

## **Reverse logistics of waste tires in Brazil: a proposal for collaborative monitoring**

### **Logística reversa de pneus inservíveis no Brasil: uma proposta de fiscalização colaborativa**

### **Logística inversa de neumáticos usados en Brasil: una propuesta de monitoreo colaborativo**

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**ABSTRACT**

This article develops a study on the current inspection practices regarding the correct disposal of unusable tires, seeking to identify flaws and propose a solution - in a collaborative manner - that involves all entities linked to this type of product. As identified in recent literature, there is a law to be applied, but it is not possible to fully monitor compliance with it. Therefore, the objective of this research was to propose a solution for this scenario, based on an audit model similar to that of Quality Management Systems in the automotive industry. The application of the concepts and audit practices of the quality management system, adapted to the context of environmental inspection, has proven effective in identifying gaps and proposing an integrated model, showing that expanding the scope of inspection can contribute to a more robust and efficient system. In this way, it is possible to provide an improvement to the environment and to the results of organizations that reuse these materials. Such relevance of the proposal is due to the current scenario of consumption heading towards environmental collapse.

**Keywords:** Waste Tires, Inspection, Audit, Quality Management System, Reverse Logistics.

**RESUMO**

O presente artigo desenvolve uma pesquisa sobre como é a prática da fiscalização atual no que tange a destinação correta dos pneus inservíveis, buscando identificar falhas e propor uma solução - de maneira colaborativa - que envolva todas as entidades ligadas a este tipo de produto. Conforme identificado na literatura recente, há a existência da lei para ser aplicada, porém, não se consegue fiscalizar em sua totalidade o cumprimento dela. Assim sendo, o objetivo desta pesquisa foi propor uma solução para este cenário, se baseando num modelo de auditoria semelhante ao de Sistemas de Gestão da Qualidade na indústria automotiva. A aplicação dos conceitos e das práticas de auditoria do sistema de gestão da qualidade, adaptados ao contexto da fiscalização ambiental, mostra-se eficaz na identificação de lacunas e na proposição de um modelo integrado, evidenciando que a ampliação do escopo fiscalizador pode contribuir para um sistema mais robusto e eficiente. Desta forma, pode-se proporcionar uma melhora ao meio ambiente e aos resultados das organizações que reutilizam estes materiais. Tal relevância da proposta se dá em função do atual cenário de consumo rumo ao colapso ambiental.



**Palavras-chave:** Pneus Inservíveis, Fiscalização, Auditoria, Sistema de Gestão da Qualidade, Logística Reversa.

## RESUMEN

Este artículo desarrolla una investigación sobre la práctica actual de inspección respecto al correcto descarte de neumáticos inutilizables, buscando identificar fallas y proponer una solución - de forma colaborativa - que involucre a todas las entidades vinculadas a este tipo de producto. Como se identifica en la literatura reciente, la ley existe para ser aplicada, sin embargo no es posible monitorear plenamente su cumplimiento. Por tanto, el objetivo de esta investigación fue proponer una solución para este escenario, basado en un modelo de auditoría similar al de los Sistemas de Gestión de Calidad en la industria automotriz. La aplicación de los conceptos y prácticas de auditoría del sistema de gestión de la calidad, adaptados al contexto de la inspección ambiental, ha demostrado ser eficaz para identificar brechas y proponer un modelo integrado, demostrando que ampliar el alcance de la inspección puede contribuir a un sistema más robusto y eficiente. De esta forma es posible mejorar el medio ambiente y los resultados de las organizaciones que reutilizan estos materiales. La relevancia de la propuesta se debe al actual escenario de consumo que se encamina hacia el colapso ambiental.

**Palabras clave:** Neumáticos de Desecho, Inspección, Auditoría, Sistema de Gestión de Calidad, Logística Inversa.

## 1 INTRODUCTION

The acceleration of technological evolution, the growth of the population on planet Earth, the high demand for manufacturing solutions that reduce the useful life of products has led to excessive disposal of materials, pollution of soil, water and air, thus reducing natural resources and contributing to the costly outlay of a country in attempts to promote environmental balance, thus trying to avoid future catastrophes due to factors associated with this scenario.

