Reverse logistics systems implemented in Brazil: a conceptual analysis using the AHP method

Sistemas de logística reversa implantados no Brasil: uma análise conceitual utilizando o método AHP

Sistemas de logística inversa implementados en Brasil: un análisis conceptual utilizando el método AHP

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ABSTRACT
Reverse Logistics is an essential tool for mitigating the environmental impacts caused by the incorrect handling of post-consumer goods. However, achieving the desired benefits from implementing Reverse Logistics Systems depends on their level of efficiency. In this context, considering the time frame of 2015/2016, this research aimed to analyze nine Reverse Logistics Systems established in Brazil, all with national coverage, classifying them according to their best compliance with pre-established performance requirements. Using the Analytical Hierarchical Process (AHP) method, the aforementioned classification took into account four analysis topics: Reverse Flow, Objectives and Goals, Number of Collection Points and Amounts of waste to be returned. As a result, performance elements were substantiated with a view to improving the nine Reverse Logistics Systems consulted, as well as pointing out analyses and considerations in order to contribute to the topic at hand, which can also be extrapolated for application in other Systems of this nature.

Keywords: National Solid Waste Policy, Reverse Logistics Systems, Analytic Hierarchy Process (AHP), Performance Indicators, Performance Measurement.

RESUMO
A Logística Reversa é uma ferramenta imprescindível à mitigação dos impactos ambientais causados pelo manejo incorreto de bens pós-consumo. Porém, o alcance das benesses almejadas com a efetuação dos Sistemas de Logística Reversa depende do nível de eficiência dos mesmos. Nessa conjuntura, considerando o recorte temporal dos anos 2015/2016, esta pesquisa teve por objetivo fazer uma análise sobre nove Sistemas de Logística Reversa instituídos no Brasil, todos com abrangência nacional, classificando-os conforme o melhor atendimento a requisitos de desempenho pré-estabelecidos. Por meio do método Processo Analítico Hierárquico (AHP), a referida classificação levou em consideração quatro tópicos de análise: Fluxo Reverso, Objetivos e Metas, Número de Postos de Coleta e Quantidades de resíduos a serem retornadas. Como resultado, foram consubstanciados elementos de desempenho visando o aprimoramento dos nove Sistemas de Logística Reversa consultados, bem como o apontamento de análises e considerações no sentido de contribuir com a temática em pauta, que podem também ser extrapoladas para aplicação em outros Sistemas desta natureza.

Palavras-chave: Política Nacional de Resíduos Sólidos, Sistemas de Logística Reversa, Processos Analíticos Hierárquicos (AHP), Indicadores de Desempenho, Mensuração de Desempenho.

RESUMEN
La Logística Inversa es una herramienta esencial para mitigar los impactos ambientales ocasionados por el manejo incorrecto de bienes postconsumo. Sin embargo, lograr los beneficios deseados mediante la implementación de Sistemas de Logística Inversa depende de su nivel de eficiencia. En este contexto, considerando el marco temporal 2015/2016, esta investigación tuvo como objetivo analizar nueve Sistemas de Logística Reversa implantados en Brasil, todos con alcance nacional, clasificándolos de acuerdo con el mejor cumplimiento de los requisitos de desempeño preestablecidos. Utilizando el método del Proceso Analítico Jerárquico (AHP), la mencionada clasificación tuvo en cuenta cuatro temas de análisis: Flujo Inverso, Objetivos y Metas, Número de Puntos de Recolección y Cantidades de residuos a devolver. Como resultado, se fundamentaron elementos de desempeño con miras a mejorar los nueve Sistemas de Logística Inversa consultados, además de señalar análisis y consideraciones para contribuir al tema en cuestión, que también pueden ser extrapolados para su aplicación en otros Sistemas de esta naturaleza.

Palabras clave: Política Nacional de Residuos Sólidos, Sistemas de Logística Inversa, Procesos Analíticos Jerárquicos (AHP), Indicadores de Desempeño, Medición del Desempeño.

1 INTRODUCTION

The continued growth of industrial activities without effective waste management leads to enormous impacts on the environment. If effective management of this waste is not feasible, it can compromise the modern lifestyle, with the potential to contaminate the soil and groundwater, becoming harmful to public health (Ribeiro; Morelli, 2009).

The uncontrolled growth of population consumption also generates an increase in waste. During 2016, 78.3 million tons of waste were collected in Brazil (Abrelpe, 2016). Considering this scenario, a viable possibility for mitigating the unfavorable results of the increasing amounts of waste to the ecosystem and public health is to implement Reverse Logistics (RL), ensuring the reduction of waste in the environment.

The term Reverse Logistics was promoted in the early 1980s and spread clearly in academic, public and business environments (Pereira *et al.* , 2012). It was accepted in the area of business disposal and began to be responsible for flow controls and logistical procedures related to the return of raw materials to their new production cycle (Adlmaier; Sellitto, 2007). It is possible to observe RL in almost all market sectors. The return of goods occurs every day and for incalculable reasons such as mishaps with raw materials, wrong orders and used products that are returned for their correct recycling (Sabbadini; Pedro; Barbosa, 2005).

RL emerged as a tool to contribute to the mitigation – and, if possible, the total eradication – of waste. In 2010, the National Solid Waste Policy (PNRS) was created, the first step of which was to designate shared responsibility among all. This made the entire community, the private sector and the government responsible for the environmental management of solid waste (Sinir, 2012). Since then, legal provisions have increasingly encouraged the design of Reverse Logistics Systems in accordance with the most diverse products, with the aim of covering all of them.

Data from the National Information System on Solid Waste Management (SINIR) show that, in force during the time frame of this research (2015/2016), considering nationwide initiatives, Brazil employed four Reverse Logistics Systems implemented prior to Law No. 12,305/2010, through other legal instruments (Unusable tires; Agrochemical packaging; Used or contaminated lubricating oil - Oluc; Batteries) and five Systems created after the PNRS was approved: Plastic packaging for lubricating oils; Sodium and mercury vapor fluorescent lamps and mixed light; Packaging in general; Electronic products and their components; Medicines. Clearly, the achievement of the desired benefits with the implementation of these Reverse Logistics Systems derives from the level of efficiency achieved by them.

In this context, this research had the following scope: to gather information regarding the nine Systems mentioned, considering the time frame of 2015/2016, with emphasis on Reverse Flows; Intended Objectives and Goals; Number of collection points and Quantities of products to be returned by the Systems; Create indicators that can be used comprehensively by all the systems addressed, as well as use the AHP method (Analytical Hierarchical Process) to measure the performance of these Systems, in order to classify them considering the established criteria.

The aim of this research is to substantiate performance foundations for the improvement of the Reverse Logistics Systems studied, as well as to list analyses and considerations that contribute to the topic at hand. To achieve this result, an analysis was made of the nine reverse logistics systems implemented in Brazil - considering the time frame of 2015/2016 - using as a basis a tool constructed - and presented step by step - through the AHP methodology.

2 THEORETICAL FRAMEWORK

This topic presents topics related to Reverse Logistics, such as the National Solid Waste Policy, Sectoral Agreements and what Solid Waste is. A brief summary of the nine Reverse Logistics Systems - with national expression - in force in Brazil in the time frame of 2015/2016 - and the research points of the work.

2.1 SOLID WASTE

The so-called solid waste includes waste in semi-solid and solid states, coming from sources such as: industries, homes, shops, plantations and hospitals. Also included are sludges that come from the treatment of water and other liquids that cannot return to water bodies or public sewage systems (Abnt, 2004; Schwarzer; Rocha; Seleme, 2021).

The hazardousness of products can be used to categorize them, and they are then divided into three classes: Class I , which are those wastes established as hazardous , referring to corrosive, flammable, reactive, pathogenic or toxic; Class II , non-inert wastes , such as fuels; and Class III , inert wastes , which do not denote any risk to the environment or health (Abnt, 2004).

According to the Brazilian Association of Technical Standards (ABNT), solid waste can also be categorized according to its particularities, such as: Plastics : bags, soda containers, sacks, latex, water and milk containers, raffia bags, cleaning product containers. Chemical contaminants : light bulbs, photographic film, batteries, glues with paints, nail polish, carbon paper, motor oil and chemical product packaging. Biological contaminants : hair, razor blades, bandages, gauze, disposable diapers, syringes, bloody cloths, hair, toilet paper and cotton swab (Abnt, 2004; Schwarzer; Rocha; Seleme, 2021).

The collection and final disposal of waste is the responsibility of the urban solid waste administration and municipal public administration. Waste that is not collected may end up being disposed of in inappropriate places, commonly being disposed of in vacant lots, streams and rivers, tending to cause clogged drains, bad odors, thus increasing the chances of proliferation of cockroaches, flies and rats, which can spread diseases in the area where the waste is located (Jacobi; Besen, 2011; Schwarzer; Rocha; Seleme, 2021).

The population of Brazil increased by 0.8% between 2015 and 2016, and waste generation decreased by 3% in the same period, as did total waste generation, which decreased by 2%, reaching 214,405 tons/day of solid waste in the country. However, approximately seven million tons of Urban Solid Waste were not collected during 2016, suggesting inappropriate disposal (Abrelpe, 2016).

2.2 NATIONAL SOLID WASTE POLICY

In Brazil, prior to the advent of the Solid Waste Policy, there was no national regulation on the management of solid waste, nor were there any institutions defined to provide guidance on the commitments and obligations of participants in the life cycle of products. However, there were some legal instruments that addressed discipline and spacing of areas (Souza, 2012; Schwarzer; Rocha; Seleme, 2021).

