systems

MDPI

Article

Proposal of a Correlation Model Integrating FDRM and CLSCM Practices and Performance Measures: A Case Study from the Automotive Battery Industry in Brazil

Antonio Marco-Ferreira [1,*], Reginaldo Fidelis [2], Francielle Cristina Fenerich [3], Rafael Henrique Palma Lima [1], Pedro Paulo De Andrade Junior [4] and Diogo José Horst [4]

1 Department of Production Engineering, Federal University of Technology Paraná (UTFPR), Curitiba 81280-340, Brazil; rafaelhlima@utfpr.edu.br
2 Department of Mathematics, Federal University of Technology Paraná (UTFPR), Curitiba 81280-340, Brazil; reginaldof@utfpr.edu.br
3 Department of Production Engineering, State University of Maringá (UEM), Maringá 87020-900, Brazil; fcfenerich@uem.br
4 Department of Mechanical Engineering and Sciences, Federal University of Santa Catarina—(UFSC), Florianópolis 88040-900, Brazil; pp.andrade@ufsc.br (P.P.D.A.J.); diogohorst@gmail.com (D.J.H.)
* Correspondence: marcoferreira@utfpr.edu.br; Tel.: +55-43-3315-6100

Abstract: The field of closed-loop supply chain management (CLSCM) seeks to replace the linear flow of materials and energy with a cyclical model in which the outputs of the production system become inputs to the same system, thus closing the cycle of materials and energy within the supply chain. Current literature on CLSCM reports a wide variety of practices, and combining these practices with environmental performance measures is an ongoing challenge, mainly because results from these practices are often diffuse and linking them with performance results is not a straightforward task. This paper addresses this problem by proposing a model to prioritize CLSCM practices and performance measures. The correlation model integrating the fuzzy direct rating method (FDRM) and CLSCM practices and performance measures was tested in a real company that is part of a closed-loop supply chain that recycles lead obtained from automotive batteries in Brazil. The results allowed the identification of which management practices are more relevant to the organization by correlating their impact with performance measures. The most relevant practices for the company under study were demand forecasting, with 21.68% of relative importance, followed by reverse logistics practices (21.15%) and production planning and control (18.16%). Another relevant finding is that upstream performance measures account for 77.72% of the company's CLSCM performance.

Keywords: closed-loop supply chain management; performance measures; management practices; fuzzy direct rating method

check for updates

Academic Editors: Elisabete Maria da Fonseca Correia and Ana Cristina dos Santos Amaro

Received: 5 December 2024
Revised: 4 January 2025
Accepted: 5 January 2025
Published: 15 January 2025

Citation: Marco-Ferreira, A.; Fidelis, R.; Fenerich, F.C.; Lima, R.H.P.; De Andrade Junior, P.P.; Horst, D.J. Proposal of a Correlation Model Integrating FDRM and CLSCM Practices and Performance Measures: A Case Study from the Automotive Battery Industry in Brazil. *Systems* **2025**, *13*, 50. https://doi.org/10.3390/systems13010050

1. Introduction

Organizations have sought sustainability-driven management and production models [1], either to comply with regulations on pollutant and waste emissions [2] or due to market pressure from consumers [3]. This has motivated researchers and practitioners to develop new environmental management practices [4].

This trend reinforces the need for research on methods that help develop and implement responsive environmental practices [5], which entail the adoption of adequate monitoring instruments to ensure the efficacy of these practices [6]. Moreover, there is a need to link environmental practices and organizational performance to measure their efficacy in achieving strategic and environmental objectives [7].

One major strategy that companies have pursued to reduce pollutant emissions and waste is to develop green practices throughout the supply chain. The scientific literature on this topic can be subdivided into various strands: green logistics management, reverse logistics (RL), green supply chain management, circular economy, and closed-loop supply chains [4]. While there are no clear boundaries between these terms, it can be argued that green logistics management focuses on the adoption of sustainable practices in all logistics functions, such as transportation, warehousing, and inventory management [8]. Conversely, RL focuses on the end-of-life of products and describes the flow of materials from the point of consumption to the point of origin [9].

In this context, closed-loop supply chain management (CLSCM) arises as a broader field of study because it considers value creation over the entire product life cycle, dynamically recovering value from different types and volumes of returns over time [10]. Therefore, a closed-loop supply chain (CLSC) integrates both the forward and reverse supply chains [11]. This makes RL and remanufacturing major processes of CLSCM [12,13].

Researchers have also studied how the adoption of sustainable logistics practices impacts organizational performance. According to current research, there seems to be a positive relationship between sustainable practices and performance outcomes [13]. However, some authors argue that this positive relationship between sustainability and performance is not experienced by all companies [8]. Hence, there is a need to carry out further research on how sustainable practices relate to organizational performance. Assessing CLSCM performance is a challenge for companies [3,9,14]. The challenge becomes even greater with more restrictive regulations that demand companies to improve their environmental performance [2,15].

Identifying which CLSCM practices impact the supply chain downstream and upstream performance is a main challenge for organizations, as performance outcomes may be the result of single or multiple management practices [4].

Some authors have dealt with environmental performance assessment by applying several techniques, such as Analytic Hierarchy Process (AHP) [16], Fuzzy TOPSIS [17], Fuzzy AHP [18], and hybrid methods integrating multi-criteria decision-making methods [19].

These authors either propose environmental measurement systems or devise hierarchical decision-making structures that include environmental aspects. However, few papers address the relationship between environmental performance and management practices. The lack of studies on this topic may be explained by the difficulty in correlating management practices with performance outcomes [20,21].

Some authors try to bridge this gap by proposing management frameworks and maturity models [7]. Environmental impacts are diffuse [22]. Determining the relationship between an environmental tragedy and its economic, social and environmental impacts is a challenge [23]. In the other sphere, when there is the adoption of environmental management practices such as CLSCM, determining their results is also a challenge [24] because, like environmental impacts, their results are also diffuse and measuring the performance of the adoption of CLSCM practices is important to determine their economic, environmental and social performance [25–27].

These authors state that linking performance and management practices is a major challenge that still needs to be addressed by the current literature. So, this paper addresses this gap by proposing a new model that relates and weights CLSCM practices and performance indicators based on the fuzzy direct rating method (FDRM). The model was tested in the Brazilian lead-acid battery recycling industry, which has a major role in reducing the impact of end-of-life automotive batteries, since the presence of lead residue in urban and rural environments can pose health risks to wildlife as well as the local population [28].

Lead-acid batteries are still used for starting, lighting, and ignition in modern vehicles with internal combustion engines. Despite the importance of lead-acid batteries, there is not a different end-of-life strategy besides recycling them [7]. According to the Brazilian Ministry of Mines and Energy (MME), approximately 220,000 tons of lead are consumed per year in the country [7], of which 47% originates from imports as raw material and 53% comes from recycling. The company studied is responsible for recycling approximately 15% of all recycled lead in Brazil; thus, finding the correlation between management practices and organizational performance is key to the sustainability of this supply chain.

Data were collected considering the company's current practices and perceptions of CLSCM. Supply chain experts helped determine the relative weights of performance measures and management practices, while supply chain-related staff from the studied organization supplied data to determine the correlation matrix, and weights were calculated using the fuzzy direct rating method (FDRM). Finally, results were analyzed to determine the correlation between CLSCM practices and organizational performance.

