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Modelling the Barriers to Reverse Logistics for Sustainable Supply Chains: A Combined ISM and MICMAC Analysis Approach

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Abstract

Reverse Logistics (RL) plays a fundamental role in supply by addressing returns, undelivered or damaged products, exchanges, and environmental concerns, directly contributing to more sustainable supply chain practices. Although firms recognize the importance and benefits of this concept, their supply chain remains focused on direct logistics, often overlooking RL's potential to enhance sustainability performance. The aim of this article is to analyse the interaction between the barriers that challenge or prevent the implementation of RL in Small and Medium-sized Enterprises (SMEs). First, a literature review identified 22 barriers to developing RL in SMEs. Then, through experts' opinions gathered in a Focus Group (FG), an Interpretive Structural Modeling (ISM) model was used to understand the hierarchy relations between barriers, and a Matrix Cross Impact Matrix Multiplication (MICMAC) analysis was carried out to aggregate the barriers in four categories according to their influencing power and dependence. Applying the methodology to the Portuguese case resulted in an ISM model with seven hierarchical levels and a MICMAC diagram without dependent barriers. Moreover, six key barriers emerged, namely, Lack of adequate organizational structure and support for RL practices, Lack of corporate social responsibility, Complexity of the operation, Lack of shared understanding of best practices, Difficulty with members of the supply chain, and Lack of support from supply chain players, which proved to be the most critical as they are positioned at the highest hierarchical levels of the ISM model and fall within the independent variable quadrant of the MICMAC analysis, thus revealing a strong driving power over the other barriers. The findings highlight that overcoming these barriers is crucial for SMEs to unlock the full sustainability potential of RL and transition towards supply chain models that are greener through a reduced carbon footprint, improved resource efficiency, and the adoption of circular economy practices. Academically, this research advances the literature by applying the ISM–MICMAC approach to SMEs, offering novel insights into the structural role of barriers in reverse logistics implementation.

Keywords: reverse logistics; barriers; ISM; MICMAC; SMEs; sustainability

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1. Introduction

Due to the growing demand for ecological products and the pressure exerted by customers and other stakeholders throughout the supply chain, emphasizing environmental

awareness and sustainable management, many companies have come to recognize the importance of applying sustainable supply chain management concepts in their activities [1].

In light of evolving market requests, a novel logistics paradigm has emerged, focusing on product reuse, reconditioning, and recycling, commonly referred to as Reverse Logistics (RL). While conventional logistics involves moving products from origin to consumption points, RL introduces a paradigm shift by promoting reverse flows. This allows products to be returned for reuse, reconditioning, recycling or deposition on landfill, thereby contributing to a more sustainable and circular economy [2]. The concept has gained global traction, influencing all tiers of supply chain operations across diverse industry sectors. Efficient RL strategies can potentially increase revenues and reduce costs significantly [3].

Recognized as a crucial component of supply chain management, implementing RL is challenging due to several barriers. Many efforts have been made to explore these barriers, but investigations are still minimal. There is still a lack of quantitative research based on the investigation of participant opinions, revealing the importance of each barrier [4].

It is fundamentally important to analyze the interaction between these key barriers that challenge or prevent the application of RL [5].

This is because these barriers inevitably interact with each other, and a particular barrier could be mitigated by removing other barriers that affect it [6]. In addition, the interrelationships among barriers could influence the importance of each barrier because a particular barrier may become an important threat to the ISM through its interaction with other barriers, although this barrier cannot directly have a significant impact [7]. However, few studies have explored the interaction of these barriers and their integrative effects.

Some barriers influence others, so monitoring the system that can determine these key barriers and understanding how their influence spreads and impacts RL is essential. Identifying the key barriers and modelling how they affect others can support the design of appropriate decision-making to overcome those barriers and restrictions [3].

Aiming to understand the relations among the barriers hindering the implementation of RL, Interpretive Structural Modelling (ISM) can be a supporting tool to consider. It can identify and summarise relations between specific variables defining a problem or issue [8]. ISM and Matrix Cross-Impact Matrix Multiplication (MICMAC 3) have been adopted in similar studies on adopting innovative technologies and practices. The literature review shows that ISM has been carefully used by researchers in various areas such as construction [9], RL suppliers [10], the health system [11], the supply chain [12], entrepreneurship [13], education [14], e-commerce [15], the lean system [16], six sigma [17], and agriculture [18].

However, few studies have explored the interaction of these barriers and their integrative effects [19], for example Waehrens et al. [20], Karim et al. [21] and Ali et al. [22].

The main objective of this article is to identify and analyse the key obstacles to the implementation of RL in SMEs. This study represents a new contribution to the literature, as the combined ISM-MICMAC analysis approach is not normally used to identify the barriers to RL implementation in SMEs, although the ISM-MICMAC approach has previously been used successfully to analyse the adoption of RL in large industries [4,23,24]. This research focuses on the Portuguese context and offers a new insight by identifying the barriers to RL implementation in SMEs through a combined ISM-MICMAC approach, supported by focus groups. The Portuguese context is particularly relevant for this research as SMEs dominate not only in the textile and footwear sectors, which play a central role in the country's economy and are under increasing pressure to improve their sustainability practices, but also in other industries such as pharmaceuticals and information technology, where reverse logistics poses distinct yet equally pressing challenges [25]. Moreover, Portugal presents structural challenges such as limited financial resources and organizational constraints

within SMEs, which may intensify the barriers to RL implementation compared to other European regions. This makes Portugal a distinctive and insightful case to study, while also providing lessons that can be adapted to similar contexts [26,27].

Thus, this study aims to contribute by identifying barriers that can assist decision-makers in making informed decisions to mitigate the obstacles to the implementation of RL in SMEs.

The article is structured in six distinct parts. The first presents a general view of RL. The second reviews the literature, addressing the fundaments of RL and the methodology adopted in the research. The methodology is presented in great detail in the third part, being divided into three stages: a review of the literature referring to the barriers to implementation of RL; application of the ISM model; and the MICMAC analysis. The last part contains the conclusions, addresses the study's limitations and suggests future research paths.

2. Literature Review

2.1. Reverse Logistics

Companies have turned their attention to RL, using it as a strategic tool to satisfy customer needs and stimulate profit. An efficient reverse distribution structure can create significant return on investment and lead to a considerable increase in market competitiveness [28]. Due to economic development and growing competition in the market, companies are more motivated to find modern solutions to improve their commercial activity, and RL can be the path to higher performance.

RL consists of a number of operations to manage products returned by customers to suppliers, generally for recycling, repair, elimination or reuse and always at the lowest possible cost [29].