Law No. 12,305, of August 2, 2010, published – in December of the same year – the National Solid Waste Policy (PNRS). This law applies to all those who have a direct or indirect relationship with the generation of solid waste (Brasil, 2010; Schwarzer; Rocha; Seleme, 2021).

Some of the PNRS's assessments involve protection, caution and sustainable development. All those involved in the production, consumption and disposal of products are leaders of this policy (Brasil, 2010; Schwarzer; Rocha; Seleme, 2021).

Recycling and reuse are some of the guidelines of the National Solid Waste Policy. In its seventh article, it defines the following objectives: to protect the characteristics of the place and the environment in which one lives, to reduce waste generation if it is not feasible to not generate any, to reuse or recycle everything possible, to encourage consumers to purchase sustainable products and to improve the use of clean technologies (Brasil, 2010; Schwarzer; Rocha; Seleme, 2021).

In this sense, LR is one of the tools that corroborates the conception of these precepts, in terms of compiling waste.

2.3 REVERSE LOGISTICS

Reverse Logistics (RL) is the part responsible for transporting waste to a suitable location after being used, it is outlined by the National Solid Waste Policy.

Reverse logistics involves all merchandise that for some reason is returned to the manufacturer, whether due to product returns, legal issues, excess stock, returned packaging, imperfections, failure to meet expectations, or discontinued products. Packaging and manipulated products also return to the factory to find their proper final destination. It is due to a reverse movement that these products can return to their origins, in the sense of completing their life cycles (Chaves; Alcantara; Assumpção, 2008).

Although it does not yet have the ideal infrastructure for the best performance in waste management, LR has, however, been developing and becoming a major differentiator for organizations (Moreira; Bonfim, 2013; Schwarzer; Rocha; Seleme, 2021).

LR is linked to the design of the product life cycle, which can be broken down into four steps: Launch , when the product reaches the market, there is little demand and some adaptations are needed in the product; Growth , when the product gains fame in the market and starts to be sold in greater quantities and becomes competitive; Maturation , when the product is already known to customers and its competitors have already formulated a similar product; Decline , when the product becomes obsolete (Wille, 2012)

There are two paths for returning products to the company, post-sales and post-consumption; post-sales is the segment responsible for the reverse logistics of products that are not used or used very much, which are redirected to the company for various reasons, such as: errors when ordering products, expired expiration dates, inventory problems, lapses and product warranty (Pereira *et al.*, 2012; Schwarzer; Rocha; Seleme, 2021).

The distribution path of post-consumer reverse logistics involves greater complexity, being classified into three categories, showing the time elapsed from its original conception to the moment it is first discarded: Durable products , whose average useful phase lasts from years to decades (such as automobiles and electronic devices); Semi-durable products , which have an average productive phase of months - never exceeding 24 months (such as car and cell phone batteries, lubricating oils); Disposable products , with an estimated useful life of less than six months (such as surgical articles, toys, packaging and batteries for electronic equipment) (Pereira *et al.* , 2012; Schwarzer; Rocha; Seleme, 2021).

The product no longer used and reintroduced into the production cycle characterizes reverse logistics; considering its disposal only as a last resort, when it is no longer possible to reuse this waste (Silva *et al.* , 2006; Schwarzer; Rocha; Seleme, 2021).

LR allows companies to be responsible for the final disposal of their solid waste, whether packaging or products, thus preventing them from being rejected erroneously by their consumers. It also helps to reduce the risk of inappropriate disposal of products that are classified as causing risks to the environment, such as lamps, batteries and pesticide packaging (Andrade; Ferreira; Santos, 2009).

2.3.1 Reverse logistics systems implemented in Brazil

Considering temporally systems with national scope in force in the years 2015/2016, this topic was divided into two subtopics, covering actions prior to and after the PNRS.

2.3.2 Reverse logistics systems implemented before the national solid waste policy

The nationwide systems implemented before the PNRS involve four distinct types of waste: agrochemical packaging, unusable tires, used or contaminated lubricating oil (Oluc) and batteries. Specific legislation supported the creation of each of these systems.

2.3.2.1 Pesticide packaging

Pesticide residues remain present in the packaging and when these are abandoned in the environment or incorrectly disposed of in landfills or landfills, the toxic elements can contaminate groundwater (Cempre, 2000). Many people, due to lack of information, reuse pesticide packaging in their daily lives, in household tasks, thus aggravating public health problems related to the ingestion of toxic products (Barreira; Junior, 2002).

The production and use of packaging and labels, research, transportation, storage, advertising, product use, import and export are defined by Law 7802/89 (Sinir, 2018a). The Law in use for this system is 9,974, of June 6, 2000, which modifies Law 7,802, of July 11, 1989 (Brazil, 2000).

The National Environmental Council – CONAMA (2014) states that environmental and health damage occurs when there is an inappropriate use of pesticide and similar packaging. Farmers are responsible for triple washing the packaging and transporting it to collection points offered by retailers (Inpev, 2017a; Conama, 2014; Sinir 2018a).

inpEV – National Institute for Processing Empty Packaging – was launched in 2001, with the aim of competently coordinating the final destination of this waste, curbing its inappropriate disposal (Inpev, 2016).

2.3.2.2 Waste tires

Due to the number of tires used and disposed of irregularly and the risk this poses to health and the environment, it is necessary to ensure that tires are preferably reused, recycled or refurbished prior to their correct subsequent disposal (Conama, 2009).

Resolution No. 416, of September 30, 2009, sets out guidelines on the final destination of tires and on the need to take care of the environmental degradation that these objects can cause (Conama, 2009).

Tire importers and manufacturers are responsible for collecting tires weighing more than two kilos and are responsible for ensuring the proper final disposal of unusable tires. Distributors, resellers, end consumers and the government must work together with manufacturers to ensure optimal tire management (Conama, 2009).

2.3.2.3 Used or Contaminated Lubricating Oil (OLUC)

In this system, CONAMA instituted Resolution number 362 of June 23, 2005, which specifies that all used or contaminated lubricating oil must be collected and managed in a manner that is compatible with what is expected so as not to affect the environment (Conama, 2005).

It is the responsibility of the importer and producer to collect and manage the final flow of OLUC, in accordance with the proportional amount of lubricating oil that was allocated to the market. The incorrect disposal of OLUC poses health risks, as it is a substance that contains toxic residues. Collection can be done at numerous stations spread throughout the country; it is the company's responsibility to set up these collection stations (MMA, 2017). The practice recommended by Resolution 362/2005 is to send OLUC for recovery of its elements through a process called re-refining (Conama, 2005).

2.3.2.4 Batteries

Due to the widespread use of batteries in the country, and the need to raise awareness among the population about the dangers to health and the environment, in the context of waste being diverted irregularly, to minimize these threats, Resolution No. 401, of November 4, 2008, determines the maximum limits of toxic substances such as cadmium, mercury and lead in the manufacture of batteries sold in Brazil (Conama, 2008).

The movement of batteries is considered risky transport, as it carries dangerous products; to regulate this transport and reduce threats, the National Land Transport

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Agency – ANTT established ANTT Resolution No. 420/2004, which establishes precisely how the transfer should occur (Antt, 2004).

2.3.3 Reverse logistics systems implemented after the national solid waste policy

This research addresses five national systems implemented after the PNRS: Plastic packaging for lubricating oils, Sodium and mercury vapor fluorescent lamps and mixed light, Packaging in general, Disposal of medicines and Electronic products and their components.

One difference between these systems and those established prior to the PNRS is the establishment of sectoral agreements to define their policies.

2.3.3.1 Sectoral Agreements

A sectoral agreement is a commitment made between manufacturers, distributors, importers, merchants and the public authorities, with the aim of establishing a life cycle for items with the costs divided equally among all (Sinir, 2018b).

2.3.3.2 Plastic Packaging for Lubricating Oils

The Sectoral Agreement regarding the Reverse Logistics System for Plastic Packaging of Lubricating Oils has as its scope the correct handling of packaging of one liter or less (MMA, 2013a).

To support this sectoral agreement, the Jogo Limpo Institute was created in 2013, and until that same year, it covered a total of 14 municipalities plus the Federal District, having collected a total of 67,930,000 packages and 3,396,000 tons of plastic collected in the following states: Paraná, São Paulo, Santa Catarina, Rio de Janeiro, Minas Gerais, Rio Grande do Sul, Espirito Santo and the Federal District (Jogue Limpo Program, 2013).

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2.3.3.3 Sodium-Mercury Vapor and Mixed Light Fluorescent Lamps

The Sectoral Agreement with the intention of introducing the Reverse Logistics System for Sodium and Mercury Vapor Fluorescent Lamps and Mixed Light was signed on November 27, 2014 with the aim of ensuring a satisfactory final destination for these objects (Sinir, 2018d).

For the purposes of this agreement, household and non-household waste generators are included. Mixed light bulbs, sodium vapor, mercury and metal vapour lamps, and low or high pressure discharge lamps containing mercury, such as compact and tubular fluorescent lamps, metal vapor lamps, mixed light bulbs, sodium vapor lamps, special application lamps, mercury vapor lamps, and solid waste and rejects generated as a result of the lamps' life cycle, are accumulated at the collection points (Sinir, 2018d). The manufacturer is required to indicate locations for collection points throughout the city, and it is the buyer's responsibility to dispose of unusable lamps at the indicated locations.

2.3.3.4 Packaging in general

Packaging in general includes packaging made from cardboard and paper, aluminum, plastic, glass and steel, or even a mixture of these materials, such as long-life cardboard packaging (Sinir, 2015).