This paper is organized as follows: Section 1 presents an introduction; Section 2 presents the proposed method, including the findings from the literature review on CLSCM practices and performance measures; Section 3 describes the application of the proposed method in the lead recycling company; Section 4 discusses the results from the practical application and develops practical implications of the method; and Section 5 outlines the main conclusions of this paper.

The proposed model contributes both to academic research and CLSCM practitioners by presenting a simple application method in organizations, as well as by identifying a wide range of CLSCM practices and performance measures. Moreover, the model links practices to multiple performance measures, which enable the assessment of their outcomes.

2. Materials and Methods

To accomplish the proposed objectives, we divided the research method into five steps:

Step 1: Conducting a bibliographic survey in order to validate the variables used in the study through the literature. A search was conducted on the topic: "CLSCM practices", using the Web of Science, ScienceDirect, and Google Academic databases. The keyword used was "practices of closed-loop supply chain management". After reading the abstract, articles that did not fit the scope of the study were discarded.

Step 2: Conducting a bibliographic survey in order to validate the variables used in the study through the literature. A search was conducted on the topic: "CLSCM performance indicators", using the Web of Science, ScienceDirect, and Google Academic databases. The keyword used was "performance of closed-loop supply chain management". After reading, articles that did not fit the scope of the study were discarded.

Step 3: Definition of the analytical procedures to evaluate the correlation between CLSCM practices and performance measures.

Step 4: Development of an integrated method that links CLSCM practices and performance measures using the analytical tools defined in Step 3.

Step 5: Application of the proposed method in a lead-acid battery recycling company to demonstrate its applicability and adherence to the research objectives.

2.1. CLSCM Practices

In order to consolidate the broad set of CLSCM practices described in the literature, this paper builds on the theoretical classification model proposed by [7], based on previous contributions [14,29]. The practices related to waste management, RL, and green manufacturing are considered process operational practices. Green design practices can be categorized as product operational practices [30]. The conceptual framework of CLSCM practices can be seen in Figure 1.

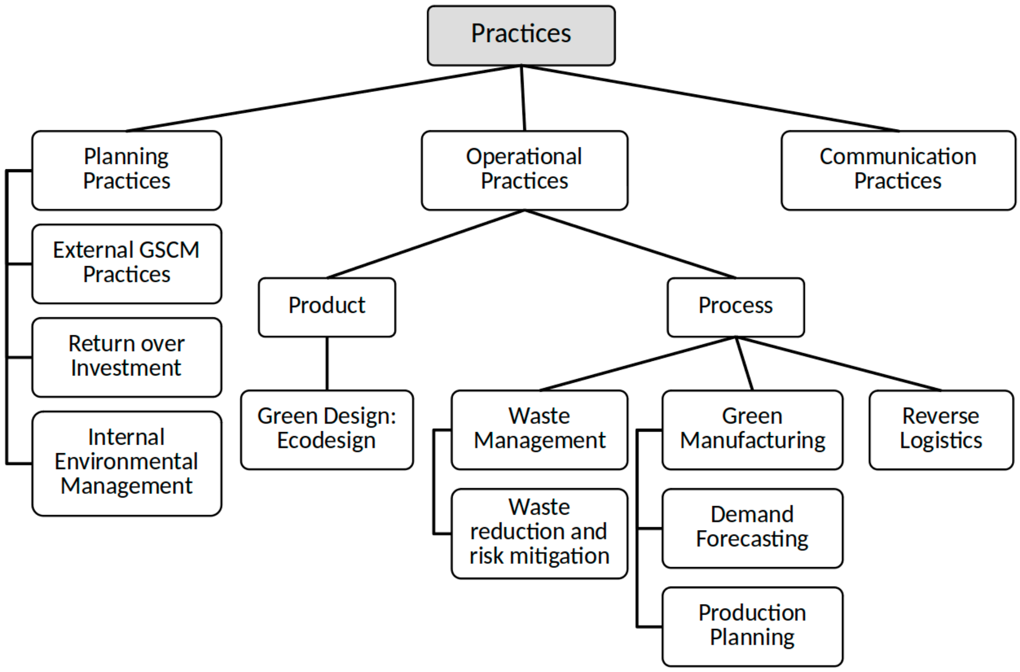

Figure 1. CLSCM-related practices.

Planning practices reflect the extent to which an environmental management system has been developed and implemented. That is, they denote the number of procedures that define the company's environmental policy; therefore, they are developed with the aim of establishing environmental objectives for the selection and implementation of environmental practices and for evaluating the results of such practices. Planning CLSCM practices were divided into external practices (PS1), return on investment (PS2), and internal environmental management practices (PS3).

In turn, operational CLSCM practices can be organized into two groups, the first with product-related practices and the second with process-related practices. Product-related practices are related to designing and developing environmentally conscious products. The second group includes practices focused on operational processes, which seek to develop and implement manufacturing processes and environmentally conscious operational methods.

Moreover, companies have given significant importance to green consumers [31], which has driven companies to adopt communication practices [7] to enable communication with stakeholders and publish results on environmental initiatives.

Once the set of CLSCM practices is followed by its theoretical justification, it follows the new model for juxtaposing CLSCM practices into categories. They are presented, linking the classification, the group, the descriptions of the practices, and the authors that support them.

After establishing a model to categorize CLSCM practices, Table 1 presents the list of practices identified by the literature review, which were used as variables in the proposed model.

Table 1. List of CLSCM practices considered in this paper.

Classification	Code	Practices	References
Planning Practices: CLSCM External practices (PS1)	Pr1	Provide design specifications for suppliers including environmental requirements on the purchased item	[32–34]
	Pr2	Cooperation with suppliers for environmental objectives	
	Pr3	Auditing of suppliers' management practices concerning environmental aspects	
	Pr4	ISO 14001 supplier certification	
	Pr5	Evaluation of the second tier of suppliers with respect to environmentally friendly practices	
	Pr6	Cooperation with customers for ecodesign	
	Pr7	Cooperation with customers for cleaner production	
	Pr8	Cooperation with customers to use green packaging	
	Pr9	Participation in an Ecoindustrial Park	
Planning Practices: Return over Investment (PS2)	Pr10	Sale of excess inventory and materials to recover investment	[32–34]
	Pr11	Sale of scrap and used materials	
	Pr12	Sale of equipment in excess of capital	
Planning Practices: Internal Environmental Management (PS3)	Pr13	Commitment to CLSCM from senior managers	[32–35]
	Pr14	CLSCM support for middle managers	
	Pr15	Cross-functional cooperation for environmental improvements	
	Pr16	Environmentally driven total quality management	
	Pr17	Compliance with environmental legislation and audit programs	
	Pr18	ISO 14001 certification	
	Pr19	Existence of environmental management systems	
Product Operational Practices: Green Design: Ecodesign (PS4)	Pr20	Design of products with reduced material and energy consumption	[32–34]
	Pr21	Product design focusing on reuse, recycling and recovery of materials and components	
	Pr22	Design of products that avoid or reduce the use of harmful substances in products and their manufacturing process	
Process Operational Practices: Waste management, waste reduction and risk mitigation (PS5)	Pr23	Waste minimization	[32–34,36]
	Pr24	Decreased consumption of hazardous and toxic materials	
	Pr25	Establishment of a checklist of substances dangerous to the environment	
	Pr26	Use of raw materials that do not contain prohibited substances	
	Pr27	Homologation data for green products	
	Pr28	Green manufacturing practices	
	Pr29	Manufacture of green products	
	Pr30	Standards for green products	
	Pr31	Use of recyclable materials, whenever possible	
	Pr32	Reduction in consumption, whenever possible	
	Pr33	Reuse of materials whenever possible	