Driven by market competition and economic growth, businesses are more motivated than ever to modernize their operations, and RL often serves as a path to improved performance. Recent findings support this trend. For instance, Saglam [30] demonstrates that RL capabilities significantly enhance firms' environmental, economic, and social outcomes—even more so when supported by a strong sustainability culture. Similarly, Appiah & Owusu-Bio [31] reveal that RL can have a positive effect on financial performance in developing economies when firms possess advanced analytics capabilities, which mitigate the cost challenges typically associated with RL implementation.

Therefore, RL is recognized as a fundamental aspect of environmental protection, having been adopted by international companies as part of a strategy to improve economic and environmental performance [32].

According to El Boudali et al. [33], RL management is a fundamental aspect of supply chain management, reducing costs and generating value for the firm. Appropriate RL implementation helps develop an ecological supply chain, increase customer satisfaction and gain a competitive advantage [34].

As a central topic in the academic debate in environmental performance and business sustainability, it has been recognized in various studies as an effective strategy for companies, the environment and sustainable development. RL is fundamental due to several factors, such as mitigating environmental problems, cost control and competitive advantage. However, despite its importance, the area of RL has not yet been sufficiently explored and several questions remain to be studied [35].

In spite of the progress made in recent years, RL is still a challenge for many developed countries and especially for developing ones [36]. Companies face several complications and challenges when carrying out RL activities due to the various barriers that hinder the process [37].

2.2. ISM and MICMAC

ISM is a computational method to develop graphic representations of the composition and structure of systems. It originated in the belief of Warfield [38] about the need to establish a relation between science and politics. The author recognized the importance of communication tools that were scientifically robust and accessible to the general public. An advantage of this methodology is that it describes the order and direction of relations between a system's elements [23].

The ISM model has been used by researchers in the last decade to analyze barriers. This methodology is widely used in ecological supply change management strategies to develop and analyze the variables hindering more sustainable supply chains [39].

The ISM approach is a technique that helps to understand and simplify complex problems. The model is particularly useful for interpreting rooted variables and transforming unclear models into visible, well-defined ones.

Kumar et al. [40] underline that ISM offers a simplified way to solve complex problems, providing orientations in interpreting rooted objectives. This approach gives a clearer, more structured analysis of problems, facilitating identification of their inter-relations and providing a broader view. Furthermore, Jha et al. [41] state that ISM helps in transforming badly segmented and unclear rational models into more visible, well-defined ones. This means that the technique not only simplifies the understanding of the system, but also makes them more tangible, facilitating the decision-making process and the implementation of effective solutions.

For more thorough knowledge about the barriers, combining ISM with the Matrice d'Impacts Croisés Multiplication Appliquée à un Classement (MICMAC) analysis is fundamental. Combining MICMAC with ISM gives a holistic approach to the analysis of complex problems, allowing a deeper understanding of the relations between the variables involved and facilitating decision-making [42].

MICMAC analysis is based on the principle of matrix multiplication properties, and one of the main objectives of this analysis is to examine and categorize the variables of interest in terms of driving power and dependence power where all variables are classified into four specified clusters [43].

The final hierarchical model of the ISM, associated with the MICMAC analysis, improves understanding of the variables considerably and increase the methodological rigor [44,45].

2.3. Justification of the Methodology Proposed for RL Development

During constant economic development and increasing market competition, enterprises are compelled to seek modern solutions to enhance their business activities, with RL potentially providing an answer to these aspirations for improved performance. However, the decision to implement RL processes within a company is not an easy one. Such investments can encounter numerous barriers and obstacles that are difficult to overcome, effectively hindering the successful implementation of RL [29].

In this context, Govindan Hasanagic [46] identified the barriers that prevent or complicate the implementation of RL in companies using multivariate descriptive and inferential statistics. Abdulrahman et al. [47] proposed a theoretical model to empirically identify significant barriers to RL concerning management, finance, policies, and infrastructure in manufacturing industries.

Lamba et al. [48] employed an analytic hierarchy process-based methodology to identify lack of investment in RL, lack of knowledge of best practices, and uncertainty regarding returns and demand as the three main obstacles to RL.

Sirisawat & Kiatcharoenpol [49] used a methodology based on the fuzzy analytic hierarchy process and the fuzzy technique for order preference by similarity to an ideal solution to classify the barriers.

Bouzon et al. [50] used a Multi-Criteria Decision-Making tool named grey-based Decision-Making Trial and Evaluation Laboratory to extract perspectives from multiple company–customer–government associations on the barriers to implementing RL.

Over the years, many efforts have been made to explore these barriers, but investigations remain minimal. Quantitative research based on participants opinions, revealing the importance of each barrier, is still lacking [6]. Furthermore, the interrelationships between obstacles systematically affect the importance of each one in implementing RL. It is crucial to classify them according to their dependency and driving powers. While previous studies have explored these barriers, few have analyzed their complex interrelationships [7,51].

Some variables, which in this study are referred to as barriers, affect the implementation of RL practices, so analysing the direct and indirect relationships between them can give a holistic view of the situation, rather than just considering the individual variable in isolation.

The effectiveness of the ISM model lies in its capacity to portray the structure of a complex problem using a carefully conceived standard combining graphs and words [28].

The basic idea of ISM is to break down a complicated system into various sub-systems, using specialists' practical experience and knowledge to construct a multi-level structural model.

ISM can be used to identify and analyze the relations between specific variables defining a problem or issue [38]. Mishra et al. [52] applied ISM methodology to identify and model the obstacles to the internationalization of SMEs in the automobile sector in the context of emerging markets. Talib and Rahman [53] used the methodology to identify the potential obstacles to telecommunication services and to develop relations between them. Dube &Gawande [54] developed the model to identify the contextual relation between ecological supply chain management obstacles. Orji [55] used the modelling technique to examine the barriers to organizational change towards sustainability and the factors supporting sustainable performance. Sarkar et al. [56] used ISM to build a structured model of the factors leading to the adoption of green businesses in emerging economies.

Therefore, this research intends to apply the ISM methodology to understand the reciprocal influences among the barriers hindering or preventing RL implementation in SMEs and identify the stimulating barriers that can aggravate others and the dependent barriers that are most affected by the stimulating barriers.

3. Methodology

This research's methodological approach consists of three phases, as presented in Figure 1: I—Determining the critical barriers; II–ISM; and III—MICMAC analysis.

The FG technique was fundamental to the operationalisation of stages II and VI of this study's methodology.

FG has a fundamental role in ISM, since the whole process and the result depend on its contribution [57], the FG is a research method of an exploratory nature that gathers qualitative data from the group's interaction in relation to a topic presented by the moderator. The group should represent all those involved in the scope of the problem, with special attention being paid to size, specialization and diversity. They should have solid experience in the area and specialized knowledge of the variables studied [44].