The Sectoral Agreement for the Implementation of the Reverse Logistics System for Packaging in General was signed on 11/25/2015 with the aim of ensuring the environmentally appropriate final destination of packaging. Through this instrument, manufacturers, importers, traders and distributors of packaging and products sold in packaging are committed to working together to ensure the environmentally appropriate final destination of the packaging they place on the market (Sinir, 2025).

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2.3.3.5 Disposal of medicines

The publication of the decree that instituted the Reverse Logistics of Expired or Unused Household Medicines, for Human Use, Industrialized and Manipulated, and their Packaging after Disposal by Consumers (Decree No. 10,388, of June 5, 2020) represented an advance in the normative field, being justified by the need for more adequate treatment of these residues that have the potential to be dangerous (Sinir, 2025).

Therefore, considering the objective of this research to focus on the time frame of 2015/2016, the reverse logistics for the elimination of drug residues, during this period, was the responsibility of the Ministry of Health, with the purpose of designing a plan for the acceptable disposal of drugs within the standards established by the PNRS. There were several recommendations warned about the expected disposal, among them: the duty of manufacturers, distributors, importers and dealers of drugs to implement a system that allocates expired or unused drugs – discarded by consumers – to an appropriate place that would not harm human health or the environment (MMA, 2013b).

2.3.3.6 Household Electronic Products and their Components

Electronic equipment is defined as all products that require magnetic fields or electric current to operate (Abdi, 2013).

Table 1 shows how electronic products are classified.

Table 1. Classification of electronic products

LINE	DESCRIPTION
White Line:	Refrigerators and freezers, stoves, washing machines and dishwashers, dryers, air conditioners.
Brown Line:	Tube, plasma, LCD and LED monitors and televisions, DVD and VHS players, audio equipment, video cameras.
Blue Line:	Mixers, blenders, electric irons, drills, hair dryers, juicers, vacuum cleaners and coffee makers.
Green Line:	Desktop and laptop computers, computer accessories, tablets and cell phones.

Source: Abdi, 2013.

After reuse, repair and recycling, these objects should be called waste electrical

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and electronic equipment (WEEE); telecommunication mechanisms have a more finite lifespan when compared to others (Abdi, 2013).

The Sectoral Agreement for the implementation of the Reverse Logistics System for Household Electronic Products and their Components was signed on October 31, 2019 and its extract published in the Official Gazette of the Union on November 19, 2019. Through the Sectoral Agreement, members of the production chain of household electronic products and their components undertake to carry out a series of actions to comply with the National Solid Waste Policy (Sinir, 2025).

Therefore, considering the objective of this research to focus on the time frame of 2015/2016, the sectoral agreement for electronic waste and its components was under discussion during this period, with the next stage being the Public Consultation (Sinir, 2018c). One of the topics discussed was the responsibility of importers, manufacturers, distributors and sellers of electronic products and their components to provide a reverse logistics system with the support of the buyer and that did not depend on the urban cleaning service (MMA, 2013c).

2.4 ANALYSIS POINTS OF REVERSE LOGISTICS SYSTEMS

As the primary scope of this research, the aim was to condense information regarding the nine Reverse Logistics Systems mentioned, considering the time frame between 2015 and 2016, regarding four points of analysis: (i) Reverse Flows; (ii) Objectives and Goals; (iii) Number of collection points; (iv) Quantities of products to be returned by the Systems; presented below.

2.4.1 Reverse flows

The reverse flow is the return path of the waste. After being collected, it is sent to the correct disposal sites. In the nine systems studied, it is the consumer's responsibility to send the objects to the collection site. The material is stored at this point until it reaches the maximum amount of waste, which varies from material to material (Play Clean

Program, 2013; Sinir, 2015; MMA, 2013b; MMA, 2013c; Antt, 2004; Conama, 2005; Conama, 2009 and Inpev, 2016).

Some materials require extra care, such as pesticide packaging, which requires triple washing before being returned, and in the case of OLUC, the oil used must be stored correctly. For plastic packaging of lubricating oil and tires, all points of sale are designated as collection points (Sindicom, 2014; Reciclanip, 2017).

The reverse flow begins when the material is discarded at collection points; a company is responsible for collecting the collected waste. From this point on, the systems begin to differentiate. Electronic devices, batteries, and accumulators need to be disassembled and then sent to the correct locations. Medicines are separated into ointments, tablets, and syrups. OLUC requires several steps to prevent further damage to the environment. It is because of these factors that each of the systems has a unique number of reverse flow steps, as can be seen in Table 2.

Table 2. Number of reverse flow steps of the nine reverse logistics systems studied

REVERSE LOGISTICS SYSTEMS	NUMBER OF STEPS
Pesticide Packaging	06
Waste Tires	09
Used or Contaminated Lubricating Oil	13
Batteries and Batteries	16
Plastic Lubricating Oil Packaging	14
Lamps	16
General Packaging	05
Electronics	08
Medicines	11

Source: Based on the Play Fair Program, 2013; Sinir, 2015; MMA, 2013b; MMA, 2013c; Antt, 2004; Conama, 2005; Conama, 2009 and Inpev, 2016.

2.4.2 Objectives and goals

In all cases, the objectives are to reduce environmental pollution, achieving the appropriate disposal of waste and meeting the deliberate regulations (Play Clean Program, 2013; Sinir, 2015; MMA, 2013b; MMA, 2013c; Antt, 2004; Conama, 2005; Conama, 2009 and Inpev, 2016).

Table 3 presents a summary about each System, with the information available in the time frame covered by this study.

Table 3. Objectives and Goals

REVERSE LOGISTICS SYSTEMS	2015 GOALS (kg)	2016 GOALS (kg)
Pesticide Packaging	45,500	46,500
Waste Tires	532,479.80	510,449.83
Used or Contaminated Lubricating Oil	379,259,502	353,188,800
Batteries and Batteries	There are none*	There are none*
Plastic Lubricating Oil Packaging	4,700	4,400
Lamps	There are none*	There are none*
General Packaging	There are none*	656.60
Electronics	452.10	516.40
Medicines	There are none*	There are none*

* Data described as non-existent are those of systems that, in the time period covered by this study (years 2015/2016), were not yet in operation or did not have defined goals for the period researched.
Source: Based on the Play Fair Program, 2013; Sinir, 2015; MMA, 2013b; MMA, 2013c; Antt, 2004; Conama, 2005; Conama, 2009 and Inpev, 2016.

The OLUC sector agreement provided for its termination by the year 2016. Due to this, considering the time frame covered by this research (years 2015/2016), the quantities were forwarded through the Product Movement Information System. (SIMP), which received the waste and was responsible for this system (ANP, 2017).

2.4.3 Number of collection points

Due to its peculiarities, each System adopted a way of defining the number of collection points (Play Clean Program, 2013; Sinir, 2015; MMA, 2013b; MMA, 2013c; Antt, 2004; Conama, 2005; Conama, 2009 and Inpev, 2016).

Each system has its own requirements when it comes to receiving waste. For example, it is worth highlighting the collection points for lubricating oil packaging, which only accept packaging up to one liter (Sinir, 2012). Batteries and batteries receive up to 30 kg; for unusable tires, they receive 2,000 units of passenger tires and 300 units of truck tires.

Table 4 presents a summary of the information available about each System, in the time period covered by this study.

Table 4. Number of Collection Points

REVERSE LOGISTICS SYSTEMS	NUMBER OF COLLECTION POINTS
Pesticide Packaging	411
Waste Tires	1024
Used or Contaminated Lubricating Oil	37
Batteries and Batteries	1250
Plastic Lubricating Oil Packaging	4213
Lamps	821
General Packaging	2103
Electronics	1522
Medicines	624

Source: Based on Recicladora Urbana, 2017; Cempre, 2017; inPEV, 2017a and 2017b; Abdi, 2013; MMA, 2015; ANP, 2017 and Ibama, 2016.

The definition of collection points for medicines and electronics - at the time - was similar, taking into account the number of households in the municipality, the amount of medicines/electronics entering the market, the annual discard rate, the number of individuals and population density (MMA, 2013b, 2013c). The light bulb delivery network also takes into account some city data. The municipality must have at least 250 inhabitants/km²; for municipalities with a population greater than 25,000 inhabitants, with an average interval of 4 km between each monitored residence, there is a fixed collection point (Sinir, 2018d).

The OLUC system used the SIMP system for monthly collection. Companies sent products to the program (Simp, 2017). In 2014, Lubricating Oil Packaging had collection points in 2,300 municipalities and the goal was to reach 100% of the municipalities in the Southeast, South and Northeast regions (except Piauí and Maranhão) by 2016 (Sinir, 2012; Sindicom, 2014).

2.4.4 Quantities to be returned

Each system has a different way of accounting for the amounts it expects to receive and how much was actually collected. This is because each one has peculiarities that need to be considered (Play Clean Program, 2013; Sinir, 2015; MMA, 2013b; MMA, 2013c; Antt, 2004; Conama, 2005; Conama, 2009 and Inpev, 2016).

Table 5 presents a summary of the information available about each System, in the time period covered by this study.

Table 5. Amount of Waste Collected

REVERSE LOGISTICS SYSTEMS	QUANTITY COLLECTED IN 2016 (kg)
Pesticide Packaging	44,528
Waste Tires	493,399.13
Used or Contaminated Lubricating Oil	383.939.006
Batteries and Batteries	131,828
Plastic Lubricating Oil Packaging	4,455
Lamps	96,000
General Packaging	3.283
Electronics	2.930
Medicines	1,007,551

Source: Based on the Clean Play Program, 2013; Sinir, 2015; MMA, 2013b; MMA, 2013c; Antt, 2004; Conama, 2005; Conama, 2009 and Inpev, 2016

The Lamps system presents data from half of 2016 and half of 2017, as it is an agreement that was not in operation throughout 2016.