In this sense, reverse logistics is of utmost importance for the effectiveness of waste management and the guarantee of environmental protection, and is also defined in the National Solid Waste Policy (Law 12,305/2010), which consequently encouraged organizations to take responsibility for this issue, and thus, shared responsibility for the management and return of waste.

Several studies have been developed on different Reverse Logistics Systems and



the diversity of factors and considerations that can impact the efficiency of these practices (such as Goeldner *et al.* , 2020; Ambrozi *et al.* , 2020; Goedert *et al.* , 2025; Bastos *et al.* , 2025, Marcos *et al.* , 2025; Klaumann *et al.* , 2025; Pokriwieski *et al.* , 2025; Milkiewicz *et al.* , 2025; Schwarzer *et al.* , 2025; Radzinski *et al.* , 2025; and Vepech *et al.* , 2025).

According to Conama (2009), due to the high quantity of tires in used condition, and because they are allocated incorrectly, as well as the high potential to cause damage to the environment and health, it is important to ensure that these products are, whenever possible, reused, refurbished or recycled (thus reinforcing the need for an efficient reverse logistics system for these).

However, tires, being an inert material, do not contain heavy metals in their properties and cannot be diluted in water; therefore, they cannot be carried to the water table by rainwater, and their disposal requires specific management, since disposal of this type of product is not easy. In landfills, there is a problem that arises due to the fact that tires absorb chemical products that, consequently, can generate gases through decomposition, damaging the landfills. Furthermore, the material has low compressibility, which causes greater occupation and a shorter useful life of landfills (Oda and Fernandes Júnior, 2001).

In this context of importance, it is up to government agencies to monitor, control and publish recycling targets. However, the complexity of application and the size of the national territory make it difficult to comply with all the requirements and rules provided for, which is the problem that underpinned the primary objective of this research: to improve the monitoring process, ensuring better performance in the disposal of unusable tires.

From this, with the purpose of proposing a viable inspection model that promotes collaboration between all entities involved, the following specific objectives were defined: to identify the opinion of end users of tires regarding the possibility of acting as voluntary inspectors in the correct disposal of unusable tires; to analyze the existing flaws in the current inspection model; and to identify good practices in Quality Management models that can contribute to improving performance in the inspection of unusable tires.



## 2 THEORETICAL FRAMEWORK

To support the research, a survey of data and information available in databases on the subject was carried out, with the main relevant concepts listed below.

### 2.1 REVERSE LOGISTICS

Reverse logistics, according to Agarwal et al. (2016), is the process of planning, implementing and controlling the efficiency, flow of raw materials, in-process inventory, finished goods and related information from the point of consumption to the point of origin in order to recapture expended value or enable sustainable disposal. According to Dowlatshahi (2005), reverse logistics is a systematic process that manages the flow of products/parts from the point of consumption back to the point of manufacture, for possible recycling, remanufacturing or disposal.

Until recently, logistics was responsible for the direct and unilateral flow of products, with the purpose of taking them to the market, thus starting the process at the supplier and concluding at the customer, without considering that the products return to the market (Nhan et al., 2003).

According to Leite and Brito (2005), Reverse Logistics is a sector of business logistics that applies planning, control of product flow, operation, as well as information related to logistics and corresponding to feedback on materials that have not yet been consumed, categorizing them as post-sale, and products that have been consumed, categorizing them as post-consumption. Consequently, returning to the normal business cycle or production cycle, thus using reverse means of distribution, thus enabling a result of added value of any nature. According to the author, these reverse means of distribution are the alternatives and ways in which post-sale and post-consumption products return to their original cycle, thus receiving value again in markets known as secondary, where there is a possibility of reuse and repurposing them.

The development of this reverse distribution system and the establishment of the destination given to the materials is related to some important variables regarding the life



cycle of the individual items. Among these variables are: whether the product is durable, that is, can be used countless times with a useful life of between two years and a few decades; whether the product is semi-durable, used more than once, but has a useful life of less than two years; or whether the product is disposable, configured by those goods that are used only once or in a few weeks (Leite and Brito, 2005).

According to Autry (2005), returns management is a critical component for the success of many organizations. However, the lack of quantification, recognition and, most importantly, a formalized policy for returns can compromise the effectiveness of reverse logistics. The same author adds that public policies in favor of reverse logistics positively influence organizational decisions, improving actions that were previously predetermined and providing a better understanding and execution of processes. This prevents leadership from having to analyze each case individually and helps identify the needs of organizations that work together with supply flow management, minimizing contractual risks, for example.

