0.26230
Proper disposal of waste.	0.11241
Partnerships with stakeholders.	0.03170
Corporate responsibility for properly disposing of their products at the end of their useful life.	0.13923
Costs to operate the reverse channel.	0.18162
Expenditure on social actions.	0.02705
Development of new technologies.	0.02452
Weight of all RL-CE activities.	0.77883
Other RL activities.	
Projects/ Advertising.	0.10629
Customer retention.	0.04723
Minimum recovery levels.	0.04759
Weight of other RL activities.	0.22117

Adapted from Bitencourt [45].

The main aspect to highlight in this case is the emergence of new categories of RL activities. The cost of operating the reverse channel and expenditures on social actions, which in Hernández's study [36] were perceived in a diluted manner by the experts, appear here as independent categories.

4. Discussion

Based on the results presented so far, comparative analyses can be conducted regarding the priority of RL practices. Table 8 shows the priority order of RL practices (programs and activities), specifically those related to the concept of CE, in each of the cases studied.

Table 8. Order of priority of RL practices in the surveyed companies.

RL Programs	Order of Priority [36]	Order of Priority [45]
Economic Programs (EP)	1°	1°
Image Programs (IP)	2°	3°
Corporate Citizenship Programs (CCP)	4°	4°
Customer Service Programs (CSP)	3°	5°
Legal Programs (LP)	5°	2°
RL activities related to CE		
Recycling	2°	1°
Proper disposal of waste.	4°	4°
Partnerships with stakeholders.	5°	5°
Corporate responsibility for properly disposing of their products at the end of their useful life.	-	3°
Costs to operate the reverse channel.	-	2°
Expenditure on social actions.	-	6°
Development of new technologies.	1°	7°

The analysis of the data from Table 8 shows significant changes regarding the two cases studied:

- In Hernández [36], economic programs (EP) had the highest importance, occupying the first position in priority order, while LP was ranked last in priority. The weight vectors of EP and LP had values of 52.88% and 2.28%, respectively (Table 5).
- In Bitencourt [45], the EP continues to occupy the first position in priority order, but with a weight of 45.75%. However, the second position is now taken by the LP with a weight of 24.76% (Table 6).

Thus, there is a noticeable emphasis on Legal Programs (LP) after the implementation of the NSWP. To corroborate this difference, and even though the result cannot be generalized, a case from the literature was brought forth, the analysis by Leite [63], which similarly obtained an importance of 50% for EP and 6% for LP, occupying the first and last positions in priority order, respectively.

This result, although from a timeline slightly preceding that of Hernández [36], exhibits a similar pattern. Thus, differences are observed in relation to the findings of studies conducted before and after the implementation of the NSWP.

Concerning specific RL activities before and after the implementation of the NSWP, some changes are also observed. After the NSWP, new categories of RL activities appear, distinctly different, such as the economic aspects of managing the reverse channel because the law requires it, or disbursing money to carry out certain social actions. It can also be observed that recycling (as a means of recovering value and reusing raw materials) holds a prominent position, both before and after the NSWP.

The Brazilian Association of Public Cleaning and Special Waste Companies (ABRELPE) [53] showcased the evolution of implemented RL systems in the country through the report “Solid Waste Overview in Brazil”. Some of these findings were highlighted by Silva and Hernández [64], providing insights into the progress made regarding recycling efforts.

- The recycling of agricultural pesticide packaging increased from 37.4 thousand tons processed in 2012 to over 53.5 thousand tons in 2021.
- Similarly, plastic packaging from lubricating oil increased from 2538 tons recycled in 2012 to 4774 tons recycled in 2021.
- The collection and environmentally correct disposal for recycling of household electronic waste, or e-waste, in 2021, amounted to 1245 tons, surpassing the target established by Federal Decree No. 10240 of 2020.
- A total of 22,336.65 tons of paper and cardboard packaging were recovered, along with 8194.43 tons of post-consumer plastic packaging from discarded electronic products.
- In 2021, approximately 303,000 tons of dry recyclable waste were recovered: 46.3% comprised paper and cardboard, 26.5% comprised plastic, 14.5% comprised metal, and 12.2% comprised glass.

It was also possible to observe that not all RL activities performed by companies are categorized as CE activities, but many of them are identified as such, even before this latter concept gained traction. Thus, when analyzing the importance or aggregated weight of RL practices related to the CE, Hernández’s study [36] shows a weight of 85.94% (Table 5).

Following the criterion established by Zhu et al. [44], the following activities found in Hernández’s study [36] are part of the CE concept (See Table 9).

This corroborates the criteria of some authors who sought to position RL as a pillar of the CE, thereby relating the two concepts and highlighting the importance of RL in implementing the circular model [65–69].

It is still evident that, despite there being few publications on CE separate from RL [70], CE practices already exist within companies, even before managers have heard of the concept. However, the concept of RL is much more widespread in the business environment.

