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THE REVERSE CHAIN OF WASTE COOKING OIL FOR BIODIESEL PRODUCTION FROM THE PERSPECTIVE OF COLLECTORS

Ilton Curty Leal Junior
iltoncurty@id.uff.br
Fluminense Federal University - UFF, Niterói, RJ, Brazil.

Vitória Palmeira Maia
vitoriapalmeiramaia@live.com
Fluminense Federal University - UFF, Niterói, RJ, Brazil.

Ricardo Cesar da Silva Guabiroba
ricardocesar@id.uff.br
Fluminense Federal University - UFF, Niterói, RJ, Brazil.

Ualison Rébula de Oliveira
ualisonrebula@id.uff.br
Fluminense Federal University - UFF, Niterói, RJ, Brazil.

ABSTRACT

Highlights: (1) In Brazil, the addition of pure biodiesel (B100) to diesel oil is mandatory. (2) Waste cooking oil is one of the possible feedstocks for B100. (3) Uncontrolled costs and risks of collection activities make waste cooking oil less competitive. (4) Actions can be implemented to improve the competitiveness of waste cooking oil. **Aim:** Identify and compare the costs and risks of two modalities of the waste cooking oil reverse chain, known as door-to-door collection, and collection point utilization. **Methodology:** Data concerning the year 2020 of two waste cooking oil collecting organizations in the municipality of Volta Redonda-RJ were collected by means of interviews and documental research. After the data survey, it was possible to map the stages of the reverse chain of the two companies and compare the results obtained regarding costs and risks in both modalities. The Supply Chain Risk Management - SCRM methodology was used to support data analysis. Finally, actions were proposed to improve results based on a bibliographical survey. **Results:** Results show that the most risky and costly stage of the reverse chain is that of transportation and collection for both modalities, if compared to the other stages analyzed, identifying a greater need for the implementation of improvement actions. It was also possible to verify that, for some stages, simple control actions can impact the risks and costs identified. **Research limitations:** The analysis considered only a part of the waste cooking oil reverse chain from a given geographic region and considered only two companies. The other limitation was data collection restricted to the year 2020 and interviews conducted with a non-probabilistic sample. Thus, the results obtained in this study cannot be generalized. **Practical Implications:** Considering the study performed, it is possible to set up a workflow of the researched organizations so as to assist their managers in the analysis and measurement of their risks and costs. The results can also help waste cooking oil collecting companies in implementing actions that can potentially contribute to improving the performance of their operations. **Originality/value:** This research contributes to the area of operations, as it raises the main risks and cost ranges per stage of the reverse chains studied, based on the reality of small and medium-sized companies in a region, considering the limitations of financial and human capital resources of organizations operating in the segment. Additionally, the research points out ways for these organizations that have relevant performance from the economic, environmental, and social point of view.

Keywords: Reverse chain; Waste cooking oil; Risk analysis; SCRM.

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1. INTRODUCTION

According to the National Agency of Petroleum, Natural Gas, and Biofuels, ANP, (2019), the equivalent of 161,774,593 m³ of oil and 5,901,104 m³ of biofuel were produced in Brazil. In 2008, the mixture of pure biodiesel (B100) to diesel oil became mandatory, and as of September 2019, this mixture became 11% by volume, as stipulated by Law 13,263/2016, changing its consumption, which grew 25.7% (BEN, 2019).

In the case of biofuels, the supply chain plays a significant role by connecting different parts of the process, establishing a flow between geographically dispersed regions, and by generally having a significant cost (Santos and Ribeiro, 2013).

For Trkman and McCormack (2009), a supply chain that is resilient and potentially adaptable to changes arising from external means, such as changes in the dynamics between businesses and environmental issues, can give competitive advantage to the organization that owns it. A supply chain with such characteristics is essential to ensure the flow of its operations and, consequently, a good performance.

A poorly managed supply chain, in terms of risks, can lead to recurrent or isolated losses and costly processes, due to risks that have a considerable degree of predictability, but are not controlled (Hunt *et al*., 2010).

In this context, the analysis of the stages of preparation, transportation, collection, and storage of waste cooking oil, along with the survey of risks, costs, and suggestions for actions to control them, can be economically useful for organizations that are present in the area and justify the scientific exploration of the theme. In view of the above, the present study is based on the following questions to represent the research problem: (1) Given the considerable growth of biodiesel consumption, how can we contribute to improve the reverse logistics chain of waste cooking oil as a raw material, considering the associated risks and costs? (2) Which stages represent the greatest risk and cost in the process of waste cooking oil reverse logistics?