According to Rogers and Tibben-Lembke (1999), efforts to improve return processes previously lacked a clear business purpose, resulting in little formal analysis and management, except when dealing with high-value assets or those with significant rates of return. Currently, the topic of “return” has gained importance in organizations, even though return rates vary between industries, providing greater detail and recognition of the processes involved.

Although there is recognition of the need to structure and organize reverse logistics processes in organizations, there is still a lack of application of metrics and obtaining information in its various stages. The return phases are complex and require a significant volume of data, which, in most cases, is unavailable, even in companies that are leaders in their segments. Most organizations do not have a structured system to monitor reverse logistics activities, and are unable to quantify or qualify these activities (Rogers and Tibben-Lembke, 1999).



## 2.2 REVERSE LOGISTICS IN BRAZIL AND SOLID WASTE POLICY

Reverse logistics in Brazil, as indicated by the National Information System on Solid Waste Management (Sinir, 2025a), shows that the country currently has four reverse logistics systems implemented before the enactment of Law No. 12,305/2010 (Brazil, 2010), which deals with the National Solid Waste Policy. These systems cover unusable tires, pesticides, their residues and packaging, used or contaminated lubricating oils, and batteries. And nine systems implemented after the enactment of the law, which cover lead-acid batteries, electronic devices and their components for household use, steel packaging, glass packaging, packaging in general, plastic packaging for lubricating oils, fluorescent lamps, sodium and mercury vapor lamps, and mixed light lamps, aluminum beverage cans, and medicines, their residues and packaging.

According to Couto and Lange (2017), the interactions between management variables in the Reverse Logistics System, in most situations in Brazil, are related to the implementation of the system as a response to an external factor, generally in accordance with Law No. 12,305/2010. This structure is configured in a relational manner, grouping unequal links in the production cycles. The system is administered through shared governance, which includes the business sector, represented by a managing entity, and the government, responsible for regulation and inspection. Management predominantly occurs through a partnership between manufacturers and importers, with a direct correlation to the type of market, whether monopolistic or competitive.

## 2.3 UNUSEABLE TIRES

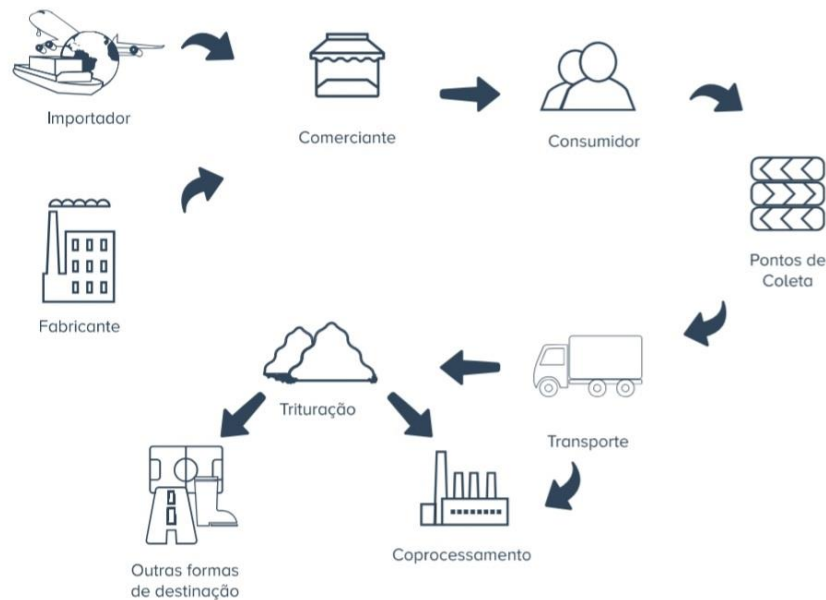
The growing generation of used tires and the improper disposal of this waste represent an environmental and public health challenge in Brazil. Recent data indicate that a large volume of tires may end up being disposed of irregularly, contributing to the proliferation of disease vectors, fire risks, and soil and water contamination. According to information from the National Information System on Solid Waste Management (Sinir, 2025b) and updates from the environmental sector, it is imperative that these materials be

recycled, refurbished, or reused, thus ensuring an environmentally appropriate and safe final destination.