The estimate for electronic products would only be established after the signing of the sectoral agreement. The General Packaging system had the goal of reducing 22% of packaging in landfills by 2018 (Sinir, 2015).

OLUC collectors needed to collect at least 30% of the volume placed on the market within a year (Conama, 2005). The target for lubricating oil packaging was to collect 4,400 tons by 2016 (Sinir, 2012). For lamps, the sectoral agreement envisaged a collection of 20% of the lamps placed on the market five years after the signing of the agreement (Sinir, 2018d).

2.5 AHP – ANALYTICAL HIERARCHICAL PROCESS

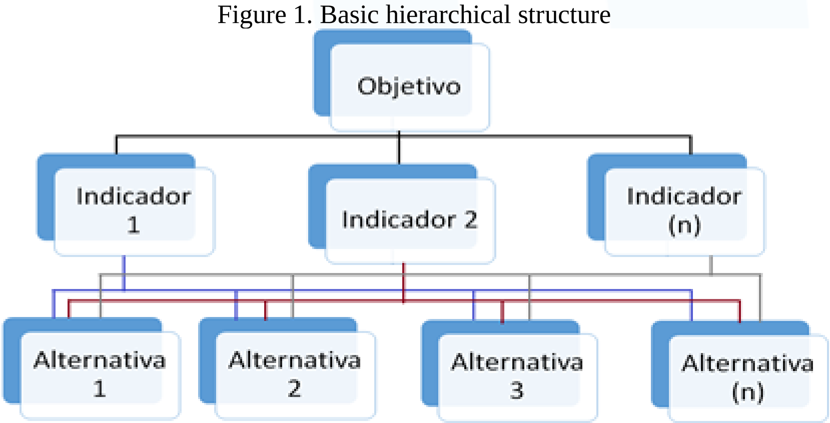
The AHP (Analytic Hierarchy Process) tool was developed by Tomas L. Saaty in the 1980s. It is a method used for decision-making. It is the best-known multicriteria methodology used in business conflicts and problems with multiple criteria (Marins; Souza; Barros, 2009).

When a decision is made, it is expected to have chosen the option that presents the greatest performance and the best option among those presented (Marins; Souza; Barros, 2009). Its main aspect is to guide the intuitive processes of choosing options, in order to make the correct decision. This tool characterizes, classifies and prioritizes the information necessary to reach the best final solution (Oliveira; Belderrain, 2008).

According to Costa (2002), Favretto and Nottar (2016), the AHP method is based on three analytical stages, namely: Construction of the hierarchy; Definition of priorities and Assessment of consistency.

Hierarchical construction begins when there is a problem that needs to be solved, which is then located in the first line of the hierarchical tree. To solve this problem, some criteria are defined that are relevant when choosing the best options for solving the problem. If the problem is very complicated, sub-criteria can be used to obtain an even more precise solution (Costa, 2002). Figure 1 illustrates a basic hierarchical structure.

Figure 1. Basic hierarchical structure



Source: Adapted from Marins, Souza and Barros, 2009.

When defining priorities, the elements are compared equally and it is at this moment that the person judging the elements must perceive the similarity between the objects studied, in order to then assemble the AHP comparison matrix. For this, the numerical scale developed by Saaty is used, which helps when characterizing the elements (Marins; Souza; Barros, 2009). Table 6 presents the scale developed by Saaty.

Table 6. Numerical scale developed by Saaty

NUMERICAL SCALE	CONCEPTUAL SCALE	DESCRIPTION
1	Equal	Both elements contribute equally to the objective
3	Moderate	The compared element is slightly important in relation to the other
5	Strong	Experience and judgment strongly favor one element over the other
7	Very strong	The compared element is much stronger in relation to the other, and such importance can be observed in practice
9	Absolute	The compared element presents the highest possible level of evidence in its favor
2, 4, 6, 8	Intermediate values between two judgments, used when the decision maker finds it difficult to choose between two adjacent degrees of importance	

Source: Based on Ribeiro and Alves, 2016.

To define the AHP matrix, it is necessary to meet the following conditions:

Table 7. Conditions for Assembling the AHP Matrix

CONDITIONS FOR ASSEMBLY OF THE AHP MATRIX	
(i)	Condense information - in the time frame of 2015/2016 - referring to the nine Reverse Logistics Systems addressed (Unusable tires; Agrochemical packaging; Used or contaminated lubricating oil; Batteries; Plastic packaging for lubricating oils; Sodium and mercury vapor fluorescent lamps and mixed light; Packaging in general; Electronic products and their components; Medicines), regarding four analysis topics (Reverse flows practiced; Intended objectives and goals; Number of collection points; Quantities of products to be returned by the systems);
(ii)	Suggest performance indicators for each of the four topics analyzed;
(iii)	Using an analytical hierarchical process (AHP) tool, designate a way of assessing the performance of these systems, in order to classify them considering the established criteria.

Source: Adapted from Marins, Souza and Barros, 2009.

The degree of consistency is calculated by Formula 1.

$$CR = \frac{CI}{RI} \qquad (1)$$

where :

CR = Degree of Consistency

CI = Consistency Index

RI = Random Consistency Index

The Random Consistency Index is tabulated by Saaty, as shown in Table 8.

Table 8 . AHP Average Random Index

n	1	2	3	4	5	6	7	8	9	10
IR	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.51

Source: Adapted from Saaty, 1991.

In this research, four indicators are compared, therefore using an RI of 0.9. And nine reverse logistics systems are also compared, therefore using an RI of 1.45.

The Consistency Index is calculated using Formula 2 (Trevizano; Freitas, 2005).

$$CI = \frac{\lambda \max - n}{n-1} \qquad (2)$$

where :

CI = Consistency Index

λ max = Largest eigenvalue of the judgment matrix

n = Number of items that are compared

In this research, the AHP method was used to hierarchize the Reverse Logistics Systems, considering, for this purpose, performance indicators related to each of the four analysis points initially presented in topic 2.4 of this article.

3 METHODOLOGY

This work was structured based on the ontological approach of the theme, which was established through data collection in periodicals, websites *and* books. Three main objectives were established to carry out this research:

(i) Condense information - in the time frame of 2015/2016 - referring to the nine Reverse Logistics Systems addressed (Unusable tires; Agrochemical packaging; Used or contaminated lubricating oil - Oluc; Batteries; Plastic packaging of lubricating oils; Sodium and mercury vapor fluorescent lamps and mixed light; Packaging in general; Electronic products and their components; Medicines), regarding four analysis topics (Reverse Flows practiced; Intended Objectives and

Goals; Number of collection points; Quantities of products to be returned by the Systems);

(ii) Suggest performance indicators for each of the four topics analyzed;

(iii) Using an analytical hierarchical process tool (AHP - *Analytic Hierarchy Process*), designate a way of assessing the performance of these Systems, in order to classify them considering the established criteria.

To meet the proposed objectives, the sequence of actions was as shown in Table 9.

Table 9. Sequence of research actions

I	Bibliographic survey aimed at constructing the theoretical framework, involving the National Solid Waste Policy, Reverse Logistics Systems and the AHP Method;
II	Preparation of the AHP Hierarchical Tree, providing for the definition of an indicator for each Analysis Point of the Reverse Logistics Systems;
III	By preparing comparative tables between the Systems, based on theory, highlight and justify the most relevant performance measures to be used at each point;
IV	Based on the established criteria, define the indicators for each Analysis Point of the Reverse Logistics Systems;
V	Run the AHP tool to obtain a classification of the Reverse Logistics Systems studied, ranked according to the best compliance with the established performance requirements;
VI	Analysis and discussion of results;
VII	Final considerations and suggestions for future work.

Source: Own authorship.

After the bibliographic survey involving the nine Brazilian Reverse Logistics Systems with national coverage - in the 2015/2016 time frame - focusing on the four topics of interest of the research (Reverse flows, Objectives and goals, Number of collection points and Quantities of products to be returned by the Systems), the fundamentals of the AHP method were presented, in order to support the structuring for the intended comparison.

To achieve this objective, it was necessary to establish an indicator that would represent, in a relevant way, each of the topics of interest addressed, which would be suitable as a parameter for comparison between the Systems.

Thus, an AHP Hierarchical Tree was created, composed of the nine Reverse Logistics Systems researched and the four representative indicators for the analysis (Number of collection points, 2015/2016 Goals, Number of stages and Quantities returned), which are presented below.

The time frame of this research between the years 2015/2016 implies considerations regarding each of the nine Reverse Logistics Systems at the time, as shown in Table 10.

Table 10. 2015/2016 time frame of the five post-PNRS sectoral agreements considered in this research

Reverse Logistics Systems	Implementation stage of each Sectoral Agreement in the 2015/2016 time frame
Plastic Lubricating Oil Packaging	Sectoral Agreement signed on December 19, 2012 and published on February 7, 2013
Lamps	Sectoral Agreement signed on 27 November 2014 and published on 12 March 2015
Electronics	Ten proposals for Sectoral Agreements received by June 2013, four of which were considered valid for negotiation. Unified proposal received in January 2014 (under negotiation in the 2015/2016 time frame)
General Packaging	Sectoral Agreement signed on 25 November 2015 and published on 27 November 2015
Medicines	Three Sectoral Agreement proposals received by April 2014 (under negotiation in the 2015/2016 time frame)

Source: Sinir, 2018c.

In this context, considerations should be given to the proposed Reverse Logistics Systems for Electronic Devices and Medicines (both with Sector Agreements still under negotiation in the 2015/2016 time frame): in general, Sector Agreements began to be discussed after the National Solid Waste Policy, but not all of them had proposals presented immediately. The programs presented - in Table 10 - under negotiation are those that had proposals launched late and, because of this, took a long time to be put into practice (Sinir, 2018d).

