Reverse Logistics of Lubricant Oil and Packaging in Brazil: Analysis of the Value Chain and Business Opportunities for Sustainable Waste Management

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ABSTRACT

The lubricant oil (LO) market faces a major environmental challenge related to the generation of waste, such as used or contaminated lubricant oil (UCLO) and its packaging. Improper disposal of these wastes can cause irreversible damage to the environment, result in fines for producing companies and negatively affect their image. The re-refine is, according to Brazilian legislation, the only environmentally correct way to dispose of UCLO, which recovers the base oil to be used as raw material for the manufacture of new products in the chain, in accordance with the principles of the circular economy. The aim of this work is to carry out a diagnosis of lubricant oil reverse logistics and its value chain, in order to generate business opportunities and boosting sustainability. Preliminary analyses show the need to address the lack of knowledge on the topic in question. Thus, it is crucial for the lubricant oil industry and competent authorities to work together to implement effective reverse logistics practices in Brazil, in order to ensure a sustainable future for mobility in the country, promoting responsible use of natural resources and environmental protection.

RESUMO

O mercado de óleo lubrificante (OL) enfrenta um grande desafio ambiental relacionado à geração de resíduos, como o óleo lubrificante usado ou contaminado (OLUC) e suas embalagens. O descarte inadequado desses resíduos pode gerar danos irreversíveis ao meio ambiente, acarretar multas para as empresas produtoras e afetar negativamente sua imagem. O rerrefino é, conforme legislação brasileira, a única forma ambientalmente correta para destinação do OLUC, que recupera o óleo básico para ser utilizado como matéria-prima para fabricação de novos produtos da cadeia, em conformidade com os princípios da economia circular. O objetivo deste trabalho é realizar um diagnóstico da logística reversa do óleo lubrificante e sua cadeia de valor, com o intuito de gerar oportunidades de negócios e impulsionar a sustentabilidade. As análises preliminares mostram a necessidade de abordar a falta de conhecimento sobre o tema em questão. Assim, é crucial que a indústria de óleo lubrificante e as autoridades competentes trabalhem em conjunto para reforçar as práticas implementadas de logística reversa no Brasil, a fim de garantir um futuro sustentável para a mobilidade no país, promovendo o uso responsável dos recursos naturais e a proteção do meio ambiente.

INTRODUCTION

Climate change, the circular economy, net-zero carbon emissions, and sustainability have put pressure on governments and companies to reduce their reliance on petroleum derivatives. However, the lubricant market continues to rely on petroleum derivatives as a production input, resulting in the generation of used lubricant oil and

packaging waste. As such, companies in this sector must commit to sustainable practices and conduct a diagnostic of the circularity of each link in their value chain. This analysis will enable them to identify opportunities for innovation, develop better processes, products, and services, and expand their value proposition while capturing lost and unrealized values for all stakeholders [1].

UCLO improper disposal can lead to severe environmental damage. For instance, discarding used lubricant oil into soil can cause infertility, while illegal collection (as depicted in Figure 1) can result in UCLO being used as fuel for burning, leading to air pollution due to the emission of harmful compounds such as heavy metals that can cause toxicity and harm human health. The burning of UCLO produces 7.1 times more greenhouse gases compared to re-refine process [2]. The reverse logistics of UCLO is mandated by Brazilian legislation, and it is crucial to achieve the targets that drive all stages, from collection and storage to the re-refining process.

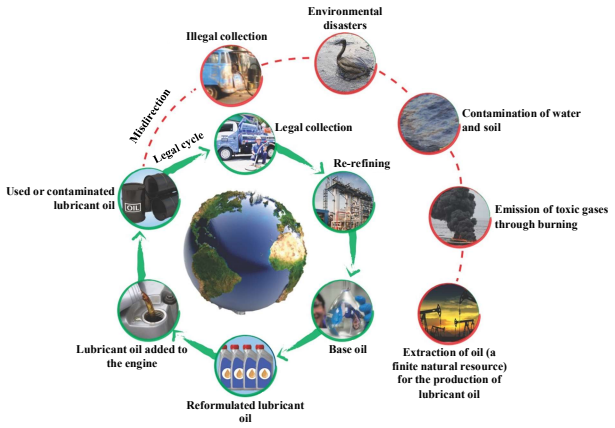

Figure 1. Life cycle of used or contaminated lubricant oil [2].