Since there is a large amount of used tires that are incorrectly disposed of, the risk and impact on the environment and health are considerable. It is necessary to ensure that these are preferably recycled, refurbished or reused and subsequently disposed of correctly (Conama, 2009). According to CONAMA Resolution No. 416 of September 30, 2009, the final destination of tires must be carefully defined to avoid the environmental degradation that these materials can cause (Conama, 2009). Tire importers and manufacturers are primarily responsible for collecting and promoting proper final disposal, while distributors, resellers, end consumers and the Government must work together with manufacturers to ensure optimal management of tires (Conama, 2009).

According to SINIR (2025b), the reverse logistics cycle for unusable tires in Brazil operates according to the model presented in Figure 1.

Figure 1. - Reverse Logistics Cycle for Waste Tires



Source: Sinir (2025b).

Current studies indicate that, in 2023 alone, more than 740 thousand tons of unusable tires were disposed of throughout Brazil, highlighting the impact of this waste when not managed correctly (Ibama, 2024). This makes it clear that it is necessary to prioritize tire recycling, whether as retreads or reuse, ensuring that final disposal minimizes damage to the environment and health risks (Conama, 2009).

Federal Decree No. 10,936/2022 reinforces the obligation for manufacturers, importers, and distributors to implement reverse logistics systems. These systems aim to ensure that tires return to the production cycle or their environmentally appropriate final destination – whether through co-processing in clinker kilns, retreading, or other recovery technologies (Brazil, 2022; Ibama, 2024).

In addition to the frequent approaches to developing new guidelines to meet growing demand, it is important to highlight the sectoral initiatives that have contributed to expanding the coverage of collection points, currently present in more than 1,400 municipalities. Entities such as Reciclanip and the National Tire Industry Association (ANIP) have invested in innovative technologies, including the use of IoT-based systems and artificial intelligence, which allow for the tracking and predictive analysis of tires throughout their entire life cycle. These innovations increase process efficiency and



transparency in waste management (Rodrigues, 2022; Reversa Pneus, 2025).

The effectiveness of reverse logistics requires broad discussions and integrated collaboration between all sectors – manufacturers, importers, distributors, consumers and the government – which must act to reduce environmental impacts. This approach, recommended by the guidelines of the National Information System on Solid Waste Management (Sinir, 2025a) and corroborated by IBAMA's annual reports, such as IBAMA (2024), represents a fundamental step towards sustainable development in the country.

#### 2.4 QUALITY MANAGEMENT SYSTEM AND AUDITS

Global competitive pressure has driven organizations to continually review their internal processes to maintain and improve their performance. According to Ramly et al. (2007), the relentless pursuit of operational excellence is essential in increasingly dynamic and competitive market environments. In this context, it is essential that companies conduct a critical assessment of their current quality situation, identifying gaps and realigning strategies, operations and processes to achieve higher levels of efficiency.

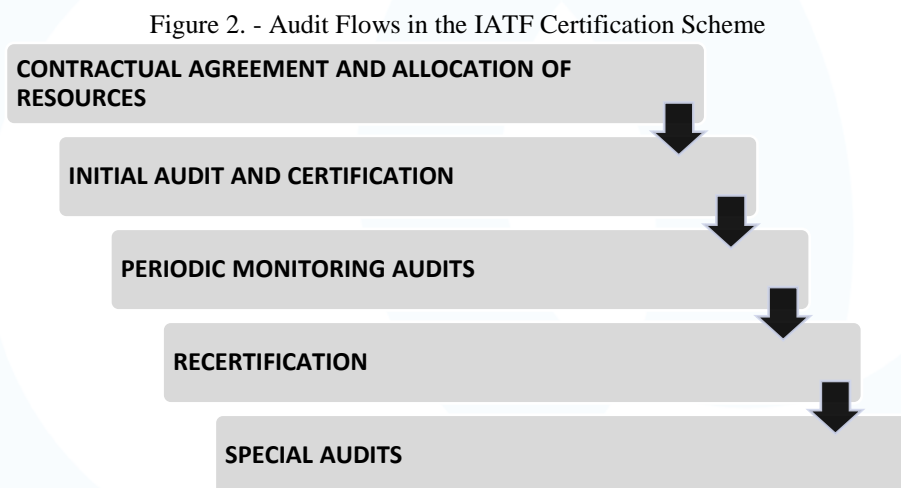
Auditing, therefore, is an essential tool for identifying opportunities for improvement and correcting deviations in internal processes. As highlighted by Williamson et al. (1996), auditing should go beyond merely verifying compliance and be aimed at promoting continuous improvement, encompassing both compliance analysis – which verifies adherence to pre-established criteria – and management auditing, which assesses the effectiveness of processes and the capacity to generate value (Arter, 1994). The ISO 19011 standard, updated in 2018, defines “audit criteria” as the set of specifications, guidelines and requirements that guide the conduct of audits, showing that the combination of compliance and management audits enhances the identification of inefficiencies and the proposal of innovative corrective actions (ISO, 2018).