The FG stimulates discussion among specialists about their perceptions, opinions, attitudes and beliefs with regard to a product, service, theory or concept, extending and improving the existing information about a topic and creating new perceptions [58].

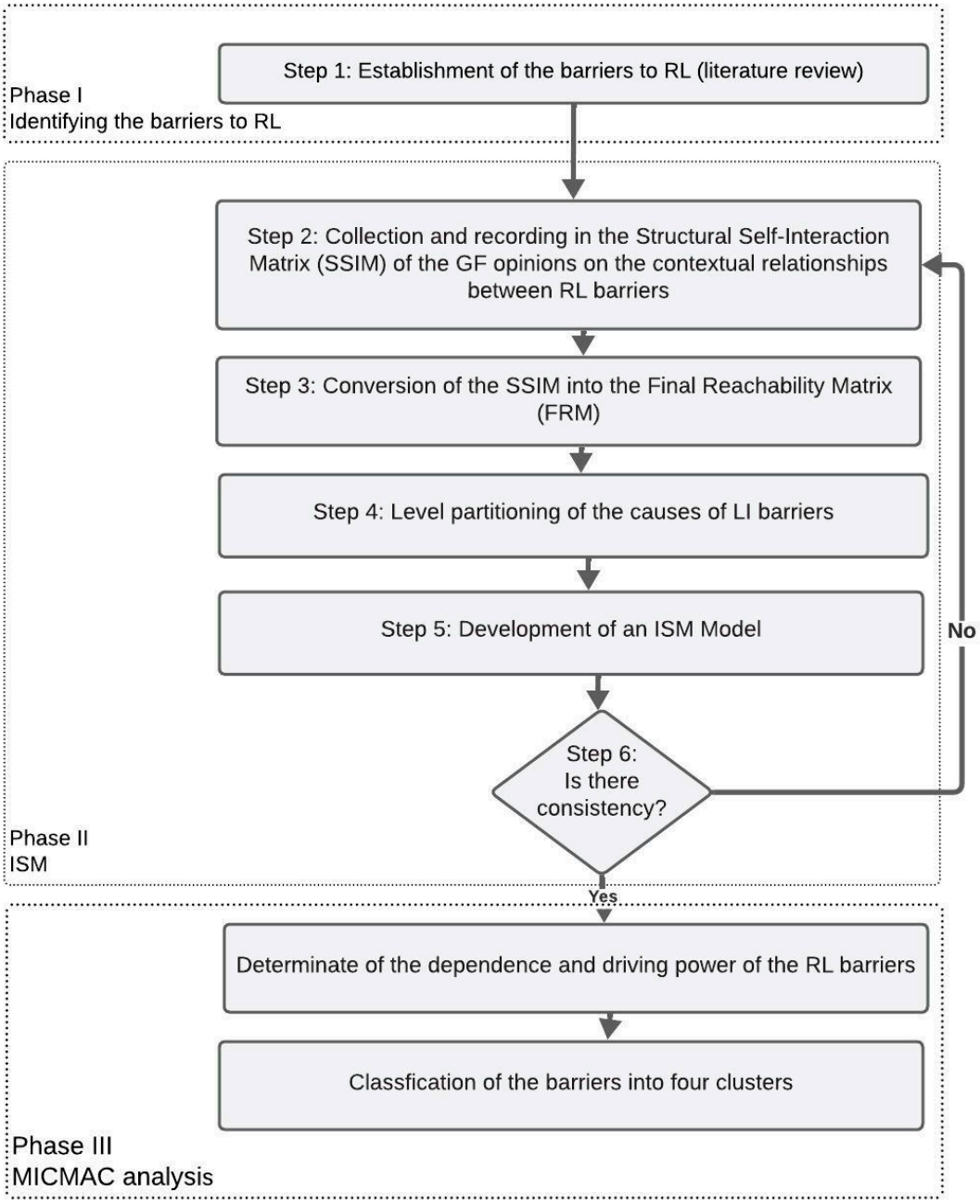

Figure 1. Research Methodology.

According to [59], FG should be formed of 4 to 12 participants. Therefore, the FG that built the SSIM (Structural Self-Interaction Matrix) for this study was made up of 8 experts with knowledge of RL and more than 5 years' experience. The focus group was composed of eight experts with more than five years of professional experience in reverse logistics. The experts represented different sectors of the Portuguese economy, namely footwear, textiles, waste management, and technology. This diversity ensured that the analysis incorporated perspectives from industries where SMEs play a central role and where reverse logistics practices face distinct operational and organizational challenges. In the meeting, held using the Zoom video-conferencing application, the barriers to implementing RL were presented and explained, and the ISM-MICMAC logic was addressed.

Although the FG sessions were conducted online via Zoom, specific measures were adopted to preserve the quality of interaction and consensus building, such as the use of

structured moderation, clear presentation of the barriers and ISM-MICMAC logic, and active facilitation to ensure balanced participation among all experts.

The meeting was moderated by one of the researchers to ensure a clear understanding of the obstacles to implementing RL, stimulate debate, and ensure that the discussion transitioned from general to specific topics to promote sincerity and reduce biases [60].

The study used the principle of "majority rules" [7] when the specialists had diverging opinions. The meeting, held using the Zoom video-conferencing application, presented and explained the barriers to implementing RL and addressed the ISM-MICMAC logic.

3.1. Phase I—Identifying the Barriers to RL

Step 1—Identification of the barriers

This study uses the barriers validated previously (Table 1). In that study, the literature review focused on the Scopus and Web of Science databases, using the terms of 'Reverse Logistics' and 'Barriers', analyzing 330 scientific articles published in international journals. That process identified 61 barriers that were subsequently grouped in seven categories. Then, the Fuzzy Delphi Method was used to obtain a critical list of barriers, with the collaboration of 20 specialists in the area. Of the 61 barriers identified, the specialists validated 22. The set of 22 barriers validated in the study was adopted without modifications, since they were considered sufficiently comprehensive and applicable to the Portuguese SME context.

Table 1. Barriers to implementation of RL.