Table 9. Alternatives/ Activities of RL prioritized in the study by Hernández [36].

Activities of RL Prioritized before the NSWSP
Investment recovery Reuse of packaging and sale as raw material for other processes. Recycling Develop new technologies (costs). Proper disposal of waste.
Green Procurement Partnerships with stakeholders.

As a contribution of this study, analyzing the relationship between RL and the CE proves to be an innovative topic for several reasons:

- Emerging concepts are being integrated: RL has already been practiced by many organizations, but CE is a relatively new and disruptive concept that deviates from the traditional linear economy model. Therefore, studying its relationship with RL offers insights on how to optimize and expand these practices and helps understand how this transition can be operationalized.
- The integration of the two concepts can help minimize the negative environmental impacts associated with the production and disposal of products, contributing to ecosystem conservation and the reduction in carbon emissions.
- The intersection between RL and CE can encourage innovation in product design, manufacturing processes, and business models, creating new opportunities for companies and startups.
- Analyzing this relationship can provide valuable insights for policymakers seeking to promote sustainability through regulations that encourage RL and CE practices, thereby supporting governmental strategies.

5. Conclusions

Based on the obtained results, the objective of the study was achieved by analyzing the impact of the NSWSP on the practice of RL in companies in the South Fluminense region. By comparing the studies of Hernández [36] and Bitencourt [45], significant changes in RL practices are observed, demonstrated by the weights or priorities determined by the AHP method. Before the NSWSP, the legal program (PL) had a low priority, whereas in the more recent study after the implementation of the NSWSP this legal program has gained greater prominence. However, Brazilian legislation still lags behind the environmental regulations of other countries.

Although the NSWSP has brought significant advancements to waste management in the country, several limitations and challenges remain in its implementation. These include fragmented and conflicting legislation that hinders uniform application across the country; lack of communication and collaboration among different levels of government responsible for enforcing the law; low public awareness regarding selective collection; insufficient environmental education programs that do not reach the entire audience necessary for significant behavioral change; last but not least, bureaucracy that can delay the implementation of waste management projects, discouraging investments and public-private partnerships.

The study also showed that, regardless of the prominence of legal programs (LP), economic motivators remain the most important for the implementation of RL in companies. An important aspect to highlight is the issue of sustainability. It can be observed that image programs (IP) have changed their level of importance in the two studies reported. However, recycling activities, waste reuse, and the responsibility of companies for the proper disposal of their end-of-life products are the most prominent and can influence various RL programs, such as economic, legal, and image-based programs.

In addition to obtaining economic gains and/or being mandated by legislation, companies also promote their sustainability practices. This reason places image programs (IP) in a

prominent position. According to Pinheiro et al. [71], in emerging countries such as Brazil, companies seek to legitimize their environmental responsibility practices through dissemination, and some of the social responsibility indicators reported in this study correspond to those highlighted in RL image programs (IP).

The research contributes practically to both organizations and sustainability, as it innovates by analyzing criteria/programs and alternatives/activities of RL and their relationship with the CE; the latter concept is considered by many to be relatively new.

Practical implications for organizations include the importance of implementing RL and CE practices to reduce operational costs by reusing, remanufacturing, and recycling materials, thus decreasing the need for new raw materials; how the adoption of these practices contributes to regulatory compliance, such as adhering to the NSWP; the improvement of reputation and image through the adoption of sustainable practices.

As a practical implication for the sustainability theme, it shows that both RL and CE practices promote more efficient resource use by recycling, remanufacturing, and reusing, aspects highlighted by the importance these activities have in the surveyed companies. All this contributes to the reduction in environmental impact. Another notable aspect is that companies adopting these concepts can set an example and educate their consumers and partners about the importance of sustainability, promoting behavioral change throughout the value chain.

As a theoretical contribution, the effectiveness of using the AHP method to achieve the proposed objectives, establish priorities for RL activities and programs, and implement CE strategies can be highlighted. Companies can replicate the study both in the same region and in different regions, as both criteria and RL activities can be added or removed to adjust to specific cases.

As a limitation, the study analyzed a specific region, the South Fluminense region, and only a few sectors, so the results cannot be generalized. As a recommendation for future research, the analysis can be conducted in other regions and sectors, or even in the same region and sectors but in different companies to enable comparison between the studies.

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Abbreviations

The following abbreviations are used in this manuscript:

AHP	Analytic Hierarchy Process
AIP	Aggregating Individual Priorities
CCP	Corporate Citizenship Programs
CE	Circular Economy
CSP	Customer Service Programs
EMF	Ellen MacArthur Foundation
EP	Economic Programs
IP	Image Programs
LP	Legal Programs
NIC	National Industry Confederation

NWSP	National Solid Waste Policy
RCRA	Resource Conservation and Recovery Act
RL	Reverse Logistics

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