The certification of Quality Management Systems, based on standards such as ISO 9001:2015 for general sectors, IATF 16949 for the automotive industry, ISO 13485 for medical devices, and AS9100 for the aerospace sector, is a strategic instrument for

organizations that strive for excellence. These systems require periodic audits – certification, monitoring and recertification – to ensure continued compliance with contractual and regulatory requirements (ISO, 2015).

Ramly et al. (2007) argue that maintaining certification, achieved after passing audits conducted by accredited certification bodies, is directly associated with continuous process improvement, which in turn increases customer satisfaction and, consequently, ensures organizational survival.

A typical audit certification is shown in Figure 2.



Source: Adapted from Ramly et al. (2007).

As highlighted by the International Automotive Task Force (IATF, 2016, p. 77), in addition to audits carried out by certifying bodies, internal audits are a crucial element for the sustainability and improvement of the performance of Quality Management Systems (QMS). The implementation of a structured internal audit program – aligned with the normative precepts of ISO 9001:2015 and IATF 16949:2016 – is essential for the organization to be able to monitor, diagnose and continuously improve its processes. According to ISO (2015) and corroborated by studies by Juran and Godfrey (1999), a documented internal audit process must cover the QMS in its entirety, encompassing not only system audits, but also the evaluation of manufacturing processes and products. In this context, the prioritization of the audit program must be based on objective criteria,



such as risk analysis, performance trends and the criticality of processes, in order to accurately identify opportunities for improvement.

In environments where software development is an integral part of organizational processes, the scope of the internal audit program must include assessments of the systems' capability to ensure compliance with specific security and functionality requirements, as emphasized by the CMMI Institute (2020). Additionally, the frequency of audits must be periodically reassessed and adjusted – based on procedural changes, the occurrence of nonconformities, and customer complaints – following the dynamic approach proposed by Pereira and Fernandes (2018). The overall effectiveness of the program must, therefore, be subject to critical analysis by senior management, integrating performance indicators and continuous improvement goals (IATF, 2016).

For quality system audits, the ISO 19011:2018 standard establishes that all QMS processes must be audited in maximum cycles of three years, adopting a process-oriented approach to verify compliance with the applicable standard. From this point on, it is recommended that samples of specific customer requirements be included in the audit to validate the effective implementation of these requirements – a practice that has been confirmed by case studies in the automotive industry (Santos et al., 2021).

Auditing manufacturing processes, in turn, requires the assessment of all production shifts, including representative samples of transitions between teams, in accordance with guidelines established by VDA 6.3 (VDA, 2016). This approach requires the analysis of the implementation of risk management tools, such as PFMEA (Process Failure Mode and Effects Analysis), control plans, and associated documentation – essential elements for locating systemic failures and promoting operational improvement (AIAG, 2019). In the absence of direct customer specifications, the organization must define methodologies aligned with industry benchmarks, as proposed by Slack et al. (2020).

Product audits should be conducted at strategic stages of production and delivery, using methods defined by the customer or, in the absence of these, internally validated approaches. Verification of compliance with specified requirements should integrate statistical techniques – such as sampling by attributes and variables – to ensure



traceability and defect prevention, as discussed by Montgomery (2020).