This study aims to contribute to the fortification of sustainable strategies in the lubricant oil sector, paving the way for more responsible and conscious waste management practices.

LUBRICANT OIL AND ITS PACKAGING

LO main function is to reduce friction between metal surfaces, protecting them from wear and removing contaminants from the engine. Additionally, they act as cleaning agents and anticorrosives. In the industry, LOs are widely used to minimize wear between parts, forming a thin oil film that separates the metal surfaces. This not only improves the efficiency of equipment and machinery, but also helps prolong their lifespan [3, 4].

Brazil is the world's sixth-largest lubricants market, consuming more than 1 billion liters of lubricant oil each year [5, 6]. Consequently, Brazil is also the sixth-largest generator of UCLO [7]. Lubricants (Figure 2) are a blend of base oils (mineral, synthetic, and/or semi-synthetic) and additives (antioxidants, anti-foaming agents, pour point depressants, dyes, viscosity index improvers, anticorrosives, detergents, dispersants, alkaline reserve, antiwear, friction modifiers, and/or extreme pressure agents) [8]. This blend is formulated to meet the demands of the intended field of use. In Brazil, all LOs must comply with the technical specifications established by ANP and be registered with this agency [9, 10].

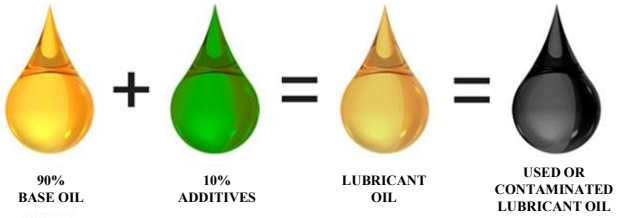

Figure 2. Production by blending lubricant oil [2].

Automotive use accounts for 60% of the national consumption of lubricant oils, while industries use them in hydraulic systems, stationary engines, turbines, cutting tools, among others [11]. Once the LO has fulfilled its function, it loses its optimal properties and is considered hazardous waste, posing a risk to both human health and the environment. UCLO is mainly composed of polycyclic aromatic hydrocarbons, organic acids, heavy metals, and dioxins [12], which can cause irreversible environmental damage if improperly disposed of. For example, spilling just 1 liter of UCLO can contaminate 1 million liters of water.

The packaging of lubricants comes in various forms to cater to different consumption rates and storage facilities. The most commonly used types include plastic containers (0.5, 1 and 3 liters), metal pails (20 liters), metal drums (200 liters), intermediate bulk containers (IBCs) (1,000 liters) and bulk tanks. Therefore, it is crucial to note that both the lubricant oil and its packaging are recyclable.

Each country or region defines the legal destination for this waste based on the different forms of treatment they can receive. Depending on the composition of UCLO, these wastes can have various destinations such as disposal (by incineration), recycling, and reprocessing [13]. In Brazil, the re-refining process is defined as the only method for the final disposal and minimization of used oil [14].

The lubricant market in Brazil saw a 3.8% increase in the first quarter of this year compared to the same period in 2022, which was a year of decreased volume [15]. The most significant increases were in the lubricant segments for diesel engines, Otto cycle engines, and transmission and hydraulic oils. The first quarter of 2023 ended with a volume of 364,847 cubic meters (m^3) of lubricants sold,

with fierce competition for leadership among the three main companies in the sector - Vibra Energia, Moove, and Iconic [15].

Table 1. Method of base oil supply in the Brazilian market for lubricant oil production [15].