Table 1. *Cont.*

Classification	Code	Practices	References
Process Operational Practices: Green Manufacturing Demand Forecasting (PS6)	Pr34	Effectiveness of uncertainty reduction methods	[37]
	Pr35	Forecasting models to predict rates and volumes of return	
	Pr36	Product reliability models to predict life cycles of products with multiple lives	
	Pr37	Inventory control models that explicitly consider returning batches of returned products	
	Pr38	Inventory models combined with production models, considering the dependent rates of return	
	Pr39	Studies considering technological advances that affect the return of products	
	Pr40	Methods for examining the benefits of synchronizing production with reverse demands	
	Pr41	Product positioning strategies to serve various markets	
	Pr42	Aggregate production planning models that consider returned products	
	Pr43	Efforts coordinated by purchasing and inventory managers to plan, manage and control rates of return	
Process Operational Practices: Green Manufacturing Planning and Control (PS7)	Pr44	Models to assist in determining which parts and components can be used to recover disassembled products	[37]
	Pr45	Models and methods that analyze the effectiveness of coordination of disassembly and reassembly operations	
	Pr46	Templates for plant design of disassembly facilities and staff	
	Pr47	Reverse transportation logistics and waste disposal	
Process Operational Practices: Reverse Logistics (PS8)	Pr48	Strategies for distribution, transportation and redesign of the components of the logistics system for greater environmental efficiency	[32–34,36]
	Pr49	Location of environmentally friendly facilities	
	Pr50	Use of alternative fuels	
	Pr51	Selection of transportation modes based on eco-friendly aspects	
	Pr52	Use of less polluting vehicles	
	Pr53	Consolidation and effective shipment of full truckloads	
	Pr54	Routing systems to minimize travel distances	
	Pr55	Vehicle maintenance and disposal	
Communication Practices (PS9)	Pr56	Periodic preparation of environmental reports	[3]
	Pr57	Sponsorship of environmental events/collaboration with ecological organizations	
	Pr58	Use of environmental aspects in marketing campaigns	
	Pr59	Regular and voluntary provision of information about environmental management to customers and institutions	

2.2. CLSCM Performance Metrics

Measuring the performance of CLSCs is a challenge [38] that arises from multiple factors such as consumer pressure [3], demands from stakeholders [13], and environmental legislation [2]. Despite the difficulties, measuring system performance in CLSCM is vital for its effectiveness [4].

Some authors have proposed methods to evaluate the performance of CLSCM. For example [13], subdivides performance measures into three main categories: (i) positive and negative environmental performance, (ii) operational performance, and (iii) organizational and economic performance. Other authors address CLSCM performance by devising separate measures for each possible direction in the flow of materials, services, and information in the SC, thus arguing that performance should be evaluated in the downstream and upstream directions [20]. Along these lines, [39] build a set of measures to quantitatively assess the performance of CLSCM.

In this paper, we classify performance measures according to the horizontal direction of the supply chain, thus forming two major sets of downstream and upstream performance measures, which are in line with previous work by authors such as [40].

Upstream (CD1) performance measures assess CLSCM performance towards its suppliers, encompassing measures ranging from transportation to environmental management. In the downstream (CD2) direction, performance is consumer-driven and includes aspects such as post-consumption and total environmental costs.

A literature review was conducted to identify upstream and downstream performance measures, which are listed in Table 2.

Table 2. List of performance measures used in this paper.

Classification	Code	Practices	References
Downstream Performance Measures (CD1)	Pe1	Total units received in a given period	[40,41]
	Pe2	Total units shipped in a given period	
	Pe3	Average units received per day	
	Pe4	Average units sent per day	
	Pe5	Average stock held per day	
	Pe6	Total stock value	
	Pe7	Duration of the order cycle	
	Pe8	Total setup costs	
	Pe9	Total spent on equipment setup	
	Pe10	Synchronization of units that received shipment correspondence	
	Pe11	Number of disruption incidents	
	Pe12	Number of unfulfilled orders	
	Pe13	Total transportation costs	
	Pe14	Total environmental costs	
	Pe15	Decrease in the use of natural resources	
	Pe16	Sale price	
	Pe17	Availability of environmental assessment systems	
	Pe18	Availability of environmental audit systems	
	Pe19	Existence of mission statement that comprises environmental sustainability	
	Pe20	Number of environmental management initiatives	
	Pe21	Level of management commitment to communicate customers about sustainability factors	
	Pe22	Availability of environmental reward systems	
	Pe23	Level of management effort to motivate suppliers	

Table 2. *Cont.*

Classification	Code	Practices	References
Upstream performance measures (CD2)	Pe24	Number of shipments received	[40,41]
	Pe25	Number of shipments departed	
	Pe26	Number of returns	
	Pe27	Number of failures	
	Pe28	Percentage of shipment returns	
	Pe29	Percentage of unfulfilled shipments	
	Pe30	Reverse logistics costs per device returned and/or processed	
	Pe31	Reverse logistics costs per dispatched device	
	Pe32	Percentage of units returned	
	Pe33	Total costs associated with returned and processed items	
	Pe34	Benchmarking rates of return with other sectors	
	Pe35	Total costs associated with the current rate of return	
	Pe36	Total environmental costs	
	Pe37	Total purchasing costs	
	Pe38	Total profit from recycling	
	Pe39	Reduction in the quantity of discarded products	
	Pe40	Increase in total profit of the supply chain	
	Pe41	Increase in resale price	

2.3. *Definition of Weights Using the Fuzzy Direct Rating Method (FDRM)*

In this paper, we use the FDRM to determine the weights of the CLSCM practices and performance measures presented in Tables 1 and 2. To determine the weights of the CLSCM practices and performance measures, the FDRM was employed for multiple reasons: first, the significant quantity of CLSCM practices and performance measures (Tables 1 and 2); second, the involvement of a substantial number of experts in assigning weights to each outcome; and third, the inherent uncertainties associated with assigning preferences to each attribute.

Alternative methodologies, such as AHP and trade-offs, were deemed unfeasible due to the requirement for pairwise comparisons; SMART and swing weighting proved challenging in defining parameters and the Delphi method encountered difficulties related to interaction with controlled feedback, among other limitations [42]. In Figure 2, the vertical axis is named u(x), which should be the membership scores of the function. Triangular fuzzy numbers (TFNs) are used to model uncertainty in the process of assigning values using linguistic variables [43]. Table 3 presents the TFNs used in the proposed method and their linguistic meaning. The FDRM can be used to classify imprecise criteria using a fuzzy approach. Most current methods rely on linguistic terms because certain decisions cannot be measured on an exact and precise scale. Thus, to avoid assigning crisp values to subjective judgments, linguistic variables defined over an interval of values can be used to reduce the uncertainty of decision-makers and specialists [21].

Table 3 presents the fuzzy numbers used in the proposed method, along with their linguistic meaning.

Table 3. Fuzzy numbers and corresponding linguistic variables.