Code	Barriers	Concepts	Rank
Category: Technology and infrastructure-related issues			
B1	Lack of information systems	The lack or incompatibility of information technology systems for effective transfer of information about product returns between those involved represents an important barrier to RL practices, since the data quality and partners' response capacity are jeopardized when returns have to be dealt with manually.	16
B2	Complexity of the operation	The complexity of the RL operational process can create significant difficulties in recycling waste.	10
B3	Lack of support infrastructure	RL frequently faces problems with infrastructure, such as storage, collection, recycling facilities and selecting the most suitable form of transport.	11
Category: Governance and supply chain process-related issues			
B4	Difficulty with members of the supply chain	An important obstacle to RL is the reluctant support from traders, distributors and retailers for activities.	19
B5	Uncertain quality and quantity of returned products	Companies cannot control the quality and quantity of returned products from the point of consumption. Product quality is not standard in RL compared to direct logistics	1
B6	Lack of support from supply chain players	Most RL processes are carried out by external logistics companies and the lack of coordination with these can have costs for the firm.	14
B7	Lack of shared understanding of best practices	Many organizations do not yet follow the best practices adopted by their competitors and by developed countries..	12
Category: Economic-related issues			
B8	Uncertain financial costs	Due to the uncertain quality of returned products, it is difficult to calculate the cost of operations.	5
B9	Financial constraints	Insufficiency or difficulty in attracting financial resources leads to postponing the implementation of RL practices.	8

Table 1. *Cont.*

Code	Barriers	Concepts	Rank
B10	High costs	Organizations have a false perception that the costs of RL are higher than the costs related to eliminating waste.	3
B11	High investments and low returns	Organizations perceive RL as an operation involving high investment, but with little financial return.	9
B12	Lack of short-term economic benefits	Companies have the perception that the economic benefits of RL are only achieved in the long term.	20
B13	Expenses for collecting used products	For correct separation and segregation of the waste produced, it is necessary to use specific techniques for subsequent reuse or recycling of material, implying a greater effort.	13
B14	Uncertainty of economic benefits	The benefit of RL is uncertain for companies.	2
B15	Lack of economy of scale	A consumer-oriented market and competition from new products raise the question of price sensitivity. Consequently, the margin on returned products is very low, which leads to RL being unattractive.	6
Category: Knowledge-related issues			
B16	Lack of corporate social responsibility	Business ethics implies that it is a company's responsibility to proceed in an approved way, and that it should necessarily reflect on the implications of its behaviour for the population.	21
B17	Lack of qualified professionals in RL	The lack of training and education is a major challenge for RL. These are the main requirements to achieve success.	18
Category: Policy-related issues			
B18	Lack of standards, codes and guidelines	Companies say that the lack of a practical guide is a barrier to implementing RL.	17
B19	Change in regulations due to political changes	Changing political orientations are an obstacle to implementing an RL network.	22
B20	Legal issues	Legal issues are an obstacle to developing reverse operations.	7
Category: Management-related issues			
B21	Lack of investment in RL	The lack of investment in RL prevents the development of reverse flows.	4
B22	Lack of adequate organizational structure and support for RL practices	The lack of basic conditions and functions in the organizational structure delimits practices in adopting RL.	15

The study serves as the basis for Phase I, wherein 22 barriers to the implementation of RL were identified and, subsequently, the authors determined both the fuzzy score and priority level associated with each of these barriers.

3.2. Phase II—ISM

In the present study, ISM was employed to identify and evaluate the interactions between critical barriers to the implementation of RL. This approach allowed for a graphical and hierarchical representation of the connections between these barriers and facilitated the identification of the main barriers that need to be mitigated.

Step 2—Contextual relationships between the critical barriers.

The 22 critical barriers to RL generated $22 \times 21/2 = 231$ different inter-relations. The FG specialists were asked to express the contextual inter-relations between a pair of barriers (Bi and Bj), obtaining four different types:

- V: Bi helps to achieve or influences Bj;
- A: Bj helps to achieve or influences Bi;
- X: Bi helps to achieve or influences Bj and vice versa;

- O: There is no inter-relation between Bi and Bj.

The SSIM elaborated by the 8 specialists is presented in Table 2. As mentioned, the study used the principle of "majority rules" when the specialists had diverging opinions.

Table 2. Structural self-intersection matrix.

Bi1 ↓, Bj2 →	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**
1		O	O	O	O	O	O	A	O	O	O	O	O	V	O	O	O	O	O	O	A	A
2			O	V	O	V	O	O	O	V	V	O	O	O	O	O	O	O	O	O	O	O
3				O	O	O	O	A	A	A	O	O	A	A	O	O	O	O	O	O	A	A
4					O	X	X	V	O	O	O	V	O	V	O	A	O	O	O	O	O	A
5						O	O	V	O	O	O	V	O	V	O	O	O	O	O	O	V	O
6							X	V	O	V	O	V	O	V	O	A	O	O	O	O	O	A
7								V	O	O	O	V	O	V	O	A	O	O	O	O	O	A
8									V	O	O	O	O	V	O	O	O	O	O	O	V	O
9										A	A	A	A	A	O	O	O	O	O	O	V	O
10											X	V	O	O	O	O	O	O	O	O	V	O
11												V	O	V	O	O	O	O	O	O	V	O
12													A	X	O	O	O	O	O	O	V	O
13														V	O	O	O	O	O	O	O	O
14															O	O	O	O	O	O	V	O
15																O	O	O	O	O	O	O
16																	O	O	O	O	O	A
17																		A	O	O	A	A
18																			A	A	A	A
19																				V	V	O
20																					V	O
21																						A

Step 3—Converting the SSIM into the Final Reachability Matrix

Initially, the SSIM was transformed into the initial reachability matrix (IRM), a binary matrix representing the direct relationships between the barriers, which was accomplished by replacing the letters with 1 s and 0 s.

If the (i, j) entry is V in SSIM, the (w, z) entry in the IRM becomes 1 and the (i, j) entry becomes 0.

If the (i, j) entry is A in SSIM, the (w, z) entry in the IRM becomes 0 and the (i, j) entry becomes 1.

If the (i, j) entry is X in SSIM, the (w, z) entry in the IRM becomes 1 and the (i, j) entry becomes 1.

If the (i, j) entry is O in SSIM, the (w, z) entry in the IRM becomes 0 and the (i, j) entry becomes 0.

Then, the IRM was checked for transitivity, giving way to the FRM. If barrier i influences barrier j and barrier j influences barrier k, then barrier i indirectly influences k through barrier j, and if the entry (i,k) in the IRM is 0, then it must be changed to 1*. Before calculating the FRM, the matrix IRM_I was obtained by adding the IRM to identity matrix I. The FRM was then obtained through the Boolean operation, which involved self-multiplication of IRM_I until it reached a stable state, as indicated in Equation (1) [9]:

$$\text{IRM_I} \neq \text{IRM_I}^2 \neq \ldots \neq \text{IRM_I}^{n-1} \neq \text{IRM_I}^n = \text{IRM_I}^{n+1} = \text{FRM} \quad (1)$$

Step 4—Level partitioning of the barriers.