Supply Method	Base Oil	
	%	m^3
Refining	34.0%	131,108
Re-refining	26.6%	102,500
Importation	39.4%	152,315

The base oils market (Table 1) moved a volume of 385,923 m^3, with imports totaling 152,315 m^3, production in refineries 131,108 m^3, and the re-refining industry placing a volume of 102,500 m^3 in the market [15]. Brazilian petroleum is poor in base oil, representing only 2 to 3% of the total volume (Figure 3), according to data from the Interstate Union of Lubricant Trade [16]. More than 50% of lubricant oil consumed in Brazil was returned via reverse logistics for re-refining in 2022 [17] and the sector rely on strong regulated system that is represented by AMBIOLUC. Regarding packaging, there is already a national sectoral agreement with a formal reverse logistics system through the Jogue Limpo Institute; however, its activities are mainly focused on plastic packaging.

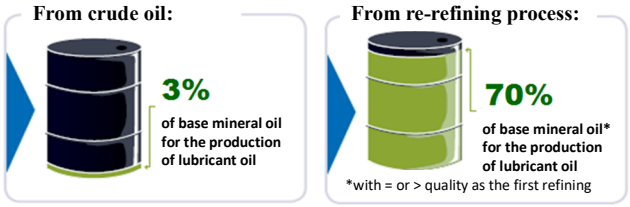

Figure 3. Production of base oil [2].

Note: The yield from re-refining varies according to the process used. In this case, the yield refers to the hydrotreatment process.

REVERSE LOGISTICS OF LUBRICANT OIL AND ITS PACKAGING

Reverse logistics is characterized as a process of returning post-sale and post-consumer goods back into the production cycle, through reverse distribution channels, in order to add value of various natures, such as economic, environmental, legal, and logistical [18].

The reverse logistics practice is also motivated by regulatory aspects, with special attention to the National Solid Waste Policy (PNRS), in Brazil [19], which defines it as "an instrument of economic and social development characterized by a set of actions, procedures, and means aimed at enabling the collection and restitution of solid waste to the business sector, for reuse in its cycle or in other production cycles, or for other environmentally appropriate final disposal". However, companies are increasingly motivated to seek sustainable competitive advantage in the reverse logistics sector. Figure 4 shows a visual scheme of direct reverse logistics [19, 20].

Figure 4. Framework for reverse logistics [21].

The reverse logistics process involves a set of activities in a branch for the collection, separation, storage, and transportation of materials to locations where they will be reprocessed, resold, or disposed of and can be classified as post-sale or post-consumer. Post-consumer reverse logistics operates on goods that have been or would have been discarded by society after consumption, returning to the business or production cycle through specific reverse distribution channels, including the reverse logistics system for UCLO [18].

LUBRICANT OIL – Throughout its use, lubricating oil undergoes processes of oxidation, thermal degradation, mechanical wear, water contamination, and chemical depletion of additives. Once it loses its efficiency, the oil must be replaced, generating UCLO as waste, which contains a series of contaminants derived from its use, such as paraffins, organic and inorganic acids, water, light hydrocarbons, highly toxic degraded additive residues, heavy metal particles, among others. Therefore, in Brazil, UCLO is classified as Hazardous Waste Class I by NBR 10,004 of the Brazilian Association of Technical Standards [22-24].

UCLO has a composition of 80 to 85% of base oil, which can be recovered through the re-refining process. Thus, the Brazilian energy policy prioritized the strengthening of the sector, as well as the development of a reverse logistics system for this post-consumer waste, with considerable potential for supplying base oils to the domestic market [13, 23].

Brazilian legislation on reverse logistics of UCLO – In legal terms, the national reverse logistics system for UCLO is fully structured in Brazil. Brazilian regulations have ensured the exponential increase in the collection of

UCLO throughout the country and the production of re-refined base oils, playing an important role in supplying the domestic market with its derivatives. The regulations currently in force are:

1. Petroleum Law No. 9,478/1997;

2. Confaz ICMS Agreement 03/1990, 38/2000 and updates, which deal with the exemption of ICMS on the circulation of UCLO and the operationalization of the tax system;

3. CONAMA Resolution No. 362/2005 [14];

4. National Agency of Petroleum, Natural Gas, and Biofuels (ANP) Resolutions No. 18, 19, and 20 of 2009 [25-27];

5. National Solid Waste Policy No. 12,305/2010 [19] and Federal Decree Regulation No. 10,936/2022;

6. MMA/MME Interministerial Ordinance No. 475/2019 [28].

CONAMA Resolution No. 362/2005 [14] represents the regulatory milestone of the sector, with significant determinations for the analysis of the market and the national panorama of reverse logistics for lubricating oil. This regulation establishes that the burning of UCLO (use as fuel) is prohibited, considering that the product's function is to lubricate and not to generate energy, especially given the high environmental impact with the emission of greenhouse gases (GHGs), chemicals, and heavy metals generated by combustion.