Numerical Variable	Linguistic Variable	Code	Fuzzy Number (a, b, c)
1	Very low	VL	(0.0, 0.0, 0.1)
2	Low	L	(0.0, 0.1, 0.3)
3	Medium low	ML	(0.1, 0.3, 0.5)
4	Medium	M	(0.3, 0.5, 0.7)
5	Medium high	MH	(0.5, 0.7, 0.9)
6	High	H	(0.7, 0.9, 1.0)
7	Very high	VH	(0.9, 1.0, 1.0)

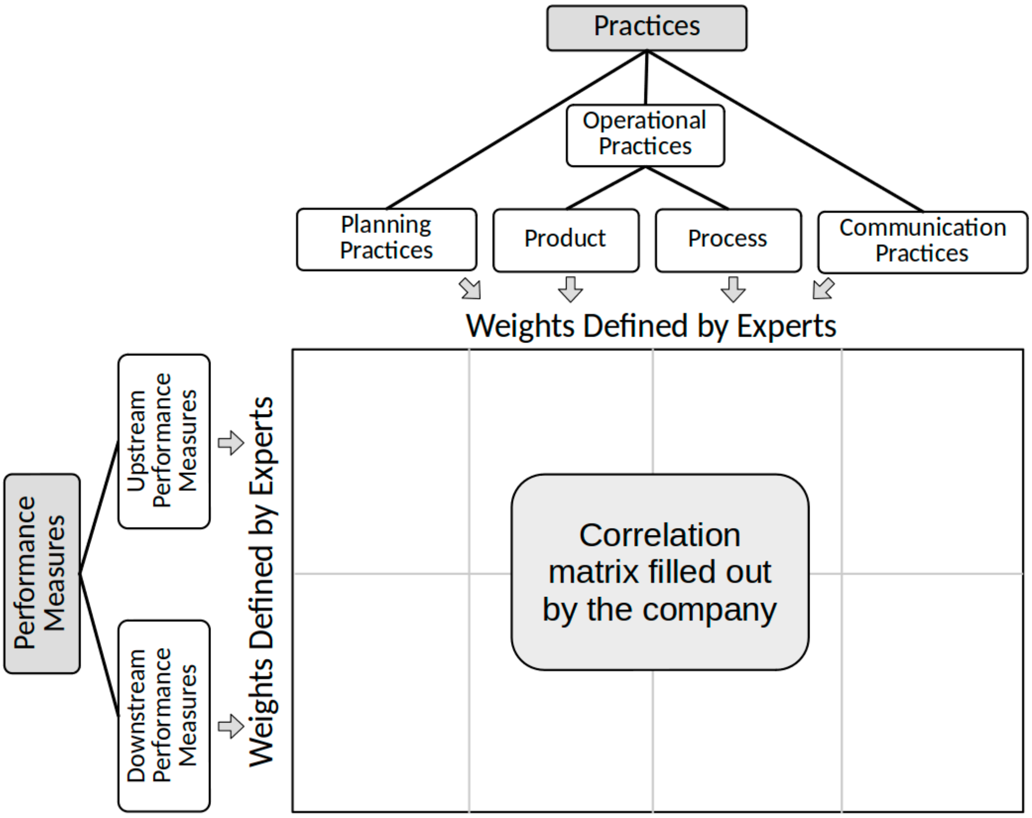

Figure 2. Overview of the proposed model.

A TFN is expressed by three values, which represent, respectively, the lowest possible value, the most promising value, and the highest possible value that characterize a fuzzy event. The application of the FDRM is subdivided into 5 steps.

Step 1: Selection of criteria and definition of a group of experts that will evaluate the performance measures and practices using fuzzy linguistic terms. In this study, there were 9 criteria (PS1 to PS9) and 59 sub-criteria (Pr1 to Pr59) for management practices, and 2 criteria (CD1 and CD2) and 41 sub-criteria (Pe1 to Pe41) for performance measures. Four experts in CLSCM helped define the weights for all criteria and sub-criteria. These specialists are university professors and researchers with PhD degrees and experience of working with CLSCM.

Step 2: Evaluation of the degree of importance of all criteria and sub-criteria using linguistic variables. Each expert carries out his/her own assessment individually.

Step 3: Fuzzy scores obtained in Step 2 are defuzzified (see Table 3). The normalized weights of each criterion and sub-criterion are obtained by dividing each defuzzified score by the sum of all defuzzified scores.

Step 4: Determination of the total scores (TS) for each sub-criterion in relation to the corresponding criterion by the FDRM, which is performed by multiplying each practice (Pr) by its class (PS) or multiplying each performance measure (Pe) by its class (CD) (See Tables 1 and 2). The total score is obtained by multiplying the score of each sub-criterion by the score of the corresponding criterion.

Step 5: The final scores are obtained by normalizing the total scores obtained in Step 4. Figure 2 shows an overview of the proposed model.

2.4. Correlation Matrix

To better visualize and quantify the correlation between CLSCM practices and performance measures, a correlation matrix (CM) was used to link variables (CLSCM practices or performance measures) and quantify their correlation. This procedure provides a mechanism to measure how CLSCM practices contribute to the organization's performance.

The proposed method combines FDRM with the CM. The former determines the weights of each practice and performance measure within their sets, while the latter correlates and defines the weights of each practice with respect to each performance measure. Hence, the proposed method allows the company to visualize which practices are related to which performance measure. The following steps consider that the weight vectors for performance measures (MW_i) and management practices (PW_j) were calculated using the steps described in Section 2.3. Hence, to obtain the correlation matrix, the following steps are carried out.

Step 1: The individual responsible for filling out the CM (an organization manager or a supply chain specialist) compares each management practice against each performance measure using a numeric scale with values 0, 1, 3, and 9, in which 0 means "no correlation", 1 means "low correlation", 3 means "some correlation", and 9 means "strong correlation". More specifically, to practice Pr41, a correlation score CM_{ij} must be defined for each of the 41 performance measures (Pe1, Pe2, …, Pe41). This needs to be repeated for each of the 59 practices (Pr1, Pr2, …, Pr59); hence, there is a $CM_{ij} \in \{0; 1; 3; 9\}$ value for all $i = 1, 2, \ldots, 41$ and for all $j = 1, 2, \ldots, 59$.

Step 2: Each CM_{ij} value from the previous step is multiplied by its corresponding performance measure weight (MW_i) and practice weight (PW_j) where $i = 1, 2, \ldots, 41$ and for all $j = 1, 2, \ldots, 59$. This results in the weighted matrix CMW where each of its values $CMW_{ij} = CM_{ij} \times MW_i \times PW_j$.

Step 3: To normalize the values in CMW, each value from Step 2 is divided by the sum of all values, resulting in the matrix CM' using Equation (1).

$$CM'_{ij} = \frac{CMW_{ij}}{\sum_{i=1}^{41} \sum_{j=1}^{59} CMW_{ij}}\text{, for } i = 1, 2, \ldots, 41 \text{ and } j = 1, 2, \ldots, 59 \tag{1}$$

Figure 2 summarizes how the proposed method should be put into practice. The weights of performance measures and management practices are defined by a set of experts using the steps presented in Section 2.3. Later, the company needs to correlate the importance of every practice and performance measure using the steps above, considering the organization's specific context and objectives.

In this study, triangular fuzzy numbers will be used as they are useful to promote the representation and processing of information in a fuzzy environment [43]. The ordered trio here is defined as (a, b, c), yielding the positive triangular number shown in Figure 3. Therefore, the membership function is defined as shown in Figure 3.

$$u(x) = \begin{cases} 0, \text{se } x < a \\ \dfrac{x-a}{b-a}, \text{se } a \le x \le b \\ \dfrac{c-x}{c-b}, \text{se } b \le x \le c \\ 0, \text{se } x > c \end{cases}$$

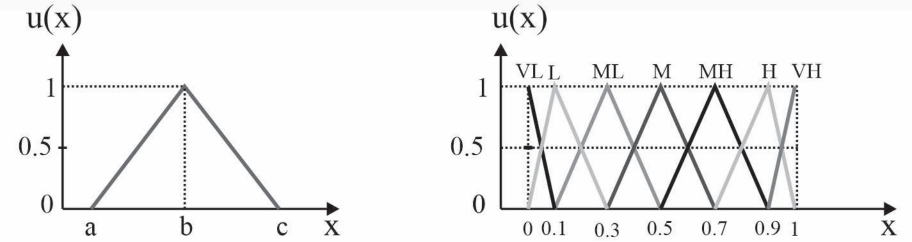

Figure 3. Triangular fuzzy numbers.