To answer the questions of the research problem, the main objective was to identify and compare the costs and risks of two modalities of the waste cooking oil reverse chain: door to door (where the collector goes to the generator) and the use of a collection site (where the generator goes to a predetermined collection point). To this end, the stages of the waste cooking oil reverse chain performed by two small and medium-sized collection companies, operating in the city of Volta Redonda-RJ, were analyzed. The specific objectives of this study are (1) to raise studies on supply chains from the point of view of risks and costs; and (2) to suggest actions that can contribute to the improvement of the performance of the reverse chain of waste cooking oil.

To improve the form of risk management in the supply chain in the case of residual oil, the research is based on Supply Chain Risk Management (SCRM) in four stages to identify, assess, mitigate, and control the possible risks present in the chain (Rangel *et al*., 2014). This research is justified by the importance of the topic for organizations and society, and because it aims to present a contribution to the reverse chain of waste, including the proposal of actions aimed at reducing and/or mitigating the risks present and, consequently, their costs. This study contributes to increasing the competitive potential of waste cooking oil as a raw material for biofuel production.

As a research delimitation, only the preparation, transportation, collection, and storage operations within the entire biodiesel production process were considered. Furthermore, the research was limited to the average costs and risks raised specifically in the southern region of the state of Rio de Janeiro.

Based on this introduction, this study is organized as follows: Section 2 presents the concepts and studies that were the basis for this research; Section 3 presents the procedures for conducting the research, followed by Section 4, the application, analysis, and discussion of results; in Section 5, the final considerations are made and, finally, the list of references used in the work is presented.

2. THEORETICAL FRAMEWORK

In this section, a literature survey was conducted on waste cooking oil for biodiesel production, reverse supply chain assessment, and Supply Chain Risk Management.

Waste cooking oil

Waste cooking oil, once used, becomes an unwanted residue and its recycling as an alternative biofuel would not only remove a pollutant from the environment, but would also allow the generation of an alternative energy source. Thus, two basic needs would be met at once (Pasqualetto and Barbosa, 2008).

As disclosed by the National Agency of Petroleum, Natural Gas, and Biofuels (ANP) in 2019, the liter of diesel oil came out of the refinery for R$1.98, on average, and B100 of the producer came out for R$3.80, i.e., almost double. This significant difference directly impacts the competitiveness of the products in the market.

Biodiesel is a generic denomination for fuels derived from renewable sources, such as vegetable oils (soybean, corn, dendê palm, castor, palm, etc.) and animal fat (beef tallow,

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and chicken fat) (Holland, 2004). According to ANP (2019), soybean oil represents the main raw material for biodiesel production in Brazil (68.33% of the total). In second place are others, such as palm oil, peanut oil, turnip rape oil, sunflower oil, castor oil, sesame oil, used cooking oil and other fatty materials (16.48%); and in third place, there is beef fat (14.06%).

Biodiesel replaces, totally or partially, diesel from fossil origin in trucks, tractors, vans, and automobile engines, and can be used pure or added to diesel oil in several proportions (Brandão *et al.*, 2009). According to Costa Neto *et al*. (2000), in the economic aspect, biodiesel becomes competitive as it complements all the new diesel technologies with similar performance and without the need to install an infrastructure or training policy.

In relation to biodiesel production, it is also important to consider some issues, such as the need for some technological adaptations and measures to reduce production costs. According to specialists, to reduce these costs, the use of residual cooking oil has been pointed out as one of the alternatives, since this residue is commonly discarded. However, there are costs to collect and reduce the acidity of this oil so that it can be transformed into biodiesel (Costa Neto *et al*., 2000).

Residual cooking oil comes from the consumption of refined virgin edible vegetable oils. After this consumption, there are basically two possible destinations for this material: (1) sanitary sewage, causing water pollution and costing its treatment, and (2) processors that transform the residue into a new product. In this context, it would be desirable to forward the residue to processors, such as biodiesel plants. For this, the residual cooking oil needs to be collected (Guabiroba and D'Agosto, 2011).

After use, the material is collected and filtered to remove possible solid residues and then stored in containers that prevent spillage. Afterwards, it is directed to ecopoints, recycling cooperatives, or specialized companies, which receive the product and process it, separating the vegetable oil from the glycerin. In this context, the oil is commonly sold for biodiesel production, and the glycerin (byproduct of the biodiesel production process) is used to make soap or meal for animal feed (ECOLEO, 2016).