It is stated that all UCLO must be collected and have environmentally adequate final disposal, which is recycling through re-refining. The producer and importer of finished lubricating oil must collect or ensure the collection and provide the final destination for UCLO. In addition, the obligations of the producer, importer, dealer, generator, collector, and re-refiners are established in [14], and the measures to be adopted by each participant in the chain are determined.

The Ministries of Environment and Mines and Energy, in a joint normative act, establish progressive targets for the collection of UCLO, proportionally to the volume of lubricating oil inserted in the market annually, which integrates the base calculation to be collected, according to Article 10 of [14]. Currently, the goals are established by MMA/MME Interministerial Ordinance No. 475/2019 [28], published quadrennially since 2007, according to Table 2. According to [28], additional collection is allowed in any region to meet the target for Brazil. It should be noted that the volumes collected must be accounted for in the same year in which the collection was effectively carried out.

Table 2. Minimum UCLO collection percentages [28].

Region	**Year**			
	2020	2021	2022	2023
Northeast	37.0 %	38.0 %	39.0 %	40.0 %
North	37.0 %	38.0 %	39.0 %	40.0 %
Midwest	38.0 %	39.0 %	39.0 %	40.0 %
Southeast	45.0 %	48.0 %	50.0 %	52.0 %
South	42.0 %	45.0 %	48.0 %	50.0 %
Total	42.0 %	44.0 %	45.5 %	47.5 %

As a petroleum-derived product, all actors involved in the chain must be regulated by the National Agency of Petroleum, Natural Gas and Biofuels (ANP), and compliance with collection targets is monitored by the Brazilian Institute of Environment and Renewable Natural Resources (IBAMA) and ANP.

AMBIOLUC, the main sector association representing re-refining companies and facilitating nationwide legal collection, has successfully collected over 567 million liters of used lube oil in 2022 alone. This remarkable achievement accounts for 55.31% of the total collection within the regulated sector [2].

Reverse logistics system of lubricant oil in Brazil – The National Solid Waste Policy [19] establishes the reverse logistics of UCLO, in which the only environmentally correct destination is re-refining, according to Brazilian legislation. This destination contributes to the rational waste use, as well as meeting the principles of recyclability, circular economy, and environmental quality, which reflects in shared, harmonious, and self-sustaining growth [14].

The regulatory framework consisting of federal, state, and municipal laws, including inter-ministerial ordinances, ANP Resolutions, and CONAMA Resolution No. 362/05, ensures a solid synergy for achieving environmental, economic, and social goals. The activity is, therefore, of interest to the community and of public utility. Producers and importers subsequently benefit from the acquisition of domestically produced base oil through re-refining, reducing the need for imports and avoiding direct and indirect pollution [14, 19].

Generators (industries, infrastructure segment, and retailers) must store UCLO in their own tanks as provided in ABNT NBR 12,235/1992 [29], a technical standard that deals with the storage of hazardous products. ANP authorized collectors are responsible for collecting the material at generator points, as well as for transportation, temporary storage, and shipment to re-refiners, which must also be authorized by ANP. At the time of collection, the

UCLO Collection Certificate (CCO) is issued, a fiscal document that accompanies the UCLO to temporary storage bases and/or directly to re-refining [25-27, 29].

For control and verification of the collection percentages established by [28], producers, importers, collectors, and re-refiners must report all movements involving UCLO monthly to ANP through the Product Movement Information System (SIMP). Annually, ANP sends a report on "compliance with UCLO collection targets" to IBAMA, which is equally responsible for controlling and verifying compliance with collection targets [14].