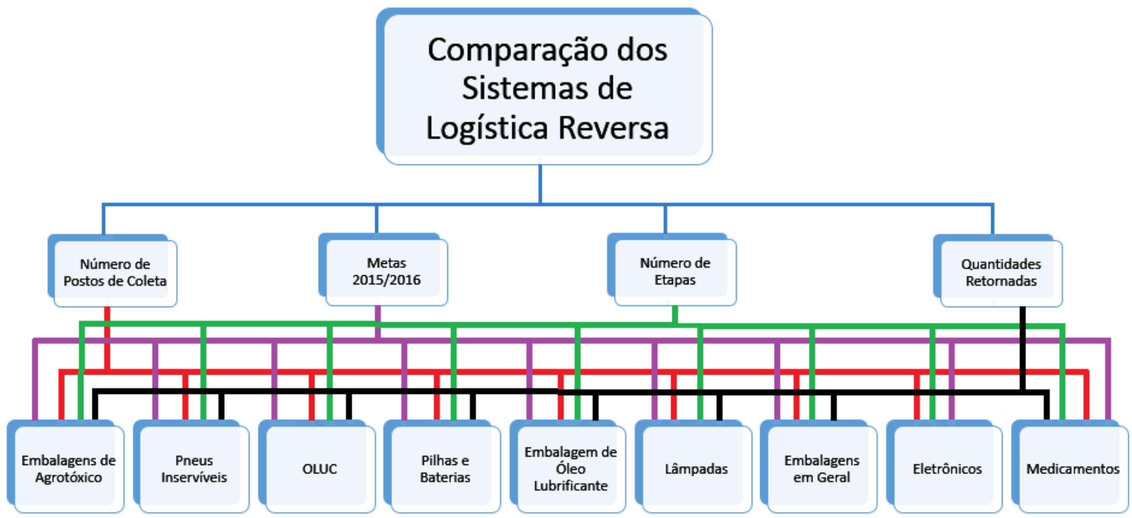
The justification for the time frame of 2015/2016 is to bring to the reader's attention some intermediate phases that today's consolidated Reverse Logistics Systems needed to meet in order to obtain their Sector Agreements; and, at the same time, to attest to the reader about the possibility of applying the AHP method - as proposed in this article - in the comparison of Systems with different degrees of maturity and performance.

ISSN: 1696-8352

3.1 STRUCTURING THE AHP TREE

The tree presented in Figure 2 is structured in three levels (considering the direction from top to bottom): the first level contains the intended objective, which is the Comparison of Reverse Logistics Systems; the second level contains the four indicators, which support the analysis parameters between the Systems; and the third level contains the nine Reverse Logistics Systems. Figure 2 presents the AHP Hierarchical Tree proposed in this research.

Figure 2 . AHP Hierarchical Tree



Source: Own authorship.

3.2 DEFINITION OF INDICATORS

To compare the nine systems, four indicators were defined: Number of Collection Points, 2015/2016 Targets, Quantities Returned and Number of Stages. The following is an explanation of how the indicators were measured:

Number of Collection Points: to decide the number of collection points spread throughout the country, the medicine, electronics and light bulb systems use the number of inhabitants as a parameter, that is, they set a maximum number of inhabitants for each

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collection point. Due to this, the number of inhabitants in Brazil in 2016 was used to create this indicator. The number of collection points for each system in 2016 was used and divided by the number of inhabitants in the country, forming the collection points indicator. The territorial extension of Brazil was not used, as there are many uninhabited regions and with these values the indicator would not be relevant. Formula 3 shows the data used to create the indicator.

$$PC = \frac{NPC}{HAB} \qquad (3)$$

where :

PC = Collection Point Indicator
NPC = Number of Collection Points
HAB = Number of Inhabitants in Brazil

2015 and 2016 targets: when the sectoral agreements are signed, collection targets are defined for all systems. The systems have a period of time with targets, which are then reviewed and reformulated. To measure these targets, an indicator was formulated, dividing the 2015 targets by the 2016 targets. The relevance of this indicator is to highlight how the targets were developed. Some of these, as can be seen in Table 3, decreased instead of increasing. This occurred due to some problems encountered during the course of the projects. The following is formula 4, which was used to develop the indicator.

$$IM = \frac{M2015}{M2016} \qquad (4)$$

where :

IM = Target Indicator
M2015 = Goals for the Year 2015
M2016 = Goals for the Year 2016

Expected return quantity and quantity actually returned in 2016: to form this indicator, reports on the 2016 targets were used, which would be the quantities expected for the same year divided by the amounts that were actually returned by the collection points. All of this data was extracted from reports of the programs and actions that manage these systems. This is the most relevant indicator, as it shows us more clearly how the systems worked in the given year. This way, we can get an idea of how much improvement is still needed in each one and, with the help of the other indicators, we can see where there is the greatest deficit in order to start improvements.

$$QR = \frac{M2016}{QRR} \qquad (5)$$

where :

QR = Returned Quantity Indicator
M2016 = Goals for 2016, quantities expected for that year
QRR = Quantities Actually Returned 2016

Number of Reverse Logistics steps: each of the deliberate systems has its own defined waste return path. To construct an indicator, the number of steps in this reverse path was divided by the number of the system with the highest number of steps, in this case 16. This value was chosen because it is agreed that the fewer the steps for returning waste, the better the system. Therefore, when divided by the highest number of steps, the values closest to zero are the best systems. The purpose of this indicator is to show that just as the period of waste collection is important, the route to the final destination is also important in these systems. The companies that receive the waste also have many responsibilities in the functioning of Reverse Logistics. Formula 6, used to create this indicator, is presented below.

$$IE = \frac{NE}{MNE} \qquad (6)$$

ISSN: 1696-8352

where :

IE = Number of Steps Indicator

NE = Number of Steps

MNE = Largest Number of Steps

3.2.1 Tabulation of indicators and normalization of results

Figure 3 shows the data used to form the indicators. The information marked in beige refers to the year 2017; it was agreed to proceed in this manner because the agreement only began to be implemented in 2016.

Figure 3 . Data used in the formation of indicators

	Embalagens de Agrotóxico	Pneus Inservíveis	OLUC	Pilhas e Baterias	Embalagens Plásticas de Óleo Lubrificante	Lâmpadas	Embalagens em Geral	Eletroeletrônicos	Medicamentos
Números de postos de coleta	411	1024	37	1250	4213	821	2103	1522	624
Número de habitantes no Brasil	206.080.000	206.080.000	206.080.000	206.080.000	206.080.000	206.080.000	206.080.000	206.080.000	206.080.000
Metas 2015	45.500,00	532.479,80	379.259.502,00	0	4.700,00	0	0	452,10	0
Metas 2016	46500,00	510449,83	353.188.800,00	0	4.400	0	656,6	516,4	0
Quantidade Retornada de resíduos	44528,00	493399,13	383939006,00	131.828	4.455	96.000	3.283	2930	100,7551
Número de etapas	6	9	13	16	14	16	5	8	11

Source: Based on the Play Fair Program, 2013; Sinir, 2015; MMA, 2013b; MMA, 2013c; Antt, 2004; Conama, 2005; Conama, 2009; Inpev, 2016; Ibge, 2016.

Figure 4 presents the values of the four indicators: Number of Collection Points; 2015/2016 Targets; Quantity of Waste Returned and Number of Stages.

Figure 4 . Indicators

	Embalagens de Agrotóxico	Pneus Inservíveis	OLUC	Pilhas e Baterias	Embalagens Plásticas de Óleo Lubrificante	Lâmpadas	Embalagens em Geral	Eletroeletrônicos	Medicamentos
Postos de Coleta	0,089559387	0,236350575	0	0,290469349	1	0,187739464	0,494731801	0,355603448	0,140565134
Metas 2015/2016	0,91603752	0,976573403	0,100640416	0	1	0	0	0,819602156	0
Número de Etapas	1	0,528505393	0,226502311	0	0,151001541	0	1	0,604006163	0,377503852
Quantidades Retornadas	0,074395298	0	0,911081935	0	0,045336576	0	0,806680657	0,829641452	0

Source: Own authorship.

To keep all data in the same range, in this case from 0 to 1, formula 7 called Rescaling was *used* .

$$x' = \frac{x - \min(x)}{\max(x) - \min(x)} \qquad (7)$$

where :

x = Number to be resized

min(x) = Smallest number found for the indicator being calculated

max(x) = Highest number found for the indicator being calculated

3.3 STEP BY STEP GUIDE TO CREATING THE PROPOSED AHP MATRIX

After calculating the range of indicators, AHP scores were assigned (1, 3, 5, 7 and 9), comparing all systems equally, with number 9 being the best assessment and 1 the worst.

The next step was to assemble the AHP matrix. A 4x4 matrix was assembled to compare the indicators and four 9x9 matrices, since nine systems were compared pairwise. First, the diagonal was filled with the number 1 for all systems, since the comparison was made pairwise, when a system is compared with itself the result will be one. Once the diagonal was filled, the rows were completed, starting from the diagonal. The columns were added with the inverse data of those found in the rows referring to the same system.

The matrix shown in Table 1 shows the comparison made between the indicators, to decide which one is most relevant.

Table 1. AHP Matrix of Indicators

	Collection Points	**Goals 2015/2016**	**Returned Quantities**	**Number of Steps**	Auto Vector	Normalized Auto Vector
Collection Points	**1**	3	1/5	7	1.43	22%
Goals 2015/2016	1/3	**1**	1/7	3	0.61	9%
Returned Quantities	5	7	**1**	9	4.21	65%
Number of Steps	1/7	1/3	1/9	**1**	0.27	4%
Sum	6.48	11.33	1.45	20.00	6.53	100%

Source: Own authorship.