However, the residual cooking oil is commonly found dispersed in urban areas, which can make the collection cost so high as to compromise biodiesel production, especially when this operation is done in a disorganized and unplanned manner. For this, it is necessary to verify whether the cost of this collection in urban areas makes it more expensive than virgin vegetable oil for biodiesel production (Guabiroba and D'Agosto, 2011).

Supply Chain Risk Management

To better understand the theme, Chart 1 was created, based on bibliographic research that shows a compilation of studies on Supply Chain and/or Supply Chain Risk Management (SCRM). They were classified and analyzed by the cases that presented practical application, by material transported, methods used for analysis, their classification as to the type of logistics used, whether direct or reverse, and, if there were any, the identification of improvement actions or enhancements in the chain studied.

9On the methodological issues for the analysis of the chains addressed, it is observed that the studies use literature review. In some cases, the studies use techniques specifically related to the supply chain such as SCM in Seuring and Gold (2012) and Dias *et al.* (2020), and SCRM in Dias *et al.* (2019). Pouriani *et al.* (2019) propose a solid waste management network from the public initiative as a solution for solid waste disposal, while the other works focus on improvement aspects of existing networks and/or literature survey.

It is also noted that Dias *et al*. (2020) focus on identifying risks and response actions commonly used in a supply chain of a Brazilian automotive industry, having the use of a chain management tool (SCRM) as the centerpiece of the study while authors such as Carvalho *et al.* (2013), despite also conducting the study of a supply chain, make use of a case study analysis without a specific tool.

It is also noticeable that, among the articles analyzed and selected during the literature survey, semi-structured interviews are widely used in the construction of the studies, as in Soto-Silva *et al.* (2016). Their main role is to bring the research as close as possible to the practical reality experienced by professionals who perform activities pertinent to the theme. The method used by Dias *et al.* (2020) in their study on risk analysis in supply chains presents the development of a risk matrix through the classification of risk points raised by the application of questionnaires and interviews.

For the improvement actions identified in the studies broken down in Table 1, actions aimed at strategically establishing routes as a way to reduce costs stand out and are observed in Pouriani *et al.* (2019) and Guabiroba and D'Agosto (2011). In Carvalho *et al.* (2013), investment in agent training and technological tools are cited as a way to promote improvement in the chain's operation and management activities.

The identified action alternatives are geared towards creating communication links between stakeholders, as noted in Dias *et al.* (2019) and Almeida *et al.* (2017). As the only work analyzed that proposes an improvement action start-

Chart 1. Improvement actions and methods

Authors	Year	Objective	Country of Study	Material	Method	Reverse Logistics	Direct Logistics	Identified Improvement Actions
Dias et al.	2020	Analyze how a vehicle manufacturer identifies and manages risk factors related to its supply chain	Brazil	Automotive	AHP method and creation of a hierarchical matrix		X	N/A
Dias et al.	2019	Identify the risks that a port can offer to the organizations in its chain and how they are handled by its managers	Brazil	N/A	SCRM	X		Establishment of a link between terminals and customers together with the companies involved, with port managers as the main agents of interaction, in order to reduce risks throughout the chain
Pouriani et al.	2019	Propose a municipal solid waste management network in order to minimize different costs	Iran	Paper, Plastic, and Metal	Two-level mathematical model		X	Definition of the location and establishment of solid waste collection stations and waste allocation to other centers
Almeida et al.	2017	Propose a specific reverse channel for açaí pulp production residues	Brazil	Açaí seed	Qualitative analysis	X		Reverse channel involving collection, sorting, treatment, and disposal stages with standardization of the analysis process in the sorting stage
Dubey et al.	2017	Argue for the use of Total Interpretive Structural Modeling (TISM) alternative research methods and frameworks in building robust approaches and techniques that consider the dynamics of the SCM environment rather than deductive or inductive approaches	India	Various	SCRM and Total Interpretive Structural Modeling (TISM)		X	Use of TISM in developing the supply chain theoretical framework, helping to describe the dynamics of operations and SCRM for better practical management, cost savings, and competitiveness
Lopes et al.	2016	Presents a comparative study of scenarios, considering different characteristics of the bioethanol supply chain, focusing on the impact of modal choice and the use of renewable energy on its environmental performance	Brazil	Bioethanol	LCA (Life Cycle Analysis) and a partial application of LCI (Life Cycle Inventory)		X	Using a configuration that consumes more renewable energy