Therefore, it is noted that in Brazil, there is full utilization of the production chain for treating this waste, although it is currently necessary to resort the imports to supply the growing market needs. The cycle involves the legal collection of used oil, followed by re-refining, which return the base oil, a raw material for reformulated lubricant oil, to this production chain. When the oil is used, the UCLO enters the cycle again, thus creating a circular economy sector. On the other hand, the diversion of oil by illegal collection, burning, and improper disposal generates water and soil contamination, emission of toxic gases, and drives the dependence on the base oil import and extraction for lubricating oil production [13]. Figure 5 illustrates a schematic summary of the UCLO reverse logistics system.

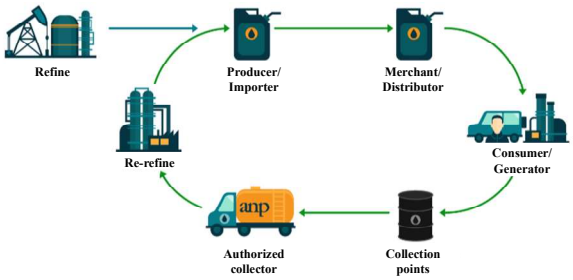

Figure 5. Lubricant oil reverse logistics cycle [2].

PACKAGING – At the same time, lubricant packaging, once used, is also classified as hazardous waste and its reverse logistics is regulated by the National Solid Waste Policy (PNRS) in Brazil [19]. This is operationalized through a sectoral agreement financed by producers who promote its recycling. According to the PNRS, established by Federal Law 12,305/2010 (article 3, item XII), manufacturers, importers, distributors, and retailers are required to implement reverse logistics systems for their products after consumer use.

A company that adopts an appropriate reverse logistics system prioritizes the circular economy over the traditional (linear) economy, promoting a behavioral change with obvious benefits for the environment and society. The reverse logistic system for plastic packaging of lubricating oils is carried out by logistics operators who work at receiving centers and through trucks that perform the routing process. Waste is received from generators through itinerant visits or deliveries at the centers where segregation and environmentally appropriate disposal are carried out. Improperly disposed used plastic lubricant packaging can have negative impacts on flora and fauna, soil contamination, surface and groundwater contamination, and difficulties in biodegradation, taking hundreds of years to degrade in nature.

In Brazil, the packaging sector generates a significant amount of waste that has a significant impact on the environment and can influence the costs of an organization, making a company more or less competitive based on the management of these assets [30].

Proper disposal of the packaging in which lubricant oil is stored, is crucial because it is a petroleum-derived product that is not compatible with human health. In 2005, the Jogue Limpo Institute began collecting lubricating oil plastic packaging in Rio Grande do Sul, and today it operates in 21 states plus the federal district (Table 3). In 2022, the institute collected 5,495 tons of plastics, which is equivalent to 109,882,700 packaging units, and successfully recycled 5,251 tons of it. There are 24 centers that receive the packages collected daily by 86 trucks that visit points where the consumer exchanges the oil, such as gas stations, workshops, and dealerships. In addition, there are 318 voluntary delivery points (VDPs) in operation. The goal this year is to recycle 5,315 tons of plastic [31].

Table 3. Results of the reverse logistics agreement for lubricant oil packaging in 2022 [31].

Item	Unit	Result Achieved
Coverage	States + Federal District	22
Municipalities served	#	4,394
Environmentally correct disposal	Total plastic (tons)	5,251
	% of volume placed on the market	23.5
Implementation of new voluntary delivery points	#	51
Campaign collections	#	46

After being collected, the material is separated by color and type of plastic. 97% of the packages are destined for recycling and can be transformed into products such as truck bumpers, new lubricating oil packaging, and plastic bags, for example. However, plastic cannot be transformed into products related to personal hygiene, toys, or food products, according to the rules of the National Health Surveillance Agency (Anvisa). The remaining 1.5% is co-

processed in the cement industry, and 1.5% is sent to the landfill [32].

In conclusion, reverse logistics and the circular economy bring many benefits to companies, society, and the environment. With awareness and proper management, it is possible to advance and close this cycle, learning to refuse, reflect, reduce, reuse, and recycle.