After assembling the comparison matrix, the calculation of the eigenvector, normalized eigenvector, λMax, CI and CR is done using an Excel spreadsheet, as shown in Tables 2 and 3. With these results, it is possible to know whether the comparison is consistent. The CR must be less than 10% for the comparison to be used, making the research valid.

Table 2 . Calculation of Eigenvector and Normalized Eigenvector

	Collection Points	Goals 2015/2016	Returned Quantities	Number of Steps	Auto Vector	Normalized Auto Vector
Collection Points	0.15	0.26	0.14	0.35	1.43	22%
Goals 2015/2016	0.05	0.09	0.10	0.15	0.61	9%
Returned Quantities	0.77	0.62	0.69	0.45	4.21	65%
Number of Steps	0.02	0.03	0.08	0.05	0.27	4%

Source: Own authorship.

Table 3 . Inconsistency Value of Comparison of Indicators

λmax	4.25156
CI	0.08385
CR	0.09317

Source: Own authorship.

This step-by-step process was followed for the system comparison matrices. The matrix shown in Figure 5 refers to the indicator of the number of collection points. It can be seen in the matrix that in the second column and second row, there are agrochemical packaging and in the third row, there are unusable tires. When comparing agrochemical packaging with unusable tires, it is found that tires are more efficient in this case, so the cell for this comparison will be 1/3 and when comparing unusable tires with agrochemicals, which would be column 2, row 3, the result is 3, since it will be the inverse.

The last line, called the sum, is the sum of the columns. To calculate the eigenvector, the geometric mean of the line is taken. And to calculate the normalized eigenvector, the sum of the eigenvector line is taken, and then each line is divided by the sum, thus obtaining the normalized eigenvector. Multiplying this value by 100, we have the percentage, showing which is the best system in each of the indicators.

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Figure 5 . AHP Collection Station Matrix

	Embalagens de Agrotóxicos	Pneus Inservíveis	OLUC	Pilhas e Baterias	Embalagens Plásticas de Óleo Lubrificante	Lâmpadas	Embalagens em Geral	Eletroeletrônicos	Medicamentos	Auto Vetor	Auto Vetor Normalizado
Embalagens de Agrotóxicos	1	1/3	3	1/5	1/7	1/3	1/7	1/5	1/3	0,36	2,73%
Pneus Inservíveis	3	1	5	1/3	1/7	1	1/7	1/5	1	0,65	4,98%
OLUC	1/3	1/5	1	1/7	1/9	1/5	1/9	1/7	1/5	0,21	1,58%
Pilhas e Baterias	5	3	5	1	1/5	1/3	1/5	1	3	1,13	8,68%
Embalagens Plásticas de Óleo Lubrificante	7	7	9	5	1	5	1	3	5	3,80	29,19%
Lâmpadas	3	1	1	3	1/5	1	1/5	1/3	1	0,79	6,07%
Embalagens em Geral	7	7	7	5	1	5	1	3	5	3,70	28,38%
Eletroeletrônicos	5	5	5	1	1/3	3	1/3	1	5	1,81	13,90%
Medicamentos	3	1	1	1/3	1/5	1	1/5	1/5	1	0,58	4,49%
Total	34,33	25,53	37,00	16,01	3,33	16,87	3,33	9,08	21,53	13,02	100,00%

Source: Own authorship.

Using this step-by-step process for the other indicators, the matrices and results in Figures 6, 7 and 8, presented below, are obtained.

Figure 6 . AHP Goals Matrix 2015/2016

	Embalagens de Agrotóxicos	Pneus Inservíveis	OLUC	Pilhas e Baterias	Embalagens Plásticas de Óleo Lubrificante	Lâmpadas	Embalagens em Geral	Eletroeletrônicos	Medicamentos	Auto Vetor	Auto Vetor Normalizado
Embalagens de Agrotóxicos	1	1	7	9	1	9	9	3	9	3,724	27,62%
Pneus Inservíveis	1	1	7	9	1	9	9	1/3	9	2,917	21,64%
OLUC	1/7	1/7	1	3	1	3	3	1/5	3	0,884	6,56%
Pilhas e Baterias	1/9	1/9	1/3	1	1/9	1	1	1/7	1	0,343	2,54%
Embalagens Plásticas de Óleo Lubrificante	1	1	1	9	1	9	9	3	9	3,000	22,25%
Lâmpadas	1/9	1/9	1/3	1	1/9	1	1	1/7	1	0,343	2,54%
Embalagens em Geral	1/9	1/9	1/3	1	1/9	1	1	1/7	1	0,343	2,54%
Eletroeletrônicos	1/3	3	5	7	1/3	7	1/9	1	7	1,586	11,76%
Medicamentos	1/9	1/9	1/3	1	1/9	1	1	1/7	1	0,343	2,54%
Total	3,92	6,59	22,33	41,00	4,78	41,00	34,11	8,10	41,00	13,48	100,00%

Source: Own authorship.

Figure 7 . AHP Returned Quantity Matrix

	Embalagens de Agrotóxicos	Pneus Inservíveis	OLUC	Pilhas e Baterias	Embalagens Plásticas de Óleo Lubrificante	Lâmpadas	Embalagens em Geral	Eletroeletrônicos	Medicamentos	Auto Vetor	Auto Vetor Normalizado
Embalagens de Agrotóxicos	1	3	9	9	9	9	1	3	7	4,208	28,30%
Pneus Inservíveis	1/3	1	5	5	5	5	1/5	1/3	3	1,513	10,18%
OLUC	1/9	1/5	1	1	1	1	1/9	1/7	3	0,467	3,14%
Pilhas e Baterias	1/9	1/5	1	1	1	1	1/9	1/7	1/3	0,366	2,46%
Embalagens Plásticas de Óleo Lubrificante	1/9	1/5	1	1	1	1	1/9	1/7	1/3	0,366	2,46%
Lâmpadas	1/9	1/5	1	1	1	1	1/9	1/7	1/3	0,366	2,46%
Embalagens em Geral	1	5	9	9	9	9	1	3	7	4,453	29,96%
Eletroeletrônicos	1/3	3	7	7	7	7	1/3	1	5	2,513	16,91%
Medicamentos	1/7	1/3	1/3	3	3	3	1/7	1/5	1	0,613	4,12%
Total	3,25	13,13	34,33	37	37	37	3,12	8,10	27	14,87	100,00%

Source: Own authorship.

Figure 8 . AHP Number of Steps Matrix

	Embalagens de Agrotóxicos	Pneus Inservíveis	OLUC	Pilhas e Baterias	Embalagens Plásticas de Óleo Lubrificante	Lâmpadas	Embalagens em Geral	Eletroeletrônicos	Medicamentos	Auto Vetor	Auto Vetor Normalizado
Embalagens de Agrotóxicos	1	3	1/7	3	3	3	1/5	1/5	3	1,037	6,96%
Pneus Inservíveis	1/3	1	1/9	1	1	1	1/7	1/7	1	0,450	3,02%
OLUC	7	9	1	9	9	9	3	3	9	5,371	36,05%
Pilhas e Baterias	1/3	1	1/9	1	1	1	1/7	1/7	1	0,450	3,02%
Embalagens Plásticas de Óleo Lubrificante	1/3	1	1/9	1	1	1	1/7	1/7	1	0,450	3,02%
Lâmpadas	1/3	1	1/9	1	1	1	1/7	1/7	1	0,450	3,02%
Embalagens em Geral	5	7	1/3	7	7	7	1	1	7	3,120	20,94%
Eletroeletrônicos	5	7	1/3	7	7	7	1	1	7	3,120	20,94%
Medicamentos	1/3	1	1/9	1	1	1	1/7	1/7	1	0,450	3,02%
Total	19,67	31	2,37	31	31	31	5,91	5,91	31	14,90	100,00%

Source: Own authorship.

With this data and formulas 1 and 2 presented previously, it was possible to calculate the eigenvector, the normalized eigenvector, which is the item that hierarchizes the systems, showing which is the best. It was also possible to calculate λmax, CI and CR. Table 4 shows the calculations for the Collection Point Number System.

Table 4 . Consistency Index of Comparison of Number of Collection Points

λmax	9.35383
CI	0.04423
CR	0.0305

Source: Own authorship.

The step-by-step process was used for all systems and the results obtained are shown in Tables 5, 6 and 7.

Table 5 . Consistency Index of Comparison of Targets 2015/2016

λmax	9.98366
CI	0.12296
CR	0.0848

Source: Own authorship.

Table 6 . Consistency Index of Step Number Comparison

λmax	9.48778
CI	0.06097
CR	0.04205

Source: Own authorship.

Table 7 . Returned Quantity Comparison Consistency Index

λmax	9,3803
CI	0.04754
CR	0.03278

Source: Own authorship.

To compare the best system, the weight of the indicator criteria was used and multiplied by the normalized autovector. After that, each line was added together, and the best overall system was obtained. Table 8 shows the weights of the criteria and the normalized autovector of each system in relation to each indicator.