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Miller et al.	2016	Suggest a new type of tool for traffic analysis that can be used in planning and/or decision-making and research contexts	Canada	N/A	Public Transit Sustainable Mobility Analysis Tool (PTSMAT) Monte Carlo Simulation - SMC		X	Use the proposed new tool to guide the decision-making and planning processes
Soto-Silva et al.	2016	Define the current state-of-the-art in operations research models applied to the new fresh fruit supply chain	Various	Fresh fruit	Qualitative analysis		X	Use of technological tools and resources for decision making on the chain
Guabiroba et al.	2014	They propose a method based on the concept of eco-efficiency for selecting an interregional public consortium responsible for implementing and operating door-to-door selective waste collection	Brazil	Recyclable household waste	Weighted average calculated by aggregating the Financial Performance Measure (FPM) and the Environmental Performance Measure (EPM)	X		Partitioning the study region into clusters and analyzing the options using financial criteria and environmental performance measurement
Luna et al.	2014	Analyze the reverse logistics process of containers of an alcoholic beverage manufacturer	Brazil	Alcoholic beverage containers	Qualitative analysis	X		Adoption of a computerized management system and diversification of supply sources
Zhang et al.	2014	Build a dynamic model between biofuel companies and recyclers to compare recycling modes and recycling rate decisions of waste cooking oil conversion to biofuel	China and Japan	Residual cooking oil	Qualitative analysis	X		It is recommended that tax advantages be provided for companies that adhere to the dynamic, consequently increasing market participation rates
Carvalho et al.	2013	Map and analyze transactions along the lettuce supply chain	Brazil	Lettuce	Qualitative Analysis		X	Investing in training that not only improves and contributes to adding value to the product, but also promotes improvement in the management and coordination of the supply chain

Seuring and Gold	2012	Show the importance of literature reviews in the SCM	Various	N/A	Qualitative Analysis		X	N/A
Guabiroba and D'Agosto	2011	Verify if the collection cost in urban areas makes waste cooking oil more expensive than virgin vegetable oil for biodiesel production	Brazil	Residual cooking oil	Simulation by Software	X		Using a software for vehicle routing
Pires et al.	2010	Verify, empirically, the implications that the supply chain configuration has on elements of its management, such as types of relationships, logistics processes, product planning, production management, and performance measurement	Brazil	automobile industry	Qualitative analysis		X	Investment in innovations and monitoring of strategic links in the supply chain

Source: The authors themselves

ing from a public initiative, Zhang *et al.* (2014) cite the creation of tax incentives for biofuel companies that join partnerships with recycling agents or specialized organizations as a way to increase the dynamism in the waste cooking oil market aimed at biodiesel production.

Aspects such as standardization of analysis and monitoring are present in the improvement actions identified in Almeida *et al.* (2017) and Luna *et al.* (2014), respectively.

3. METHODOLOGICAL PROCEDURES

To carry out this research, the stages and sub-stages in Chart 2 were established.

It is important to emphasize that, for this study, two waste cooking oil collection modalities were considered in order to provide a comparative analysis and, consequently, their risk points and costs. This choice was based on observations of collection models analyzed in the works of Guabiroba and D'Agosto (2011) and Pouriani *et al*. (2019).

The models analyzed were the door-to-door model, in which the collection agent goes to the generator agent, and the collection point model, where the generator agent has pre-defined points for the disposal of the waste to be collected by the collection agent.

For the initial part of this paper, literature and documentary research was conducted. A bibliographic search of relevant articles was conducted using the Web of Science™ database, filtered by subject, considering the title, abstract, and keywords. This literature search (Stage 1) contributed to broadening knowledge and definition of concepts about: (1) supply chain; (2) risk management method, using the SCRM tool; and (3) proposal of actions related to the reduction or extinction of costs and/or risks in the supply chain.

To build Chart 1 of the theoretical framework (Sub-stages 1.1 and 1.2), research papers were gathered that addressed the supply chain theme and used risk or cost analysis tools and/or provided proposals for improvement actions with potential replicability for the residual cooking oil reverse chain.

Moving on to Stage 2, the measurement and classification forms for the risks were developed, based on the analysis method adopted by Dias *et al.* (2020), in which scores are related from 1 to 5 for two variables, and their respective interactions generate a final score, which is related to a classification.

For the analysis, two variables were defined to be measured: (1) the first is the probability of occurrence of each risk by assigning a score from 1 to 5, where 5 = daily; 4 = very frequent; 3 = frequent; 2 = infrequent; and 1 = never happened; (2) the second variable determined was the impact generated for the chain in the event that that risk occurs, by assigning a score, where 5 = critical; 4 = high; 3 = moderate; 2 = low; and 1 = negligible.