3. Application of the Proposed Model

3.1. Description of the Lead Recycling Company

The model was tested in a lead recycling organization located in Brazil. The company operates mainly in the southern, southeastern, and central regions of Brazil. Most of its suppliers are in these regions. It is strategically located, close to most of its consumers and suppliers. It also has ISO 9001, ISO 14001, and OHSAS 18001 certifications.

The main services provided by the company are the recycling of battery scraps and other lead waste. The company provides its clients with the appropriate disposal of materials and sells lead and high-quality lead alloys. The main raw materials used are scrap lead-acid batteries.

According to current Brazilian legislation, battery manufacturers are responsible for collecting their products after being disposed of by customers. Hence, manufacturers need facilities that allow for the proper disassembly and disposal of materials. The main destination of automotive battery scraps is lead recycling companies. The lead recycling process is the main strategy used by manufacturers to return value to the product and reinsert it into the market.

3.2. Data Collection and Calculations

The first step consisted of measuring the relative importance of each CLSCM practice and performance measure. This was conducted with the assistance of four experts, who are consultants with experience in the field of reverse logistics and CLSCM. Because the proposed method can be seen as a decision-making tool, its application in other contexts, such as companies from different sectors located in countries other than the one studied in this paper, may obtain the relative importance of each performance measure and management practice by constructing a new correlation matrix based on scores provided by experts from the sector under analysis without compromising the essence of the method put forward in this paper.

To measure the relationships between CLSCM practices and performance measures, a specialist appointed by the lead recycling company built a correlation matrix by assigning values according to the scale described in Section 2.3. The correlation matrix has two columns that can be used to measure which practices and performance measures should be prioritized in the organization (see Supplementary Data Files). In Table 4, we present the aggregate correlations between management practices and performance measures.

Table 4. Aggregate correlation values between CLSCM practices and performance measures.

	Performance Measures		
CLSCM Practices	**Downstream**	**Upstream**	**Practice Total**
Planning Practices: CLSCM External practices (PS1)	1.32%	2.99%	4.31%
Planning Practices: Return over Investment (PS2)	0.16%	0.11%	0.27%
Planning Practices: Internal Environmental Management (PS3)	7.45%	7.26%	14.70%
Product Operational Practices: Green Design and Ecodesign (PS4)	1.44%	13.64%	15.08%
Process Operational Practices: Waste management, waste reduction and risk mitigation (PS5)	1.58%	1.27%	2.85%
Process Operational Practices: Green Manufacturing Demand Forecasting (PS6)	5.49%	16.19%	21.68%
Process Operational Practices: Green Manufacturing Planning and Control (PS7)	0.00%	18.16%	18.16%
Process Operational Practices: Reverse Logistics (PS8)	4.30%	16.85%	21.15%
Communication Practices (PS9)	0.54%	1.26%	1.80%
Supply Chain Direction Total	22.28%	77.72%	100.00%

The correlation matrix allows the determination of a set of performance measures that are more suitable for analyzing the performance of their CLSCM system. Also, the correlation between performance measures and practices enables the quantification of the influence each practice has over the results of performance measures. It provides deeper insight into the effectiveness of implementing the CLSCM system, minimizing the gap between environmental performance measures and practices. The application of the proposed method was capable of showing which practices generate the greatest performance impacts.

Combining environmental performance practices and measures is a major challenge [20,21], and this sort of analysis often generates conflicting results, as they are linked both to economic and environmental performance factors [14].

The proposed model helps visualize the relationship between performance measures and practices and categorizes the results as upstream and downstream performance. After applying the method in the studied company, it was found that 77.72% of the organization's performance refers to upstream performance measures. As for the relative importance of CLSCM practices, the results show that the company emphasizes the operational process practices of green manufacturing through demand forecasting practices (PS6), which yielded 21.68% of relative importance.

Operational process practices, which comprise RL practices (PS8—21.15%) and planning and control practices (PS7—18.16%), were deemed the second and third most important practice sets. Together, they account for 65.87% of the organization's upstream performance. It should be highlighted that there are only 3 groups of practices (PS6, PS7, and PS8) that comprise 22 practices (Pr34 to Pr55) among a total of 9 groups of practices that comprise 59 individual practices, which demonstrates that the proposed method successfully detected the most relevant practices for the company and quantified their importance to the company's CLSCM performance.

3.3. Downstream Performance Results

Table 4 shows that the sets of practices with the greatest importance scores are related to internal environmental management (PS3), demand forecasting (PS6), and RL (PS8). Table 5 presents the list of practices that have the greatest impact on downstream performance. These tables indicate that practices Pr48 and Pr13 stand out in terms of downstream performance. Moreover, practice Pr48 (distribution, transportation, and redesign strategies) is also among the most relevant practices for upstream performance, making it a major relevant management practice in the company overall.

Table 5. List of practices with the highest impact on downstream performance.

Practice	Practice Set	Description	Impact over Performance		
			Downstream	Upstream	Total
Pr48	PS8	Strategies for distribution, transportation and redesign of the components of the logistics system for greater environmental efficiency	2.47%	5.20%	7.68%
Pr13	PS3	Commitment to CLSCM from senior managers	2.16%	1.45%	3.61%
Pr49	PS8	Location of environmentally friendly facilities	1.58%	3.32%	4.90%
Pr19	PS3	Existence of environmental management systems	1.43%	0.33%	1.76%
Pr16	PS3	Environmentally driven total quality management	1.29%	0.30%	1.59%
Pr42	PS6	Aggregate production planning models that consider returned products	1.21%	2.55%	3.76%
Pr37	PS6	Inventory control models that explicitly consider returning batches of returned products	1.17%	2.47%	3.64%
Pr38	PS6	Inventory models combined with production models, considering the dependent rates of return	1.15%	2.41%	3.56%
Pr14	PS3	CLSCM support for middle managers	0.94%	0.91%	1.85%
Pr18	PS3	ISO 14001 certification	0.91%	0.21%	1.12%
Pr34	PS6	Effectiveness of uncertainty reduction methods	0.90%	1.88%	2.78%
Pr35	PS6	Forecasting models to predict rates and volumes of return	0.76%	1.59%	2.35%
Pr17	PS3	Compliance with environmental legislation and audit programs	0.57%	3.76%	4.34%
Pr21	PS4	Product design focusing reuse, recycling and recovery of materials and components	0.55%	5.20%	5.75%
Pr22	PS4	Design of products that avoid or reduce the use of harmful substances in products and their manufacturing process	0.44%	4.22%	4.66%
Pr20	PS4	Design of products with reduced material and energy consumption	0.44%	4.22%	4.66%

As for downstream performance, the set "internal environmental management" (PS3) also stands out, more specifically the practice of commitment to CLSCM from senior managers (Pr17—2.16%), which corroborates with the predictions made by [44]. After analyzing the results of the correlation between CLSCM practices and performance measures, it seems that this set of practices is not among the most relevant for the company. This indicates that this set has greater meaning in the downstream direction.