After completing the reachability matrix, the barriers are divided into levels. To establish the relevance of each barrier, they are divided into various levels, and three sets are created to divide the barriers efficiently. These are the sets of intersection, reachability and antecedents. The set of reachability includes the barrier in question and all the barriers that depend on it. The antecedent set includes the barrier and all those that affect or influence it. Finally, the intersection set combines the sets of reachability and antecedents,

representing the barriers that depend on and affect the original variable. In the ISM hierarchy, the barriers with the same reachability and intersection are designated as Level I or higher-level barriers. The process of determining the remaining levels is iterative, with the variables of the previous level being eliminated until all have been attributed to a level. Level I barriers are at the top of the ISM hierarchy and do not influence the other barriers. In the higher levels, the barriers are in the lower part of the ISM hierarchy and have a greater influence on the other variables [44,61].

Step 5—Development of the ISM model.

The ISM model was constructed by creating a diagram based on the FRM and the hierarchical level of each barrier. First, the conical matrix of the FRM was built, grouping barriers of the same hierarchical level in the rows and columns of the matrix to facilitate the creation of the ISM model. Second, a preliminary diagram was developed by placing the barriers vertically according to their level partitioning and connecting the barriers with arrows as per the conical matrix. Third, indirect links between the barriers were eliminated to obtain the ISM model.

Step 6—Consistency check.

Finally, the GF experts were asked to verify the conceptual consistency of the hierarchical structure and the interrelations of barriers to the implementation of RL in the obtained ISM model. The experts were instructed to check for any ambiguities in the ISM model and to ensure that it accurately represented their mental model of the system of barriers affecting the implementation of RL.

3.3. Phase III—MICMAC

For a more thorough analysis of the main barriers to implementing RL, as defined in phase III of the methodology, we perform a MICMAC analysis, exploring these barriers' power of influence and dependence.

The MICMAC analysis was developed by [62] based on the matrices' multiplication properties. MICMAC is a technique to classify variables. The variables are mapped on a two-dimensional grid based on their values of dependence and stimulating strength, represented on the horizontal and vertical axes, respectively. The interval of these values varies between 1 and the total number of variables, and the axis are bifurcated at the mid-points, resulting in four quadrants. Each 1 or 1* in the entry (i,j) of the FRM shows that barrier i has an influence on barrier j and the other way around, meaning that barrier j is affected by barrier i. Thus, the dependence power of a barrier is obtained by adding up the values in its column, while the driving power is determined by adding up the values in its row. These quadrants classify the variables in autonomous, dependent, connecting and independent categories. The autonomous variables are not linked to the rest of the system of variables, whereas the linking variables are sensitive and are strongly connected to the independent and dependent variables.

4. Results

4.1. Phase II: ISM

The ISM model was developed by following steps 3 to 6 of phase II of the methodology (Figure 1). In step 2, the SSIM was initially converted into the IRM (Table 3). Next, in step 3, the IRM was checked for transitivity, resulting in the FRM (Table 4) with the help of a VBA program in Microsoft Excel. The driving power and dependence of each barrier were also determined, with the former representing the sum of the respective row and the latter the sum of the respective column in the FRM.

Table 3. Initial Reachability Matrix.

Bi1 ↓, Bj2 →	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
2	0	1	0	1	0	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0
3	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	1	0	1	1	1	0	0	0	1	0	1	0	0	0	0	0	0	0	0
5	0	0	0	0	1	0	0	1	0	0	0	1	0	1	0	0	0	0	0	0	1	0
6	0	0	0	1	0	1	1	1	0	1	0	1	0	1	0	0	0	0	0	0	0	0
7	0	0	0	1	0	1	1	1	0	0	0	1	0	1	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	1	1	0	0	0	0	1	0	0	0	0	0	0	1	0
9	1	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0
10	0	0	1	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	0
11	0	0	1	0	0	0	0	0	1	1	1	1	0	1	0	0	0	0	0	0	1	0
12	0	0	0	0	0	0	0	0	1	0	0	1	0	1	0	0	0	0	0	0	1	0
13	0	0	0	0	0	0	0	0	1	0	0	1	1	1	0	0	0	0	0	0	0	0
14	0	0	1	0	0	0	0	0	1	0	0	1	0	1	0	0	0	0	0	0	1	0
15	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
16	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0
21	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0
22	1	0	1	1	0	1	1	0	0	0	0	0	0	0	0	0	1	0	1	0	0	1

Table 4. Final Reachability Matrix.

Bi [1] ↓, Bj [2] →	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	DVP [4]
1	1	0	1 *	0	0	0	0	0	1 *	0	0	1 *	0	1	0	0	1 *	1 *	0	0	1 *	0	8
2	1 *	1	1 *	1	0	1	1 *	1 *	1 *	1	1	1 *	0	1 *	0	0	1 *	1 *	0	0	1 *	0	15
3	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
4	1 *	0	1 *	1	0	1	1	1	1 *	1 *	1 *	1	0	1	0	0	1 *	1 *	0	0	1 *	0	14
5	1 *	0	1 *	0	1	0	0	1	1 *	0	0	1	0	1	0	0	1 *	1 *	0	0	0	0	10
6	1 *	0	1 *	1	0	1	1	1	1 *	1	1 *	1	0	1	0	0	1 *	1 *	0	0	1 *	0	14
7	1 *	0	1 *	1	0	1	1	1	1 *	1 *	1 *	1	0	1	0	0	1 *	1 *	0	0	1 *	0	14
8	1 *	0	1 *	0	0	0	0	1	1	0	0	1 *	0	1	0	0	1 *	1 *	0	0	1	0	9
9	1	0	1	0	0	0	0	0	1	0	0	1 *	0	1 *	0	0	1 *	1 *	0	0	1	0	8
10	1 *	0	1	0	0	0	0	0	1	1	1	1	0	1 *	0	0	1 *	1 *	0	0	1	0	10
11	1 *	0	1	0	0	0	0	0	1	1	1	1	0	1	0	0	1 *	1 *	0	0	1	0	10
12	1 *	0	1 *	0	0	0	0	0	1	0	0	1	0	1	0	0	1 *	1 *	0	0	1	0	8
13	1 *	0	1 *	0	0	0	0	0	1	0	0	1	1	1	0	0	1 *	1 *	0	0	1 *	0	9
14	1 *	0	1	0	0	0	0	0	1	0	0	1	0	1	0	0	1 *	1 *	0	0	1	0	8
15	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	2
16	1 *	0	1 *	1	0	1	1	1 *	1 *	1 *	1 *	1 *	0	1 *	0	1	1 *	1 *	0	0	1 *	0	15
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	2
19	1 *	0	1 *	0	0	0	0	0	1 *	0	0	1 *	0	1 *	0	0	1 *	1	1	1	1	0	10
20	1 *	0	1 *	0	0	0	0	0	1 *	0	0	1 *	0	1 *	0	0	1 *	1	0	1	1	0	9
21	1	0	1	0	0	0	0	0	1 *	0	0	1 *	0	1 *	0	0	1	1	0	0	1	0	8
22	1	0	1	1	0	1	1	1 *	1 *	1 *	1 *	1 *	0	1 *	0	1	1 *	1	0	0	1	1	16
DEP [3]	18	1	20	6	1	6	6	8	18	8	8	18	1	18	1	2	20	19	1	2	18	1	

[1] Bi—barrier in line i; [2] Bj—barrier in column j; [3] DEP—Dependence; [4] DVP—Driving Power; 1 *—Transitive relationships.