According to Karapetrovic and Willborn (2000), the effectiveness of an audit system can be measured by means of models that calculate the probability of reliability of the audited processes, highlighting the importance of a structured program that extends beyond the main processes and also includes support processes. Including everything from the formulation of new policies and product design to management and manufacturing processes, it allows the identification of systemic weaknesses, allowing effective corrective actions.

Additionally, according to Hrda et al. (2019), QMS auditing should be understood not only as a control instrument, but also as a strategic tool for promoting systematic and regular research on the effectiveness and efficacy of the management system. This perspective is in line with the view that quality management systems – based on standards such as ISO 9000:2015 – can also serve as a marketing differentiator, where it is possible to visualize the organization's commitment to continuous improvement. Thus, QMS auditing, whether internal or external, is essential to ensure that production practices strictly meet established standards and, in cases of significant deviations, to propose and implement corrective actions that enhance the quality of final products.

Through the competence of auditors who play a central role in the effectiveness of the audit process, Karapetrovic and Willborn (2000) emphasize that the use of effective audit techniques and the high level of knowledge of auditors are decisive for the organization's classification in the global scenario. Qualification criteria, such as those defined by the IATF, are considered exemplary models to ensure that auditors are able to identify critical areas and propose improvements that contribute to organizational performance. Thus, the implementation of a structured self-audit program, which covers everything from preparation and conduct to the preparation of the final report and follow-up activities, represents the first step to ensuring the effectiveness of the QMS, promoting a culture of continuous improvement (Hrda et al., 2019).



### **3 METHODOLOGY**

The methodology adopted in this study integrated approaches aligned with the guidelines for applied research in environmental management and quality. The bibliographic research was based on a review of databases such as Scopus, Elsevier and Google Scholar, using descriptors such as inspection of waste tires, auditing of automotive quality management systems and reverse logistics of solid waste. Scientific articles, regulatory standards and technical reports were analyzed, which detail the mechanisms for collection and environmentally appropriate disposal according to CONAMA Resolution No. 416/2009.

The empirical research combined mixed methods, with the application of a structured questionnaire to assess consumers' perceptions of their role as volunteer inspectors in the tire disposal chain. The sample, composed of participants from different Brazilian regions, followed criteria of socioeconomic and geographic heterogeneity, ensuring representativeness for the analysis of the proposed variables.

Primary data were collected via an online form, while documentary sources included annual Ibama reports on collection points, case studies on reverse logistics and critical analyses of environmental management models (Sampieri, 2006).

The integration between normative review, primary data and comparative analysis made it possible to map structural flaws in the current inspection model, such as gaps in the articulation between sector actors and the population, in addition to validating proposals for inter-institutional collaboration based on quality management models.

### **4 RESULTS AND DISCUSSIONS**

#### **4.1 RESULTS**

The documentary research and the application of the questionnaire made it possible to confirm that the responsibility for the inspection of unusable tires is currently concentrated in IBAMA.

#### 4.1.1 Model and inspection flow for unusable tires:

A. Public Authority (IBAMA) - Responsibility for Supervision

↓↓↓↓↓↓↓↓

B. Manufacturer Importers - Not responsible for inspection.

C. Recipients, Resellers - Not responsible for inspection

D. Consumers - Not responsible for monitoring.

Likewise, in research into the automotive segment's own standards, and in articles that define the effectiveness of the audit model in the IATF scheme, where it is perceived that the established requirements have greater adherence in their implementation, and that the causative factor for this effectiveness can be correlated to the audit model applied to all entities involved in the process, in this way the scheme presented below was identified:

#### 4.1.2 IATF 16949 Automotive Quality Management System Audit Template:

A. IATF Global - Audit Services

↓↓↓↓↓↓↓↓

B. Certification Bodies - They work with Auditing

↓↓↓↓↓↓↓↓

C. Companies that have the certification - Work with Auditing

↓↓↓↓↓↓↓↓

D. Clients of certified companies - They work with Auditing

↑↑↑↑↑↑↑↑

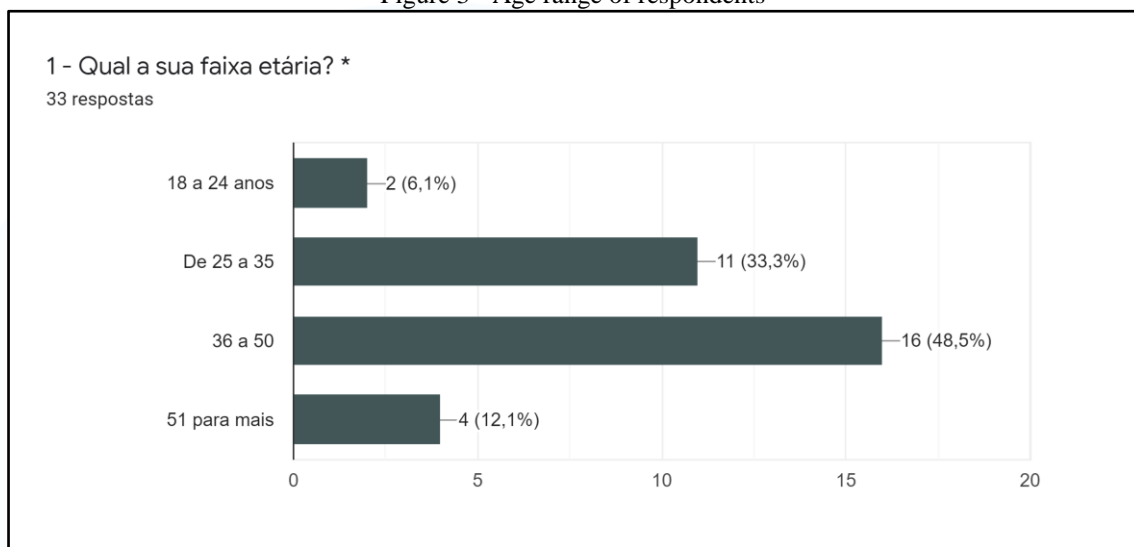
As in item D - Final Consumer - of the scheme presented in the inspection model for unusable tires, there is a greater degree of importance in the entire link, as it is closer to the final destination and generates production motivation for all previous entities, a survey was carried out to identify the potential of this entity to collaborate with the inspection of Unusable Tires in Brazil.

33 people were surveyed, who are spread across the country and are part of the authors' contact network.



The research questions and the results obtained are listed in the sequence of Figures 3 to 8.

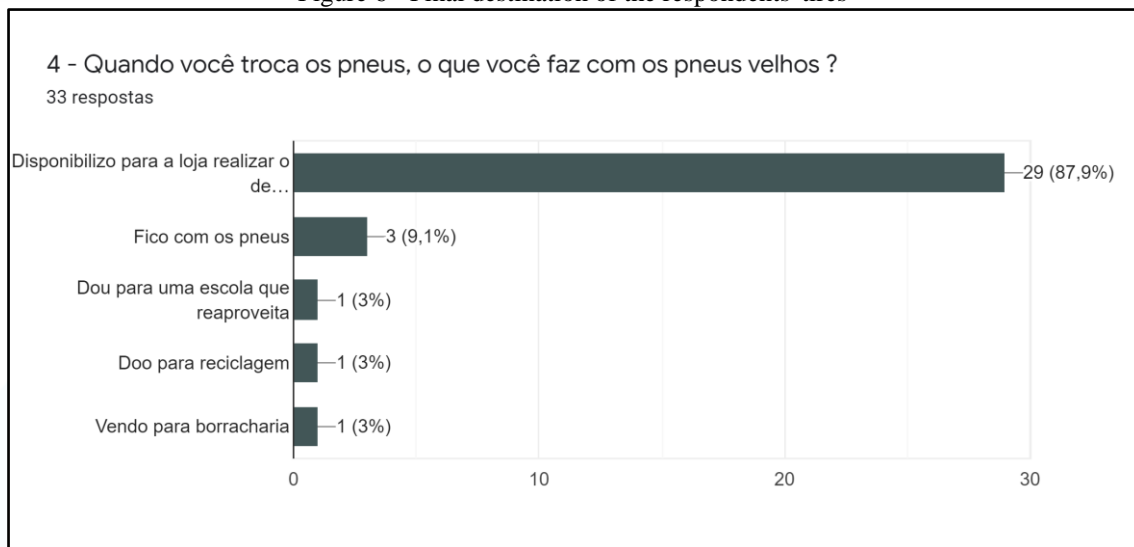
Figure 3 - Age range of respondents



Source: Research data.