3.4. Upstream Performance Results

Table 6 presents the results for upstream performance measures. Practice Pr47 was the most relevant for the company since it deals with the reverse transportation of the waste that becomes raw material for its production system. Additionally, “Compliance with Environmental Legislation and Audit Programs” (Pr17) from the set “internal management practices” (PS3) also received high relevance scores.

Table 6. List of practices with the highest impact on upstream performance.

Practice	Practice Set	Description	Impact over Performance		
			Downstream	Upstream	Total
Pr47	PS7	Reverse transportation logistics and waste disposal	0.00%	7.66%	7.66%
Pr44	PS7	Models to assist in determining which parts and components can be used to recover disassembled products	0.00%	6.37%	6.37%
Pr45	PS7	Models and methods that analyze the effectiveness of coordination of disassembly and reassembly operations	0.00%	6.17%	6.17%
Pr46	PS7	Templates for plant design of disassembly facilities and staff	0.00%	5.62%	5.62%
Pr48	PS8	Strategies for distribution, transportation and redesign of the components of the logistics system for greater environmental efficiency	2.47%	5.20%	7.68%
Pr21	PS4	Product design focusing on reuse, recycling, and recovery of materials and components	0.55%	5.20%	5.75%
Pr22	PS4	Design of products that avoid or reduce the use of harmful substances in products and their manufacturing process	0.44%	4.22%	4.66%
Pr20	PS4	Design of products with reduced material and energy consumption	0.44%	4.22%	4.66%
Pr17	PS3	Compliance with environmental legislation and audit programs	0.57%	3.76%	4.34%
Pr49	PS8	Location of environmentally friendly facilities	1.58%	3.32%	4.90%
Pr40	PS6	Methods for examining the benefits of synchronizing production with reverse demands	0.00%	2.65%	2.65%
Pr42	PS6	Aggregate production planning models that consider returned products	1.21%	2.55%	3.76%
Pr37	PS6	Inventory control models that explicitly consider returning batches of returned products	1.17%	2.47%	3.64%
Pr38	PS6	Inventory models combined with production models, considering the dependent rates of return	1.15%	2.41%	3.56%
Pr43	PS6	Efforts coordinated by purchasing and inventory managers to plan, manage and control rates of return	0.00%	2.04%	2.04%
Pr34	PS6	Effectiveness of uncertainty reduction methods	0.90%	1.88%	2.78%
Pr35	PS6	Forecasting models to predict rates and volumes of return	0.76%	1.59%	2.35%
Pr13	PS3	Commitment to CLSCM from senior managers	2.16%	1.45%	3.61%
Pr6	PS1	Cooperation with customers for ecodesign	0.15%	1.34%	1.49%
Pr14	PS3	CLSCM support for middle managers	0.94%	0.91%	1.85%

A deeper analysis shows that it has its highest relationship scores with the performance measures “RL costs per processed device” (Pe30–0.39%) and “RL costs per dispatched device” (Pe31–0.40%). Another relevant finding is that the practice of “product design for reuse, recycling, and recovery of materials and components” (Pr21), which is an operational practice that accounts for 5.75% of the overall organizational performance, has a significant impact on eight performance measures (Pe26, Pe28, Pe29, Pe30, Pe31, Pe32, Pe35, and Pe36).

In the set “planning and control” (PS7), three practices stand out: models to help in the planning of which parts and components are used to recover the disassembly (Pr44—6.37%), models and methods that analyze the effectiveness of the coordination and release of disassembly with reassembly (Pr45—6.17%), and models for the design, layout, and personnel of disassembly facilities (Pr46—5.62%). These are practices that involve a combination of management and mathematical models to improve production planning and control. This indicates that the effectiveness of the supply chain relies strongly on production planning practices. In the studied company, these practices had significant relationships with 10 performance measures.

As for RL practices (PS8), the highest degrees of relationships were “RL of transportation and waste disposal” (Pr47—7.66%), which was the practice with the highest individual score in the company, followed by “distribution strategies, transportation, and redesign of the components of the logistics system for greater environmental efficiency” (Pr48—7.68%). These results are noteworthy because some authors emphasize the importance of RL for CLSCM [10]. However, our results show that in the studied company, its importance is similar to other management practices.

Results also show that upstream performance measures account for 77.72% of the total organizational performance. The main highlights are the “costs of RL per device dispatched” (Pe31—6.81%), “costs of RL per device returned” (Pe30—6.63%), “reduction in the quantity of products discarded”, (Pe39—6.19%) and the “percentage of units returned” (Pe32—6.02%). Together, these four measures account for 25.66% of the overall performance.

4. Discussion

The practical application of the correlational model showed that it is effective in determining which practices and performance measures should be prioritized in the case studied, where the company adopts CLSCM. Also, the proposed method is based on weighting and correlation techniques that are simple and have been widely tested in the literature. The paper offers original insight into the correlation model integrating the fuzzy direct rating method (FDRM) and CLSCM practices and performance measures. It was tested by a real company that is part of a closed-loop supply chain that recycles lead obtained from automotive batteries in Brazil.

From the standpoint of the company where the application took place, the method identified the two highest-rated practices, demand forecasting (PS6) and planning and control (PS7), which belong to green manufacturing. It was also found that upstream performance measures account for 77.72% of the overall CLSC performance. After the application of the proposed method, the company has a clearer view of which practices and performance measures are more relevant to the success of its supply chain.

Some low-scoring practices also deserve attention, such as waste management (PS3) and planning and control (PS7). These practices obtained weights of 1.58% and 0% in the downstream direction, respectively, and 1.27% and 25.81% in the upstream direction. Because the objective of CLSCM is to close the supply chain cycle, the focus should be primarily on maintaining products that were previously discarded within the chain, so practices linked to the upstream direction are highly relevant [38]. Moreover, the practices linked to waste management (PS3) also played a secondary role for the studied company. This indicates an area for improvement in the firm's supply chain performance.

In general, the proposed method may help the industrial sector adopt sustainable practices that are more effective for managing their CLSC, thus contributing to the preservation of natural resources [4]. This stems from the fact that our method aligns different management practices and performance measures, which balance environmental goals with financial and market objectives [4]. Authors such as [4] discuss the predominance of economic performance factors over environmental factors, which was also observed during the practical application of the proposed method. However, our method links performance measures to a series of management practices.

Practical Implications

The most prominent benefit of adopting the proposed method is that the organization can better visualize which performance measures should be prioritized. The company was able to determine that upstream measures are responsible for 77.72% of its performance. A possible explanation for the greater importance of upstream performance stems from the fact that the organization is a lead recycler, which is a material with high recyclable content.

By correlating management practices and performance measures, the company could determine which practices had a greater impact on its performance, which were operational processes related to green manufacturing, demand forecasting, and production planning and control. Therefore, to improve its performance, the organization needs more precise methods of forecasting demand since the company is part of the lead reverse supply chain, and its demand starts with the disposal of automotive batteries. Moreover, the forecasting is linked with production planning, because the company cannot purchase lead in a traditional fashion, thus relying solely on disposed of car battery carcasses. If automotive batteries stop being disposed of, the company may run out of raw materials for its operations.