Table 8 . Defining the Best Overall System

	Collection Points	Goals 2015/2016	Returned Quantities	Number of Steps
Weight of Criteria	0.219	0.094	0.645	0.041
Pesticide Packaging	0.02730	0.27621	0.06962	0.28304
Waste Tires	0.04984	0.21638	0.03020	0.10181
OLUC	0.01583	0.06559	0.36053	0.03142
Batteries and Batteries	0.08677	0.02542	0.03020	0.02461
Plastic Packaging for Lubricating Oils	0.29186	0.22250	0.03020	0.02461
Lamps	0.06068	0.02542	0.03020	0.02461
General Packaging	0.28382	0.02542	0.20942	0.29957
Electronics	0.13899	0.11764	0.20942	0.16907
Medicines	0.04491	0.02542	0.03020	0.04124

Source: Own authorship.

Table 9 shows the data after multiplication and the result of the best system.

Table 9 . Best Overall System Result

	Collection Points	Goals 2015/2016	Returned Quantities	Number of Steps	Global Priority	Global Priority (%)
Weight of Criteria	0.219	0.094	0.645	0.041	1,000	100%
Pesticide Packaging	0.006	0.026	0.045	0.012	0.089	9%
Waste Tires	0.011	0.020	0.019	0.004	0.055	5%
OLUC	0.003	0.006	0.233	0.001	0.212	22%
Batteries and Batteries	0.019	0.002	0.019	0.001	0.042	4%
Plastic Packaging for Lubricating Oils	0.064	0.021	0.019	0.001	0.105	11%
Lamps	0.013	0.002	0.019	0.001	0.036	4%
General Packaging	0.062	0.002	0.135	0.012	0.244	24%
Electronics	0.030	0.011	0.135	0.007	0.184	18%
Medicines	0.010	0.002	0.019	0.002	0.033	3%

Source: Own authorship.

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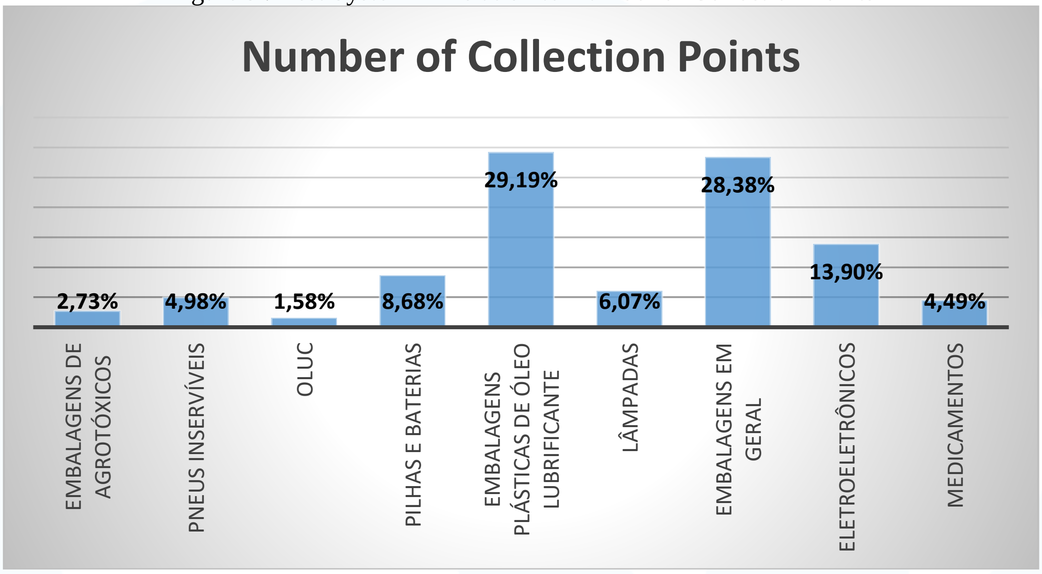
4 RESULTS AND DISCUSSIONS

chosen due to the growing environmental awareness nowadays. Initiatives from everyone are needed so that Reverse Logistics of materials can be further developed, and so that these materials are no longer discarded in inappropriate places. There are sectoral policies and agreements that govern the progress of these programs and what should or should not be done in each case. The companies that supply these inputs are responsible for their collection, and may be fined if they do not do so. Because of this, a large part of these materials are being disposed of correctly and thus causing less harm to the environment. The collaboration of consumers of these materials is also necessary, because after use they must be sent to collection points where they will be collected by the responsible companies.

Comparing all systems under the indicator **Number of collection points** , it was found that: the Agrochemical Packaging system had a poor performance in relation to the number of collection points, which was expected, since there were not many collection points for this waste; the Waste Tire system had a low number of collection points, leaving its performance lacking in this indicator. Batteries and Accumulators had a large number of collection points, this happened due to initiatives of companies that placed collection points for batteries and accumulators in their local businesses, thus increasing the number of collection points of this system. OLUC was the least favored system under this indicator, due to the few legalized and recognized collection points. Plastic Packaging of Lubricating Oil was the system that had the largest number of collection points, since gas stations are available to collect this waste; when there is an oil change at the gas station, the packaging is redirected to the correct location. Packaging in general had a high performance in relation to the number of collection points, since these are commonly used materials and many already recycle and separate them before removing this waste from their homes. The Lamps and Electronics systems were relatively new in the time frame of this research and did not yet have many collection points spread throughout the country, as well as the Medication system , which had the support of pharmacy chains that collected discarded medications.

Based on the data obtained by the AHP matrix and with the consistency index demonstrating that the data are acceptable, it was possible to assemble Figure 9, showing the ranking of the systems in relation to the indicator of the number of collection points.

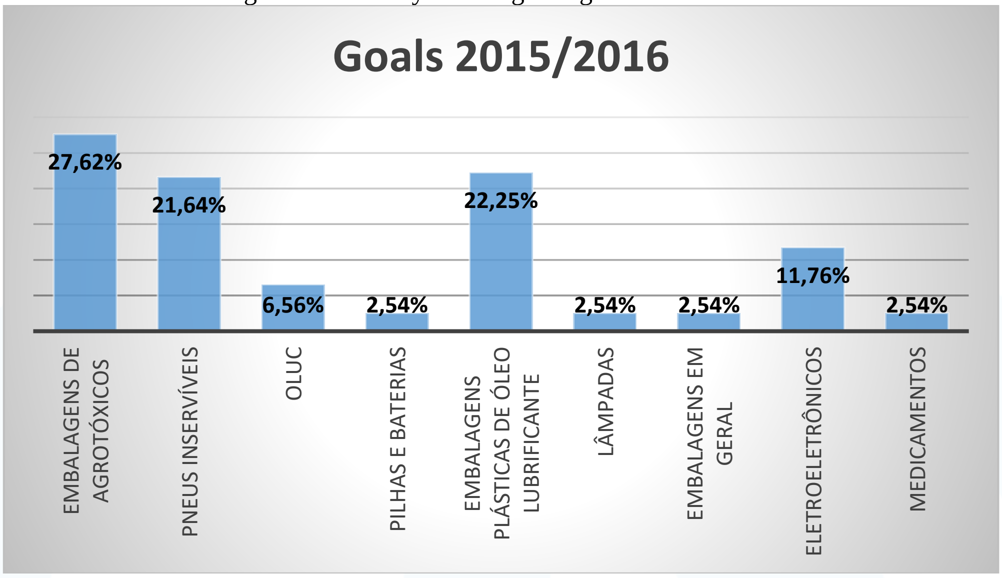
Figure 9 . Best System in Relation to Number of Collection Points



Source: Own authorship.

Regarding the **2015/2016 Targets indicator** , Pesticide Packaging and Waste Tires were the systems that performed best in defining targets from one year to the next, demonstrating an increase in objectives. Medications , General Packaging , Light Bulbs and Batteries demonstrated low performance, each presenting only 2.54% of the total, which shows that these systems did not define more ambitious targets when establishing the systems. When assembling the indicator, the value zero was used for systems that did not have targets , this was done to demonstrate that systems that do not define targets are disadvantaged in relation to the others. Figure 10 presents this ranking.

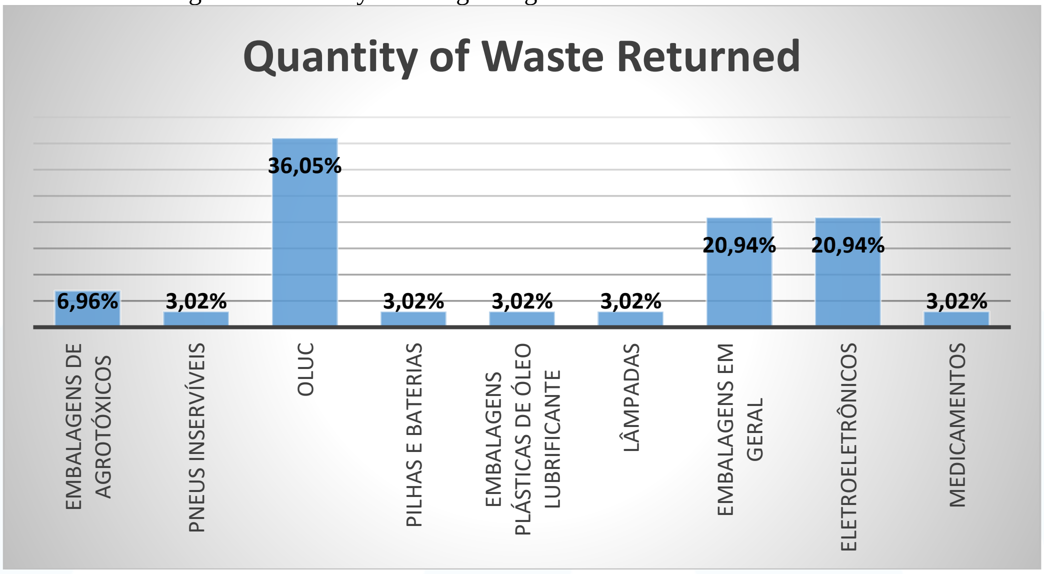
Figure 10 . Best System Regarding Goals 2015/2016



Source: Own authorship.