RE-REFINING LUBRICANT OIL VALUE CHAIN

Re-refining is a technique used in lubricating oils that have already been used and are degraded or contaminated. That process is capable of separating the worn-out additives from the base oil, which does not deteriorate over time, transforming it into a new, high-quality product, ready to be inserted in the production chain of lubricants, such as automotive and industrial. This process encompasses several steps, which include thermal and chemical treatment of UCLO, with the aim of eliminating impurities and compounds that are harmful to its effectiveness. The re-refining process begins with the elimination of impurities, such as solid particles and water, through filtration and atmospheric distillation procedures. Then, the fractional distillation of the UCLO is carried out, resulting in fractions with different physical and chemical properties [33].

After these phases of physical separation of contaminants, the fractions with a higher concentration of hydrocarbons proceed to the finishing stage, as illustrated in Figure 6. In Brazil, there are two main routes used in re-refining: acid/clay and hydro-treatment. The acid/clay route utilizes a method developed by Bernd Meinken in Germany [34], but it is currently widely considered outdated and environmentally unsafe. This is due to the large amount of acid residue generated during the process, known as acid sludge. The hydrotreatment route employs catalysts and hydrogen under conditions of high pressure and temperature to remove molecular impurities and undesirable compounds, such as sulfur, nitrogen, and metals [35].

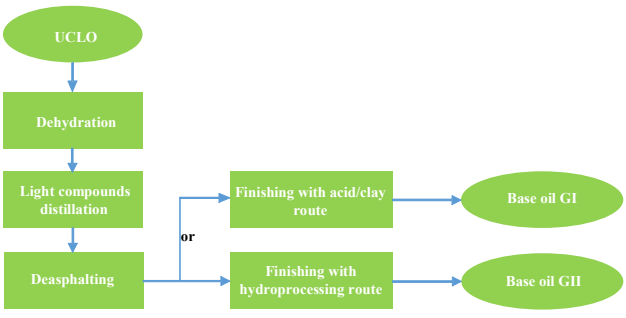

Figure 6. Flowchart of the re-refining process with the two most common routes.

The product obtained through the re-refining process of used lubricating oil is mineral base oil, which is derived from the distillation of crude oil in a refinery. This oil consists of long chains of saturated and unsaturated hydrocarbons and is known for its thermal stability and oxidation resistance [13]. As there are more than one technology to obtain base oils through refining and re-refining, some of these processes are more advanced and technological, resulting in higher-quality products. The classification of base oils according to ANP Resolution 911/2022 [36] depends on three properties: saturate content, sulfur content, and viscosity index. Groups I, II, and III are classified as mineral oils, by ANP 911, while Groups IV and V are synthetic oils [36, 37].

For the lubricant chain, the base oil obtained through the re-refining process serves as an input along with lubricant additives, which together formulate the finished mineral lubricant oil. Additives have the ability to improve the characteristics of the base oil, such as its antioxidant and antiwear property, increased viscosity index, and reduced pour point. Additionally, additives can introduce new properties such as high-pressure resistance and improved detergent and dispersant capabilities [38-40].

It is important to note that the re-refining process not only yields base oil production but also generates other co-products that are utilized as raw materials in different industrial sectors. For example, the asphalt fraction of the oil, is used as a plasticizer in petroleum-derived products in the waterproofing industry, and the light fractions are used to generate heat within the company itself. Thus, re-refining not only contributes to base oil production but also maximizes the utilization of co-products, promoting sustainability and waste reduction [41].

The residues resulting from the re-refining process of UCLO through the acid-clay method are mainly composed of the clay used in the bleaching step and the acids used in the acid refining step, among the residues resulting from this route, clay used is generally considered a solid waste and is disposed of as such. As for the hydrotreatment process, the only residue generated is the used catalysts, which are directed to companies that capture the metals that compose them. With regard to the effluents produced during the re-refining process, regardless of the route, they pass through a treatment system, the effluents are sent to a primary treatment, which separates the water from the oil. In turn, the water resulting from the primary treatment is sent to an effluent treatment station, where a biological process takes place with the aim of degrading the pollutants present in the effluent.[41].