This can help the firm devise initiatives to reduce environmental impacts, but not in a traditional manner. Despite the importance of waste management practices in reducing anthropogenic environmental impact, the organization seems to produce positive environmental, social, and economic results by adopting practices not directly linked to environmental and social factors, such as creating models to predicting return rates and volumes, as well as adopting reliability models that predict the life cycle of products with multiple lives. Understanding how much material will be returned to the company and knowing the product life cycle are critical for improving performance in the studied organization.

It should be noted that the company has a certified integrated management system that complies with the ISO 9001, ISO 14001, and OHSAS 18001 standards. In addition to carrying out environmental and social programs, the company has a well-established 5S (5-senses) quality program in place. During the visits to the company, the researcher could see that the program helps maintain a very clean work environment, and some environmental initiatives stem from the 5S program.

For example, trucks that enter the plant receive a protective layer to avoid oil leakage. The company also breeds sheep, which are used to provide biological mats at the company's plant and that are later donated to employees at all levels. This shows that the company trusts its environmental practices, since one form of lead pollution is contaminating the food chain. These aspects show that the company puts great emphasis on environmental management. However, a question that arises is whether increasing the efficiency and effectiveness of these practices would result in performance improvements for the CLSCM. The results from the model application indicate that the answer is no, since most of the company's performance is linked to other types of practices, more specifically demand forecasting and production planning and control.

In summary, the proposed method proved useful in assisting managers in making decisions related to prioritizing performance measures and practices by providing a quantitative measure of how much a given practice impacts all performance aspects. The method is thus effective for companies inside a closed-loop system since it provides a comprehensive view of CLSCM practices and performance measures. The practical application of the method shows its potential for helping organizations better understand CLSCM performance and devise practices that will be more effective in improving performance.

5. Conclusions

CLSCM is a complex and multifaceted field that is essential for companies that seek sustainability. This paper contributed to this field by proposing a correlational model that links FDRM with CLSCM practices and performance measures, thus helping companies to set their priorities.

Another important contribution of this paper is the bibliographic survey that was used to determine the set of CLSCM practices and performance measures. In total, 59 practices and 41 performance measures were identified and subdivided into categories using the guidelines put forward by [7,39].

The proposed model in this article fills this gap in the current CLSCM literature [20,21], because it relates practices to performance by identifying a wide range of management practices and performance measures along with a method to correlate them and quantify the relevance of a set of management practices with respect to each performance measure. This was performed using a correlation matrix, and the weights of each performance measure and management practice were calculated using the FDRM, filling the gaps by linking practices and performance indicators in CLSCM [4].

As for the practical application, the results show that the method is effective in determining the interplay between CLSCM practices and performance measures. More specifically, the correlation matrix allows the company to quantify how much a certain practice influences CLSCM performance, both in the upstream and downstream directions. Conversely, the correlation matrix enables the identification of which practices should be prioritized to maximize performance. Hence, the main contribution of the proposed method lies in the visualization of how performance is spread throughout the various dimensions of CLSCM. This, in turn, may be used as a decision-making tool by managers to more effectively implement actions over the CLSCM.

As for the application carried out in the lead-acid recycling company, the model proved capable of correlating CLSCM practices and performance measures.

For future practical applications, new practices and performance measures can be included, and the model will remain consistent because the weighting and correlation equations can be easily adjusted to accommodate these additions. The same model can be tested in other organizations to verify its adherence to other companies in different segments, and longitudinal studies can be conducted to verify whether the weights found are compatible with the performance found in the proposed model. The research limitations include that the analysis was conducted in a single company, which prevents the generalization of the results to other organizations. However, it is recommended to apply the study to companies in the same or other sectors to enhance its validity. Additionally, the use of other mathematical models, such as the Analytic Hierarchy Process (AHP), is suggested as an opportunity for future research.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/systems13010050/s1, Supplementary Data Files.

Author Contributions: Conceptualization, A.M.-F., R.F. and R.H.P.L.; methodology, A.M.-F., R.F. and R.H.P.L.; validation, A.M.-F., R.F., R.H.P.L. and F.C.F.; formal analysis, A.M.-F., R.F. and R.H.P.L.; writing—original draft preparation, A.M.-F., R.F. and R.H.P.L.; writing—review and editing, P.P.D.A.J. and D.J.H.; project administration, A.M.-F.; funding acquisition, P.P.D.A.J. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: Data is contained within the article or Supplementary Materials.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Queiruga, D.; Benito, J.G.; Lannelongue, G. Evolution of the electronic waste management system in Spain. *J. Clean. Prod.* **2012**, *24*, 56–65. [CrossRef]
2. Jia, F.; Yin, S.; Chen, L.; Chen, X. The circular economy in the textile and apparel industry: A systematic literature review. *J. Clean. Prod.* **2020**, *259*, 120728. [CrossRef]
3. González-Torre, P.L.; Adenso-Díaz, B. Reverse logistics practices in the glass sector in Spain and Belgium. *Int. Bus. Rev.* **2006**, *15*, 527–546. [CrossRef]
4. Marco-Ferreira, A.; Jabbour, C.J.C. Relating maturity levels in environmental management by adopting Green Supply Chain Management practices: Theoretical convergence and multiple case study. *Gest. Prod.* **2019**, *26*, e1822. [CrossRef]
5. Rostamzadeh, R.; Govindan, K.; Esmaeili, A.; Sabaghi, M. Application of fuzzy VIKOR for evaluation of green supply chain management practices. *Ecol. Indic.* **2015**, *49*, 188–203. [CrossRef]
6. Shen, Z.; Li, X.; Ju, L.; Jia, Z. A real-time flash translation layer via adaptive partial garbage collection. *Int. J. Embed. Syst.* **2014**, *6*, 167. [CrossRef]
7. Ferreira, M.A.; Jabbour, C.J.C.; de Sousa Jabbour, A.B.L. Maturity levels of material cycles and waste management in a context of green supply chain management: An innovative framework and its application to Brazilian cases. *J. Mater. Cycles Waste Manag.* **2017**, *19*, 516–525. [CrossRef]
8. Agyabeng-Mensah, Y.; Afum, E.; Ahenkorah, E. Exploring financial performance and green logistics management practices: Examining the mediating influences of market, environmental and social performances. *J. Clean. Prod.* **2020**, *258*, 120613. [CrossRef]
9. Guide, V.D.R., Jr. Production planning and control for remanufacturing: Industry practice and research needs. *J. Oper. Manag.* **2000**, *18*, 467–483. [CrossRef]
10. Atasu, A.; Guide, V.D.R.; Van Wassenhove, L.N. Product reuse economics in closed-loop supply chain research. *Prod. Oper. Manag.* **2008**, *17*, 483–496. [CrossRef]
11. Abbey, J.D.; Guide, V.D.R. Closed-Loop Supply Chains: A Strategic Overview. *Sustain. Supply Chain. A Res.-Based Textb. Oper. Strategy* **2017**, *1*, 375–393. [CrossRef]
12. Carrasco-Gallego, R.; Ponce-Cueto, E.; Dekker, R. Closed-loop supply chains of reusable articles: A typology grounded on case studies. *Int. J. Prod. Res.* **2012**, *50*, 5582–5596. [CrossRef]
13. Bhatia, M.S.; Jakhar, S.K.; Mangla, S.K.; Gangwani, K.K. Critical factors to environment management in a closed loop supply chain. *J. Clean. Prod.* **2020**, *255*, 120239. [CrossRef]
14. Zhu, Q.; Sarkis, J.; Lai, K.H. Green supply chain management implications for "closing the loop". *Transp. Res. E Logist Transp. Rev.* **2008**, *44*, 1–18. [CrossRef]
15. Fidelis, R.; Marco-ferreira, A.; Cristina, L.; Kenji, A. Resources, Conservation & Recycling Socio-productive inclusion of scavengers in municipal solid waste management in Brazil: Practices, paradigms and future prospects. *Resour. Conserv. Recycl.* **2020**, *154*, 104594. [CrossRef]
16. Pipatprapa, A.; Huang, H.H.; Huang, C.H. Enhancing the effectiveness of AHP for environmental performance assessment of Thailand and Taiwan's food industry. *Environ. Monit. Assess.* **2018**, *190*, 1–16. [CrossRef]
17. Shen, L.; Olfat, L.; Govindan, K.; Khodaverdi, R.; Diabat, A. A fuzzy multi criteria approach for evaluating green supplier's performance in green supply chain with linguistic preferences. *Resour. Conserv. Recycl.* **2013**, *74*, 170–179. [CrossRef]
18. Larimian, T.; Zarabadi, Z.S.S.; Sadeghi, A. Developing a fuzzy AHP model to evaluate environmental sustainability from the perspective of Secured by Design scheme—A case study. *Sustain. Cities Soc.* **2013**, *7*, 25–36. [CrossRef]
19. Kaya, T.; Kahraman, C. Multicriteria decision making in energy planning using a modified fuzzy TOPSIS methodology. *Expert Syst. Appl.* **2011**, *38*, 6577–6585. [CrossRef]