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Chart 2. Stages and sub-stages of the methodological procedures used in the research

Stage	Description	Sub-stages	Stage Outputs
1	Concept survey	1.1 Bibliographic research 1.2 Documentary research	Concepts and methods needed to develop the research, introduction text, and definition of methodological processes (Table 1)
2	Definition of metrics for the classification of stages and risks	2.1 Definition of metrics and measurement methods 2.2 Definition of scoring range classification (SCRM - Evaluation)	Priority matrix in attackable risk points (Table 1) and risk score ranking table (Table 2)
3	Data survey	3.1 Interviews and questionnaire application (SCRM - Identification)	Definition of stages, cost ranges, and risk identification and classification (Tables 3 and 4)
4	Organization of the data collected	4.1 Layout Design 4.2 Distribution of the stages of the chains, according to the data collected	Tables of structured supply chains and debt according to collection mode (Tables 3 and 4)
5	Suggestions for action	5.1 Propose actions that reduce or inhibit the identified risks (SCRM - Mitigation and Control)	Suggested actions in the tables of analyzed supply chain stages according to their respective models (Tables 3 and 4)
6	Analysis of the results	6.1 Comparison by collection model and results	Model Comparative Analysis and Conclusion Texts

Source: The authors themselves

As developed by Dias *et al*. (2020), the interaction between the scores of two analyzed variables results in a matrix, generating a final score for a given risk and its consequent classification. The combination of the probability and impact scores gave rise to the matrix of risk points to be prioritized, which is an easy way to visualize and guide managers on which points should be prioritized or postponed in case of limitations of financial resources and/or available time. The result of this interaction in this study is presented in matrix form in Table 1.

Table 1. Matrix of priority on attackable risk points

Frequency / Impact	1	2	3	4	5
5	5	10	15	20	25
4	4	8	12	16	20
3	3	6	9	12	15
2	2	4	6	8	10
1	1	2	3	4	5

Source: Elaborated from Dias *et al.* (2020)

From the construction of the matrix, it is possible to classify each risk found according to the score obtained, as shown in Table 2.

Table 2. Risk classification.

Classification	Score
Extreme Risk	15 to 25
High Risk	8 to 12
Moderate Risk	3 to 6
Low Risk	1 to 2

Source: Elaborated from Dias *et al.* (2020)

Two managers responsible for the operational area of two waste cooking oil collecting companies, operating in the city of Volta Redonda-RJ, were interviewed. During the interviews, the managers identified the stages executed by their organizations within the waste cooking oil supply chain, with each stage designed according to the peculiarities of the process observed in each model. Subsequently, respondents defined cost ranges in percentages for each defined stage. The three proposed stages were detailed based on the reality of the organizations studied and on influential factors in the structuring of their reverse channels (Sub-stage 3.1).

Subsequently, according to the definition of Rangel *et al*. (2014), the application of the 4-phase SCRM was initiated, as presented in Figure 1.

Besides the individual risk classification, in order to aggregate for the discussion established in the comparative analysis section, general classifications were established for each of the stages, resulting from the interaction between the scores obtained by the risks, producing a numerical result, in which the higher the score obtained, the riskier the stage is considered, thus building a risk hierarchy among the stages.

For this classification, the individual scores of each risk in their respective stages were added up, thus generating an overall score, as shown in Equation 1.

$$C_r = \sum_{i=1}^{n}(x_i + y_i) \quad (1) \qquad (1)$$

In which:

C_r: risk classification;

X: risk probability, determined by its score set according to the criteria in the risk score priority matrix (Table 1);

Y: impact, also established according to the score given in Table 1.

For data organization (Stage 4), the information and data gathered through the bibliographical survey, interviews, and questionnaires are schematized as presented in Tables 3 and 4.

Through the suggestion of mitigation and control actions (Stage 5), in which alternatives are proposed to reduce or extinguish the identified risks, the last two SCRM stages were applied according to Rangel *et al.* (2014). As pointed out in Hallikas (2004), these stages depend directly on the previous stages of the SCRM.

For the proposals of improvement actions, the issues and/or suggestions for improvement cited as potential in previous works were used as a basis and were raised in the theoretical framework (Chart 1) through bibliographic research, according to Sub-stage 1.1.

Finally, Stage 6 is dedicated to the comparative analysis between the collection modalities analyzed in this study, considering the information gathered and the research limitations.

4. STUDY PRESENTATION AND COMPARATIVE ANALYSIS

This section presents the information gathered during the research and, subsequently, its analysis in a comparative manner in order to understand which modality presents the greatest risk, weight relative to total cost, and which stages are decisive for this finding, considering the percentage of cost per stage and their respective classifications as to the degree of risk presented.