In stage 3, the process of partitioning the levels of barriers to implementing IL resulted in seven iterations and the corresponding seven hierarchical levels, as shown in Table 5.

Table 5. Level partitioning.

Barrier	Reachability Set	Antecedent Set	Intersection Set	Level
3	B3	B:1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,19,20,21,22	B3	I
17	B17	B:1,2,4,5,6,7,8,9,10,11,12,13,14,16,17,18,19,20,21,22	B17	I
15	B15	B15	B15	II
18	B18	B:1,2,4,5,6,7,8,9,10,11,12,13,14,16,18,19,20,21,22	B18	II
1	B:1,9,12,14,21	B:1,2,4,5,6,7,8,9,10,11,12,13,14,16,19,20,21,22	B:1,9,12,14,21	III
9	B:1,9,12,14,21	B:1,2,4,5,6,7,8,9,10,11,12,13,14,16,19,20,21,22	B:1,9,12,14,21	III
12	B:1,9,12,14,21	B:1,2,4,5,6,7,8,9,10,11,12,13,14,16,19,20,21,22	B:1,9,12,14,21	III
14	B:1,9,12,14,21	B:1,2,4,5,6,7,8,9,10,11,12,13,14,16,19,20,21,22	B:1,9,12,14,21	III
21	B:1,9,12,14,21	B:1,2,4,5,6,7,8,9,10,11,12,13,14,16,19,20,21,22	B:1,9,12,14,21	III
8	B8	B:2,4,5,6,7,8,16,22	B8	IV
10	B:10,11	B:2,4,6,7,10,11,16,22	B:10,11	IV
11	B:10,11	B:2,4,6,7,10,11,16,22	B:10,11	IV
13	B13	B13	B13	IV
20	B20	B:19,20	B20	IV
4	B:4,6,7	B:2,4,6,7,16,22	B:4,6,7	V
5	B5	B5	B5	V
6	B:4,6,7	B:2,4,6,7,16,22	B:4,6,7	V
7	B:4,6,7	B:2,4,6,7,16,22	B:4,6,7	V
19	B19	B19	B19	V
2	B2	B2	B2	VI
16	B16	B:16,22	B16	VI
22	B22	B22	B22	VII

In stage 5, the ISM model was established using the conical matrix of the FRM and is presented in Figure 2. Finally, in stage 6, this model was discussed in the GF, where experts were asked to verify any potential inconsistencies. The experts agreed on the consistency of the ISM model. Thus, the model was deemed appropriate, highlighting both the hierarchical structure and the interrelationships of the barriers to implementing RL.

Analysis of Figure 2 shows that Lack of support infrastructure (B17) and Lack of qualified professionals in RL (B3) are at the top of the table, since they were considered Level I barriers. These barriers do not exert an influence on the others but are strongly influenced by other barriers. Barriers positioned at Level I are not classified as "influential" because they do not drive other barriers; rather, they are the most "influenced" by the rest of the system.

Levels II to V are considered intermediate levels in the model. Level II includes Lack of economy of scale (B15) and Lack of standards, codes and guidelines (B18). Level III includes Lack of information systems (B1), Financial constraints (B9), Lack of short-term economic benefits (B12), Uncertainty of economic benefits (B14) and Lack of investment in RL (B21). Level IV includes High costs (B10), Uncertain financial costs (B8), Legal issues (B20, High investments and low returns (B11) and Expenses for collecting used products (B13). Level V includes Uncertain quality and quantity of returned products (B5), Difficulty with members of the supply chain (B6), Lack of support from supply chain players (B7), Lack of shared understanding of best practices (B8) and Change in regulations due to political changes (B19).

Figure 2 also reveals that barriers in the category of Economic-related issues are concentrated in Levels III and IV, and those in the category of Governance and supply chain process-related issues in Level V.

The barriers attributed to the intermediate levels influence the barriers of the lower hierarchical levels and are also influenced by the barriers of the higher hierarchical levels.

Finally, the barriers at the highest level are positioned in the lower part of the ISM model and are considered the main barriers to implementing RL in Portugal. Level VI includes Complexity of the operation (B2) and Lack of corporate social responsibility (B17) and Level VII, the highest level, includes Lack of adequate organizational structure and support for RL practices (B22).

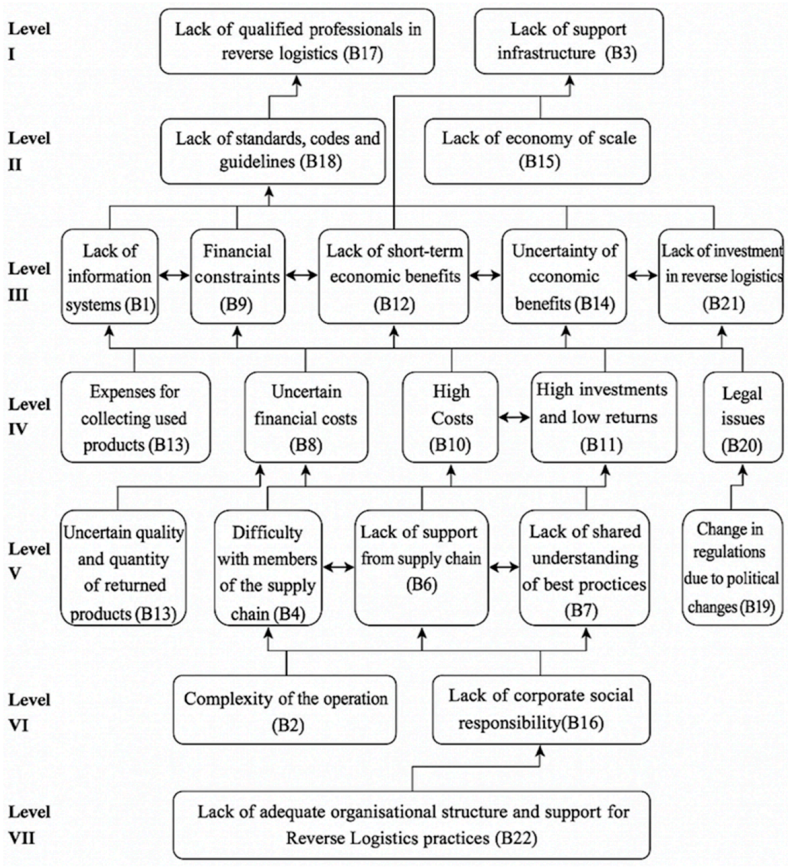

Figure 2. ISM model of the barriers to RL in Portugal.