20. Khatri, J.K.; Metri, B. SWOT-AHP Approach for Sustainable Manufacturing Strategy Selection: A Case of Indian SME. *Glob. Bus. Rev.* **2016**, *17*, 1211–1226. [CrossRef]
21. Pishvaee, M.; Torabi, S. A possibilistic programming approach for closed-loop supply chain network design under uncertainty. *Fuzzy Sets Syst.* **2010**, *161*, 2668–2683. [CrossRef]
22. Nakamura, S.; Kondo, Y. Toward an integrated model of the circular economy: Dynamic waste input–output. *Resour. Conserv. Recycl.* **2018**, *139*, 326–332. [CrossRef]
23. Lis, A.; Sudolska, A.; Tomanek, M. Mapping research on sustainable supply-chain management. *Sustainability* **2020**, *12*, 3987. [CrossRef]
24. Fu, R.; Qiang, Q.P.; Ke, K.; Huang, Z. Closed-loop supply chain network with interaction of forward and reverse logistics. *Sustain. Prod. Consum.* **2021**, *27*, 737–752. [CrossRef]
25. Zhou, Y.; Xiong, Y.; Jin, M. Less is more: Consumer education in a closed-loop supply chain with remanufacturing. *Omega* **2021**, *101*, 102259. [CrossRef]
26. Szmelter-Jarosz, A.; Abdi, H.; Nozari, H. Closed-Loop Supply Chain Management (CLSCM) in the Circular Economy. *J. Bus. Future Econ.* **2024**, *1*, 24.
27. Alghababsheh, M. Understanding whether, how and when circular supply chain management influences firm performance. *Bus. Strat. Environ.* **2024**, *33*, 7139–7161. [CrossRef]
28. Díaz-Pilpe, J.; Maldonado-Galarza, F.; Helguero, C.G.; Ramírez, E.; Rejeb, H.B.; Zwolinski, P.; Hidalgo-Crespo, J.; Amaya-Rivas, J.L. Methodology for the third-party reconditioning process of automotive vented lead-acid (VLA) batteries. In *Procedia CIRP*; Elsevier: Amsterdam, The Netherlands, 2023; Volume 118, pp. 970–975. [CrossRef]
29. Azevedo, S.G.; Carvalho, H.; Duarte, S.; Cruz-Machado, V. Influence of green and lean upstream supply chain management practices on business sustainability. *IEEE Trans. Eng. Manag.* **2012**, *59*, 753–765. [CrossRef]
30. Srivastava, S.K. Green supply-chain management: A state-of-the-art literature review. *Int. J. Manag. Rev.* **2007**, *9*, 53–80. [CrossRef]
31. Mohanty, R.P.; Prakash, A. Green supply chain management practices in India: A confirmatory empirical study. *Prod. Manuf. Res.* **2014**, *2*, 438–456. [CrossRef]
32. Lin, R.J. Using fuzzy DEMATEL to evaluate the green supply chain management practices. *J. Clean. Prod.* **2013**, *40*, 32–39. [CrossRef]
33. Liu, X.; Yang, J.; Qu, S.; Wang, L.; Shishime, T.; Bao, C. Sustainable production: Practices and determinant factors of green supply chain management of Chinese companies. *Bus. Strat. Environ.* **2012**, *21*, 1–16. [CrossRef]
34. Zhu, Q.; Sarkis, J.; Lai, K.-H. Institutional-based antecedents and performance outcomes of internal and external green supply chain management practices. *J. Purch. Supply Manag.* **2013**, *19*, 106–117. [CrossRef]
35. Green, K.W., Jr.; Zelbst, P.J.; Meacham, J.; Bhadauria, V.S. Green supply chain management practices: Impact on performance. *Supply Chain Manag. Int. J.* **2015**, *17*, 290–305. [CrossRef]
36. Carvalho, H.; Govindan, K.; Azevedo, S.G.; Cruz-Machado, V. Modelling green and lean supply chains: An eco-efficiency perspective. *Resour. Conserv. Recycl.* **2017**, *120*, 75–87. [CrossRef]
37. Martin, P.; Guide, J.V.D.R.; Craighead, C.W. Supply chain sourcing in remanufacturing operations: An empirical investigation of remake versus buy. *Decis. Sci.* **2010**, *41*, 301–324. [CrossRef]
38. Geng, Y.; Zhu, Q.; Doberstein, B.; Fujita, T. Implementing China's circular economy concept at the regional level: A review of progress in Dalian, China. *Waste Manag.* **2009**, *29*, 996–1002. [CrossRef]
39. Mondragon, A.E.C.; Lalwani, C.; Mondragon, C.E.C. Measures for auditing performance and integration in closed-loop supply chains. *Supply Chain Manag.* **2011**, *16*, 43–56. [CrossRef]
40. Georgiadis, P.; Athanasiou, E. Flexible long-term capacity planning in closed-loop supply chains with remanufacturing. *Eur. J. Oper. Res.* **2013**, *225*, 44–58. [CrossRef]
41. Özceylan, E.; Paksoy, T. Fuzzy multi-objective linear programming approach for optimising a closed-loop supply chain network. *Int. J. Prod. Res.* **2013**, *51*, 2443–2461. [CrossRef]
42. Dodgson, J.S.; Spackman, M.; Pearman, A.; Phillips, L.D. Multi-Criteria Analysis: A Manual. *J. Multi-Criteria Decis. Anal.* **2009**, *11*, 35–53. [CrossRef]
43. Kumar Sagar, M.; Jayaswal, P.; Kushwah, K. Exploring Fuzzy SAW Method for Maintenance Strategy Selection Problem of Material Handling Equipment. *Int. J. Curr. Eng. Technol.* **2013**, *3*, 600–605.
44. de Sousa Jabbour, A.B.L.; Jabbour, C.J.C.; Govindan, K.; Kannan, D.; Salgado, M.H.; Zanon, C.J. Factors affecting the adoption of green supply chain management practices in Brazil: Empirical evidence. *Int. J. Environ. Stud.* **2013**, *70*, 302–315. [CrossRef]