Regarding the **Returned Amounts indicator** , the system that collected the most waste in 2016 was OLUC , even with the small number of collection points. This occurred because this system managed to exceed the target set for 2016, thus being the best system in this comparison criterion. General Packaging and Electronics demonstrated good results, but were unable to reach the targets, but came very close to the expected result, as shown in Figure 11.

Figure 11 . Best System Regarding the Amount of Waste Returned

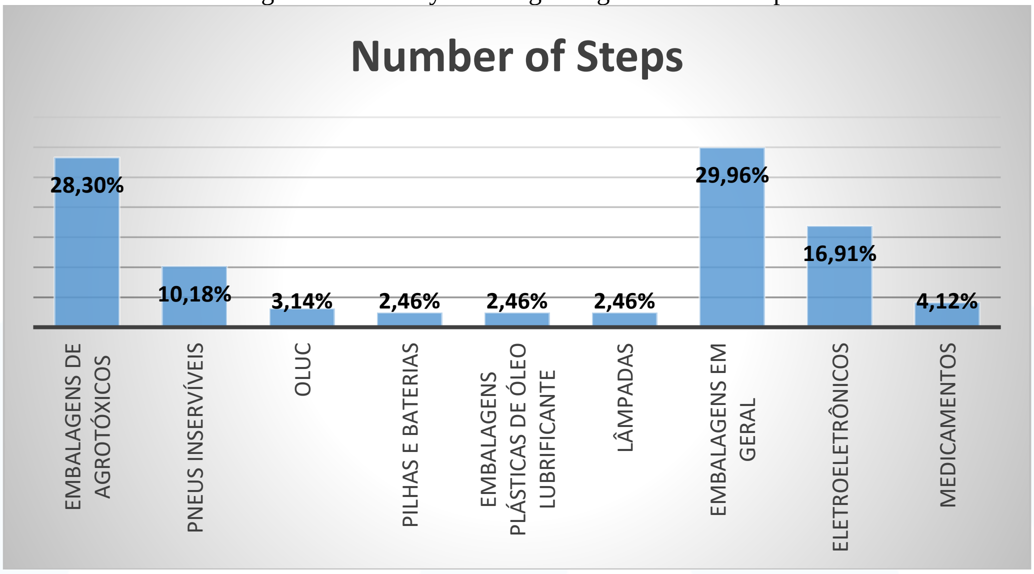


Source: Own authorship.

The Medicines , Lamps , Batteries and Plastic Packaging for Lubricating Oil systems had a very low performance in this indicator, this occurred due to the fact that they were unable to achieve the goals established for the year 2016 and, in the case of the first three systems mentioned, they were relatively new systems in the time frame of this research, which did not have defined goals yet and, in the assembly of the indicators, the systems without goals were defined as inferior systems when compared to others.

Number of steps indicator, Pesticide Packaging showed growth in relation to the other systems, being the second best system in relation to this indicator. The best system in this indicator was the General Packaging system , as it has simpler disposal and fewer steps when returning the waste. In the case of the Plastic Lubricating Oil Packaging System , its number of steps was high, for its correct recycling several steps would be necessary, due to the need to decontaminate the packaging. Light bulbs and Batteries were the least favored in this indicator, this happened because this waste is composed of several components and needs to be separated and destined for the correct destination, not being possible to recycle this waste completely. Medications also showed a low performance evaluation, because at the time of its reverse logistics, it would need to separate the tablets from the ointments and syrups, making the process more complex. The performance of the systems is shown in Figure 12.

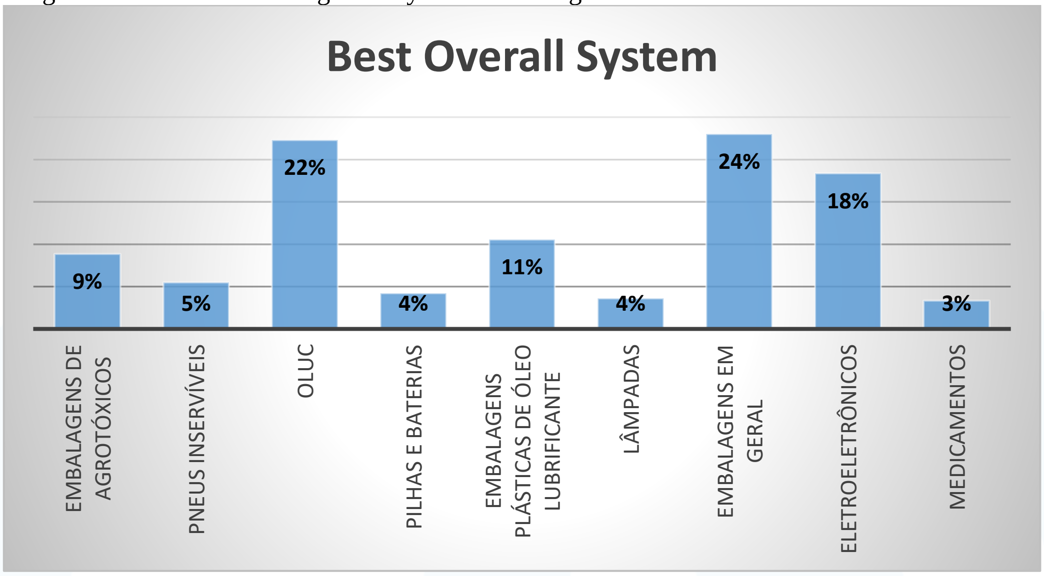
Figure 12 . Best System Regarding Number of Steps



Source: Own authorship.

The comparisons made it possible to rank all the systems in general. In this case, the General Packaging plan stood out the most, and was the system that performed best in relation to the listed indicators. Of the four indicators used, it performed well in three of them, but only in the target category did it perform poorly. The project can still be improved by providing more collection points and raising awareness among the entire population about the importance of separating waste in their daily lives. With everyone separating waste, waste collection becomes much easier and more waste will be disposed of correctly. Figure 13 shows the ranking of the systems studied.

Figure 13 . Best Reverse Logistics System according to the criteria established in this research



Source: Own authorship.

5 FINAL CONSIDERATIONS

This research aimed to compare the reverse logistics systems implemented in Brazil considering the 2015/2016 time frame, in four points of interest: Collection Points, Number of stages of material return, Quantities Returned and Defined Goals. The systems that were in operation in the country at the time were: Agrochemical Packaging, Unusable Tires, OLUC, Batteries, Plastic Packaging for Lubricating Oil, Lamps, Packaging in General, Electronics and Medicines, the first four being implemented before the National Solid Waste Policy.

The purpose of this comparison was to rank the systems in general, according to suggested performance criteria, comparing all indicators and also how each system would be developing in each topic. These results provide support for redoubling efforts in specific topics, in order to improve the Reverse Logistics Systems currently implemented.

The Packaging in general system was ranked as the best overall system, because among all the Reverse Logistics Systems examined, it suggests less complexity in its operation, since Packaging in general is used in everyone's daily lives and the consumer population is increasingly aware of the need to separate this waste from organic waste, which ends up facilitating the correct return of this waste. The material that represents the most difficulties at the time of separation is cardboard packaging, since it is composed of more than one material. Despite some difficulties, this system stood out among the other systems, but there are still points for improvement, such as increasing the targets for the return of waste; it was the only indicator in which it did not show a better performance.

Regarding the number of collection points, at the time of the data research, it was already possible to predict this impact, as the number of collection points for plastic packaging of lubricating oils was much higher than those of other systems. Thus, there was a performance of 37% in this indicator.

The best system was the one with the fewest steps, showing that materials can be disposed of more quickly. The Packaging system in general stood out in this indicator, because when this material was sent to collection points, it was already separated in most cases, thus reducing the number of steps for the subsequent disposal of this waste. The systems with the least satisfaction were Light Bulbs and Batteries, this was due to the fact that these are materials that contain compounds that are harmful to the environment and must be separated.

The number of items returned took into account the goals for 2016 and the amount returned in that same year, showing which system achieved the expected results and how much more waste was collected. OLUC collected the largest amount of used and contaminated lubricating oil, with a performance of 36%. Of all the indexes, this is considered the most important, as it allows us to learn a little more about the return of waste, showing which ones reached the target, which ones did not, and which ones exceeded it. If some systems were managing to exceed the target for returned items, it suggested that they were working well. Even though there were few collection stations at the time, many gas stations volunteered to join this system, reserving this oil in a suitable location.

The 2015/2016 Goals indicator was determined with the aim of demonstrating the goals set for the progress of the project. The goals should always be higher than those of previous years, to demonstrate that the system was continually improving. The system that demonstrated the best development was Plastic Packaging for Lubricating Oil, with its 2016 goal being much higher than that of 2015, showing that good performance was expected from the system. The systems that were harmed were the most recent ones, which did not have goals for 2015.

Therefore, this research achieved its objectives by providing support for improvements in the Reverse Logistics systems implemented in Brazil during the period considered, suggesting points of attention for analyzing the performance of these systems.

The justification for the time frame of 2015/2016 is to bring to the reader's attention some intermediate phases that today's consolidated Reverse Logistics Systems needed to meet in order to obtain their Sector Agreements; and, at the same time, to attest to the reader about the possibility of applying the AHP method - as proposed in this article - in the comparison of Systems with different degrees of maturity and performance.

By presenting step by step the entire methodology used, including the composition of the proposed indicators, this research aims to encourage future work involving the development of new indicators to aid decision-making, to improve the performance of Reverse Logistics Systems.

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