4.2. Phase III: MICMAC Analysis

As observed in Figure 3, the barriers to RL are classified in four groups. The first is formed of autonomous variables that have a weak power of influence and weak dependence. These variables are disconnected from the system, with which they have only a few, but strong, links. The second group is formed of the dependent variables that have a weak power of influence but strong dependence. The third cluster contains the linking variables that have a strong power of influence and also strong dependence. These variables are unstable inasmuch as any action on them will have an effect on the others and also a feedback effect on themselves. The fourth group includes the independent variables that have a strong power of influence but weak dependence. It is noted that the variables with a very strong power of influence, called key variables, belong to the category of independent variables.

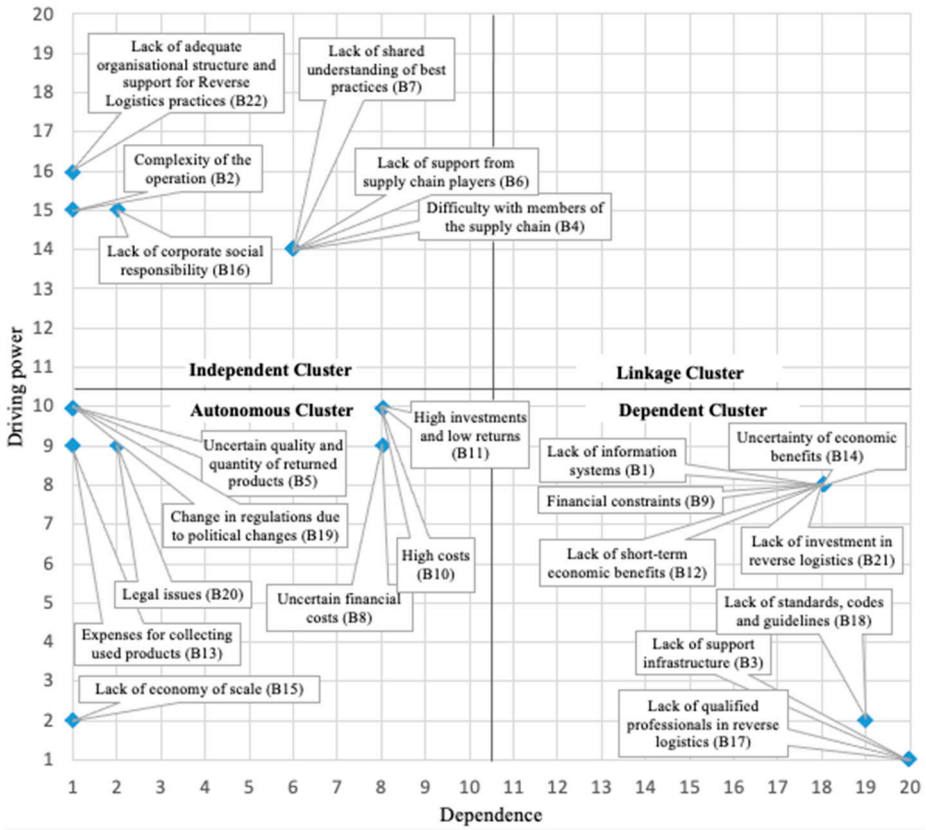

Figure 3. MICMAC diagram of the barriers to implementing RL.

5. Discussion

The model based on ISM proposed to identify the obstacles to RL can give decision-makers a realistic representation of the problems involved in implementing RL. This can help them decide on priorities for taking proactive measures to overcome these barriers.

Lack of adequate organizational structure and support for RL practices (B22), at the highest hierarchical level of the ISM model, is the barrier with greatest influence on the system. A lack of conditions and basic functions in the organizational structure limits the adoption of RL practices [63].

According to the results, Lack of adequate organizational structure and support for RL practices directly influences Lack of corporate social responsibility (B21). An appropriate structure could improve the company's social responsibility (B16), Lack of shared understanding of best practices (B7), Lack of support from supply chain players (B6) and Difficulty with members of the supply chain (B4).

Regarding the MICMAC analysis, we can observe that B5, B8, B10, B11, B13, B15, B19, and B20 are in the autonomous cluster. This means these barriers have low influence and low dependence, indicating no significant relationship with the system due to their weak connection with other barriers. These barriers are outside the barrier system, and they need to be dealt with autonomously.

The analysis also shows that B2, B4, B6, B7, B16, and B22 are classified as independent barriers, as they have a high influence. This implies that these are fundamental barriers for the effective implementation of RL in the supply chain.

Integrating the hierarchical structure and the interrelationships of the barriers (ISM model) with their influence and dependence (MICMAC analysis) contributes to the discussion about the importance of barriers to the implementation of RL in SMEs and their relationships.

It is worth noting that the linkage cluster in the MICMAC diagram is empty, which indicates that none of the identified barriers simultaneously present strong driving and

dependence power. This absence suggests that the system of barriers in the Portuguese SME context is more polarized, with barriers acting either primarily as independent drivers or as dependent outcomes, rather than occupying an unstable intermediary position.

The main barriers from the MICMAC analysis (independent cluster) and the main barriers from the ISM model (level VII barriers) are now classified as key barriers to RL in Portugal (specifically barriers B2, B4, B6, B7, B16, and B22).

Compared to other critical barriers, the key barriers have a relatively low ranking in terms of perceived importance by the respondents. This result confirms the need to go beyond merely classifying the barriers when the goal is to adapt mitigation measures to reduce their impact and promote the implementation of RL [64].