After understanding the concepts, a semi-structured questionnaire was set up that sought to understand the steps, peculiarities, and processes contemplated in the activities performed within the reverse chain of the material by the organizations, besides the potential risks observed and/or experienced by the managers and those responsible. The questionnaire was answered by an operations manager and a general manager from different organizations that work directly in the waste cooking oil reverse chain for the generation of new products such as biodiesel. Their experience in the function varies from 4 to 9 years.

The results found by the research are organized in two tables, the first referring to the door-to-door collection model (Table 3) and the second, to the collection point (Table 4).

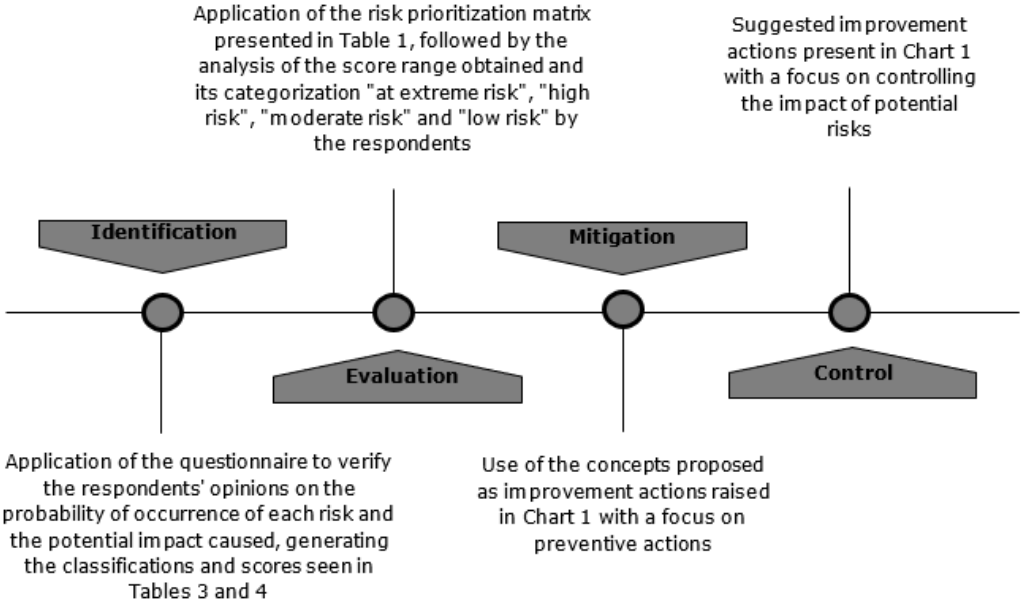

Figure 1. Stages of the study application
Source: The authors themselves

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Table 3 presents the structure and description of the stages of the waste cooking oil reverse logistics, adopting the door-to-door collection mode used by organization A, in which the collection unit travels according to the demand of the generating unit. In this modality, collection focuses on domestic waste generated by family homes.

As raised in the interviews and described in Table 3, the route definition process in the preparation stage uses the volumetric history and calls as determining criteria. Although relevant, when considered in isolation, the criteria used lose efficiency precisely because they do not consider other variables that can be crucial for improving performance and reducing potential costs, such as the distance traveled and the intersection between routes.

It is observed that the stage of transport and collection corresponds to the most significant percentage in relation to the total cost attributed to this modality, highlighting the relevance of this stage in the chain and, consequently, the need for mitigation and control actions to reduce costs in the logistics process in general. This observation was also verified by Demirbas (2009) in his studies.

As far as the storage stage is concerned, the treatment process is incorporated into the stage as a kind of guarantor of the integrity of the collected material. In some cases, it is possible to recover the waste contaminated by other materials, such as water and debris.

As for the risks identified in this collection modality, three items were raised by the interviewees for each stage. One can see that the preparation stage has the lowest representativeness of the chain and presents varied risk classifications, highlighting the risk of an outdated route, which was assessed as an extreme risk due to its high probability of occurrence and high impact on the chain. The importance of efficient routing for a sustainable final cost to the activity was evidenced in Guabiroba and D'Agosto (2011).

To structure the chain, following the collection point mode, Table 4 was constructed.

The preparation stage adopted in this modality contemplates, in addition to registration, the collection and issuance of documentation, along with some bureaucratic processes due to the partnership with firms that demand the delivery of disposal certifications. This peculiarity impacts on the demand for more qualified personnel and, consequently, on the stage costs.