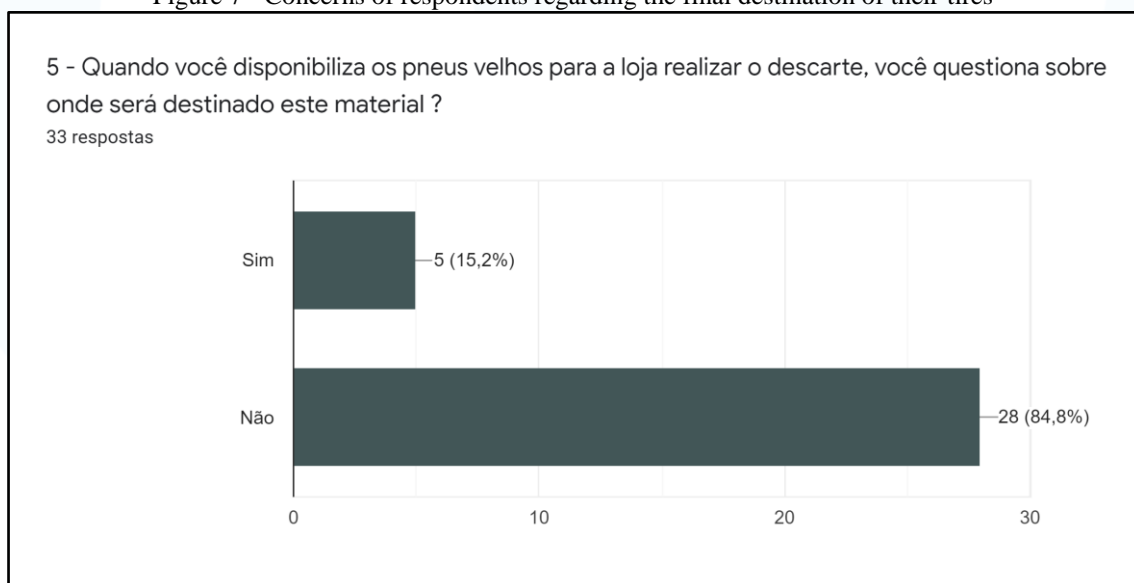


Figure 6 - Final destination of the respondents' tires



Source: Research data.

Figure 7 - Concerns of respondents regarding the final destination of their tires



Source: Research data.

Figure 8 - Potential of respondents to collaborate as volunteer inspectors



Source: Research data.

Graphs were presented relating to age range, number of vehicles, frequency of tire changes, final destination of tires, consumer concerns and the potential for collaboration in inspection – highlighting the need for an integrated inspection model.

The data collected indicate that importers, manufacturers, distributors, retailers and consumers do not effectively perform their role of inspection, which leads to failures in the application of the legislation, since those involved who should report errors do not do so. The survey data indicate that 84.8% of consumers are not concerned about the final destination of their tires, although 57% of those surveyed express an interest in acting as volunteer inspectors, demonstrating significant collaborative potential.

## 4.2 DISCUSSIONS

Comparative analysis between the **current model** , focused exclusively on IBAMA , and the **collaborative model** inspired by quality management system audits, it shows that expanding responsibilities can lead to greater effectiveness in the inspection of unusable tires. The proposed model suggests the inclusion of importers, manufacturers, distributors, resellers and consumers, each with a defined role and, in the case of

consumers, incentivized through rewards.

The data obtained reinforce the hypothesis that integration and collective participation can contribute to improving the tire disposal system, promoting more rigorous monitoring and identifying opportunities for process improvement. The discussion also highlights the importance of applying audits – both internal and external – to monitor and ensure compliance with standards and the effectiveness of the implemented processes.

## 5 CONCLUSION

The research demonstrated that the current model for inspecting waste tires, which is restricted to IBAMA, has weaknesses that can be overcome through a collaborative approach. The proposal to include all stakeholders in the chain – importers, manufacturers, distributors, retailers and, especially, end consumers – is viable and capable of promoting significant improvements in both the correct disposal of tires and environmental preservation.

The application of auditing concepts and practices of the quality management system, adapted to the context of environmental inspection, has proven effective in identifying gaps and proposing an integrated model. Thus, this research fulfills its objectives, demonstrating that expanding the inspection scope can contribute to a more robust and efficient system.

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