We also note that B14, classified as the second most important barrier in the rank, is situated in the dependent cluster. This analysis indicates that B14 significantly depends on the mitigation of other barriers, which are considered less important by the experts. This divergence between the perceived importance of barriers and their structural influence can be hypothesized as a consequence of how experts typically assess obstacles [65]. In practice, decision-makers often prioritize barriers that have a visible and immediate impact, such as financial costs or infrastructure gaps. By contrast, the ISM–MICMAC methodology uncovers the systemic and indirect influence of barriers, revealing hidden causal relationships. As a result, certain barriers may be underestimated in perception-based rankings but emerge as structurally critical once their interdependencies are analyzed. This indicates that less apparent barriers can, in fact, play a fundamental role as root causes that shape the overall system of constraints [20].

Therefore, key-cause mitigation measures are more effective than those based solely on importance. For instance, in the case of SMEs facing the barrier "Lack of adequate organizational structure and support for RL practices" (B22), a key-cause mitigation measure could involve establishing a dedicated reverse logistics unit, even if on a small scale, by reallocating existing resources rather than creating a fully new department. This structural adjustment could also be complemented by training programs to address the "Lack of qualified professionals in RL" (B3). By focusing on these root-cause barriers, SMEs can create internal capabilities that in turn reduce the impact of dependent barriers, such as uncertainty of economic benefits or lack of shared understanding of best practices, thereby triggering a positive cascading effect throughout the system [66].

Identifying the six key barriers—lack of adequate organizational structure, lack of corporate social responsibility, complexity of operations, lack of shared understanding of best practices, difficulty with supply chain members, and lack of support from supply chain players—offers decision-makers a structured view of where to intervene first.

From a managerial perspective, the lack of organizational structure (B22) indicates that SMEs should begin by assigning clear responsibilities for reverse flows, even if through small dedicated teams or cross-functional task forces. Without such structural adjustments, other initiatives tend to fail. Likewise, corporate social responsibility (B16) emerges as a driver of both internal and external change: SMEs that explicitly integrate sustainability goals into their strategies are more likely to secure cooperation from supply chain partners and to meet customer expectations [67].

The complexity of reverse operations (B2) suggests that managers need to simplify processes by adopting digital solutions, outsourcing specialized activities, or forming partnerships with logistics providers. In turn, the lack of shared understanding of best practices (B7) reveals an urgent need for benchmarking and training initiatives. SMEs can benefit from participating in industry associations, clusters, or EU-funded projects that disseminate circular economy practices adapted to their scale.

Barriers related to the supply chain (B4 and B6) highlight that reverse logistics is not an isolated function but a collaborative effort. Managers must invest in building trust and formal agreements with distributors, retailers, and waste management operators [68]. Practical measures include establishing standardized return policies, cost-sharing mechanisms, and joint investment in infrastructure.

At the policy level, the Portuguese context reinforces the need for support instruments that enable SMEs to invest in reverse flows, such as fiscal incentives, targeted training, and sector-specific guidelines. These measures would not only reduce barriers at the firm level but also strengthen collective capabilities across industries like textiles, footwear, pharmaceuticals, IT, and waste management.

6. Conclusions

A duly planned and well-managed RL network is crucial to increase a company's income and customer satisfaction. To concentrate on the business's main operations and achieve good cost effectiveness, companies need to organize their RL activities correctly. Consequently, identifying barriers is a challenge for both decision-makers and managers.

In this study, the barriers to implementing RL activities were identified through a review of the literature and introduced in the ISM model to develop a contextual relation between the selected barriers and to establish the hierarchical structure of the barriers, identifying those with the greatest influence and their dependence.

The ISM converted the perception of 8 RL specialists, in the Portuguese context, into a clear, structured map deciphering the contextual relations among the barriers to implementing reverse flows.

Besides the ISM model, a MICMAC analysis was performed to determine the dependence and strength of influence of the variables identified. This analysis helped to determine the factors that can be worked on immediately and those requiring most attention.

Application of the ISM and MICMAC analysis revealed that Lack of adequate organizational structure and support for RL practices stimulates Lack of corporate social responsibility, which in turn and jointly with Complexity of the operation, influences the barriers of the Governance and supply chain process-related issues category. The barriers of the Economic-related issues category are at the intermediate level, meaning that they influence the lower levels, but these barriers are also greatly influenced by the higher levels. This analysis reveals that these barriers depend significantly on mitigation of the higher-level barriers.

The research also showed that Lack of adequate organizational structure and support for RL practices, Lack of corporate social responsibility, Complexity of the operation, Lack of shared understanding of best practices, Difficulty with members of the supply chain and Lack of support from supply chain players are the key barriers to implementing RL. This observation suggests it is crucial to mitigate these barriers, as they exert a significant influence on the others.

Lack of support infrastructure and Lack of qualified professionals in RL were found to be lower-level barriers, which indicates they are influenced by most of the other barriers.

The results underline the importance of mitigating barriers related to management, corporate social responsibility and the complexity of operations.

The findings of this research reinforce and expand upon previous studies on barriers to RL implementation. For example, Ravi and Shankar [24] and Bouzon et al. [69] identified operational complexity and uncertain costs as critical factors, which is consistent with this study's emphasis on the complexity of operations and the uncertainty of economic benefits. On the other hand, recent works such as Saglam [70] and Appiah & Owusu-Bio [31] highlight the importance of internal capabilities, such as a strong sustainability culture

and analytics, to overcome RL barriers. This perspective resonates with our results, which stress the need for SMEs to establish dedicated structures and invest in training qualified professionals. Therefore, this study contributes to the existing literature by applying the ISM–MICMAC approach in the Portuguese SME context, uncovering a hierarchical system of barriers that has not been previously explored in this type of organization.

By giving priority to these barriers and taking appropriate measures, those involved can overcome the obstacles and promote effective adoption of RL practices.

This research contributes to the existing body of academic knowledge and provides valuable guidelines so that professionals and policy-makers can strengthen sustainability. Future research efforts can focus on developing strategies and interventions to address the barriers identified and assess their effectiveness in facilitating RL implementation. There should also be a focus on mitigating the key barriers found here and determining whether the barriers have the same impact in different industrial sectors.

While this study has made significant contributions, it is important to recognize some limitations. Firstly, the sample used was relatively small, which can limit generalization of the results beyond the group studied. Moreover, the results referred to the Portuguese context, and so care is necessary in extrapolating them to other European markets with different characteristics.

Future research could explore whether the barriers identified in this study manifest differently across specific industrial sectors, such as electronics, food and beverage, or textile industries, where reverse logistics plays a critical yet distinct role. Additionally, applying complementary methodologies, such as longitudinal case studies, simulation modelling, or hybrid approaches combining ISM–MICMAC with methods like DEMATEL or fuzzy logic, could provide deeper insights into the dynamic interactions between barriers. Such sector-specific and methodologically diverse studies would strengthen the generalizability and practical applicability of the findings.

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