As for the risks raised in the collection and transportation stage, the risk of cargo and/or container theft was identified. This risk is mentioned only in the collection point modality, offering a risk classified as high, while the accident along the way is present in both modalities.

Departing for a comparative analysis of the results found in the two modalities, one can notice points of similarity and significant divergences due to the particularities observed.

Table 3. Waste cooking oil supply chain - door-to-door collection model

	Preparation	Collection and Transportation	Storage
Process Description	Route definition, taking as criteria the neighborhoods that previously presented the highest volume and/or in case there is a formal call from at least two residents	The waste collection process at the generating points, also including the transportation of the material to the headquarters of the collection unit. A vehicle travels a standard route with a beep and the residents deliver their waste in pet bottles	Process subsequent to collection, comprising the conditioning of the waste at the headquarters of the collection unit. If necessary, treatment is applied using a filtering process and decantation by heating or gravity
Cost Range (%)	12% to 17%	60% to 65%	18% to 23%
Risk Points	(a) Failure to answer the call (b) Outdated route (c) Loss of volumetric history	(d) Setback (e) Low volumetry (f) Leaky and/or contaminated containers	(g) Waste leakage (h) Waste contamination by other materials (i) Waste loss due to low quality
Risk Classification	(a) Probability: 2; Impact: 1; Low risk (b) Probability: 4; Impact: 5; Extreme risk (c) Probability: 2; Impact: 4 ; High risk	(d) Probability: 2; Impact: 5; High risk (e) Probability: 4; Impact: 5; Extreme risk (f) Probability: 4; Impact: 4; Extreme risk	(g) Probability: 3; Impact: 2; Moderate risk (h) Probability: 3; Impact: 4; Moderate risk (i) Probability: 4; Impact: 4; Extreme risk
Score per Stage	30	46	34
Suggested Actions	(a) Creation of an exclusive channel for calls (b) Multi-criteria and simulated routing (c) Digitization and reorganization of information	(d) Good traffic practices and programmed circulation for off-peak hours (e) Establishment of collection points (f) Use of proper containers at the collection points	(g) Periodic inspection of the storage containers (h) Periodic maintenance of the storage containers (i) Standardization of the visual analysis of the waste at the generating point

Source: The authors themselves

In terms of processes, it is possible to observe greater similarity in the storage stage, considering that both modalities follow similar protocols, except for a slight variation in the representativeness of the cost percentages, which can be attributed to the outsourcing of the laboratory analysis of the waste collected in the door-to-door collection modality. Due to process similarity, the risks and classifications are the same. The preparation stage is distinguished in relation to the adoption of distinct processes, such as routing according to a collection schedule and pre-registration of partners in the preparation stage. Thus, it is possible to draw a parallel between the adoption of this process and the increase in representativity, in terms of cost of this stage compared to the same stage in the door-to-door modality, in which this process is not incorporated.

Considering the percentage of representativity in terms of costs, it is possible to identify, both in the door-to-door and at the collection point modality, the collection and transportation stage as the most representative among the three analyzed, even though they adopt similar processes in relation to the previous stage and the collection modality used. As noted in a prior study by Santos and Ribeiro (2013), transportation is the primary stage within the logistics process since, besides having higher costs, it is responsible for interconnecting different geographical spaces and meeting inter-regional demands.

As to the risk points identified by the interviewees, it is intuitive to associate them with the processes defined as pertinent to each stage analyzed, with risks directly linked to the technical aspects of each modality. As an example of the previous statement, container theft is a risk identified in the collection point chain, since this model uses its own container for transportation, while in the door-to-door chain, the container used for transportation comes from third parties.

A higher concentration of risks classified as extreme and/or high can be seen in the collection and transportation stage. This occurs both in the door-to-door modality and at the collection point, with scores of 46 and 42, respectively. This observation is potentially linked to the fact that this stage also presents the highest percentages of costs.

In the overall risk score obtained at each stage, both modalities present the same sequence of positions, with the collection and transportation stage being the riskiest, achieving the highest score, followed by the storage stage and the preparation stage, considered the least risky, scoring 18 and 30 for door-to-door and collection point modality, respectively.

For the proposed improvement actions, suggestions and issues addressed in previous works were adapted, as seen in Chart 1. They include programmed circulation and routing for the door-to-door collection model, as cited in Guabiroba and D'Agosto (2011), in addition to the investment in training and qualification addressed in Carvalho *et al.* (2013).

Through the classification of the risks raised during the research, it is possible to identify those that present the greatest need for mitigation and control. By establishing priori-

Table 4. Waste cooking oil supply chain in the collection point model

	Preparation	Collection and Transportation	Storage
Process Description	Registration process of the new partner, issuance of the certificate of waste destination, data survey for collection, such as location and availability of storage tank at the generator point, estimated volume of waste generated per period, and lastly, definition of the collection calendar based on the existing schedule	Waste collection process at the generator point, on a pre-established date, also including the transportation of the material to the headquarters of the collection unit	Process subsequent to collection, comprising the conditioning of the waste at the headquarters of the collection unit. If necessary, treatment is applied using a filtering process and decantation by heating or gravity
Cost Range (%)	25% to 30%	45% to 50%	15% to 20%
Risk Points	(a) Low personnel qualification (b) Lack of documentation (c) Failure in the service channel	(d) Accident on the way (e) Absence of waste at the moment of collection (f) Theft of waste and container	(g) Waste leakage (h) Waste contamination by other materials (i) Laboratory analysis failures
Risk Classification	(a) Probability: 2; Impact: 5; High risk (b) Probability: 2; Impact: 4; High risk (c) Probability: 2; Impact: 4; Moderate risk	(d) Probability: 2; Impact: 5; High risk (e) Probability: 4; Impact: 5; Extreme risk (f) Probability: 3; Impact: 4; High risk	(g) Probability: 2; Impact: 5; High risk (h) Probability: 2; Impact: 3; Moderate risk (i) Probability: 2; Impact: 5; High risk
Score per stage	18	42	26
Suggested Actions	(a) Standard personnel training (b) Follow-up checklist (c) Creation of an official channel for partners	(d) Good traffic practices and programmed circulation for off-peak hours (e) and (f) Contact schedule close to the collection dates	(g) Periodic inspection of the storage containers (h) Periodic maintenance of the storage containers (i) Standardization of the visual analysis of the waste at the generating point

Source: The authors

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ties for the development of possible improvement projects, it is possible to guide the managers in the decision-making process, as they were oriented towards actions that present feasibility, practical benefits, cost reduction, and, hence, are able to contribute, in part, to the competitiveness of waste cooking oil as raw material for biodiesel production.

5. FINAL CONSIDERATIONS

Throughout the study, with the application of the SCRM tool and the analysis method adopted, the general goal of the study to identify and compare the costs and risks of two modes of the waste cooking oil reverse chain was achieved. It was also possible to identify the points that represent the greatest risks and costs for each stage in the chain. From the understanding of the concepts and the survey of literature on the subject, it was possible to achieve specific objectives 1 and 2, the latter being related to the establishment of proposed improvement actions aimed at risk mitigation and control.

Thus, in general, the aims of the study were achieved, and it was possible to analyze the stages of the waste cooking oil reverse chain contemplated by the collecting organizations, identify risk points, and propose control and mitigation actions through the application of SCRM, which is a risk management technique in chains and can be applied both in direct and reverse chains.

The research results indicated the stages included in the waste cooking oil reverse chain, their respective cost and risk percentage ranges, and the classification of each risk according to the analysis of its likelihood of occurrence and impact generated, concluding that the riskiest stage, among those analyzed, is collection and transportation, as pointed out by Guabiroba and D'Agosto (2011) and Santos and Ribeiro (2013). It should be noted that this conclusion is for the case under study. In the case of transportation cost, this can represent a smaller percentage in relation to the other preparation and storage steps. This cost can be lower if non-motorized transport mode is used and if the waste cooking oil processing point is located close to the generating sites.

As a theoretical contribution to the area, works related to the theme were surveyed, pointing out the main risks and costs per stage and the possible analysis forms. As a practical contribution, the study suggests improvement actions addressed in previous studies, considering the limitations of financial and human capital resources of organizations operating in the segment.

In terms of study limitations, the analysis was based on the interview with only two respondents, whose perspectives are based on individual experiences and, therefore, subject to their opinion as to the risk criteria presented. There is also a geographical limitation, focusing on southern Rio de Janeiro state, a limitation regarding the costs analyzed, and the focus is only on the stages of the waste cooking oil reverse logistics chain executed by the collecting organizations and not on the chain as a whole, thus providing proposals for improvement actions and risk assessment limited to this universe.

As opportunities for future research, since the waste cooking oil is one among other possibilities of raw material for biodiesel production, it is proposed to analyze the other chains of competing materials in order to obtain results for comparative purposes. We also propose a survey of replicable actions of more competitive chains in the residual cooking oil chain. Another possibility is to examine the chain after the implementation of the proposed improvement actions through simulation and/or practical application, thus establishing a parallel between efficient actions in practice and in theory.

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