RE-REFINING MARKET IN BRAZIL – Re-refining in Brazil is a consolidated and regulated market that contributes both to the economy by providing base oil for various industries, especially the lubricant industry, and to

the environment by removing a potential contaminant from nature through legal collection of UCLO, which is the exclusive raw material for the process. Currently, there are 28 companies licensed by the ANP for UCLO collection and 14 companies engaged in the re-refining process, with some operating in both businesses. Therefore, in 2022, the domestic market was supplied with 366 m³ of re-refining derived base oils, representing 41% of the total production volume, with 54% being Group I (GI) and 46% being Group II (GII), as shown in Figure 7 [42].

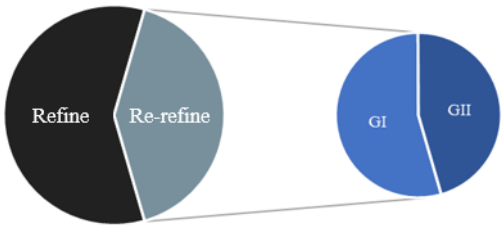

Figure 7. Production of base oil in Brazil in 2022.

Regarding UCLO collection, as discussed in the legal section of this article, Brazil has one of the most up-to-date legislations, regulating the used oil market and establishing official guidelines to prevent illegal practices such as diversion for burning and landfills, unauthorized collection by ANP, and oil adulteration. In terms of the re-refining process, the two routes mentioned earlier are employed: acid/clay, capable of producing Group I base oil, and hydroprocessing, which currently only one re-refinery has the technology for and supplies the local market with Group II base oil, accounting for approximately 30% of the total demand (Figure 8). Other re-refineries, on the other hand, are capable of producing Group I base oil.

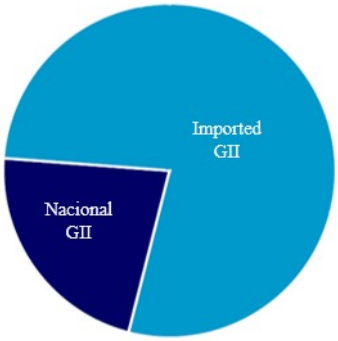

Figure 8. Supply of Group II/II+ Base Oil in Brazil in 2019 [43]

Group II base oils, along with Group III, are used in the formulation of finished lubricants that require higher performance, such as API CK-4 developed to meet the demands of new heavy-duty vehicle engines, which require lower emissions and increased fuel efficiency, or industrial lubricants that require higher energy efficiency. Meanwhile, Group I base oils are used on a larger scale to produce industrial and older automotive lubricants, which require a lower level of performance.

Brazil predominantly has a supply of Group I base oils from refineries and some re-refining industries. As for Group II, the domestic market is supplied by local production from re-refining, while the remaining volume is imported. Regarding Group III base oils, there is currently no industry in Brazil with the technology to produce this type of product, so the entire national demand is supplied through imports.

ANALYSIS OF REVERSE LOGISTICS OF LUBRICANT OIL AND ITS PACKAGING IN BRAZIL

Increasing circularity (Figure 9) means moving towards a circular economy where products and materials are reused, repurposed, and recycled, instead of a linear economy that follows a take-make-dispose model. This reduction in the consumption of virgin raw materials not only reduces waste but can also decrease the need to extract and process additional raw materials [1]. In addition to being the right thing for a responsible business, a focus on the circular economy and waste can bring opportunities to create business models, drive innovation, and supply customer expectations [44]. [45] shows that sustainability and environmental consciousness are high among Generation Z and Millennials, and 64% of respondents are willing to pay more for brands that are more sustainable.

Figure 9. Framework of the circular economy [46].

Therefore, a diagnosis of the value chain and working together with all partners are vital to help companies progress towards the ultimate goal. In Brazil and around the world, there are already institutions with movements focused on the circular economy, such as the World Business Council for Sustainable Development (WBCSD), Ellen MacArthur Foundation, Ethos Institute and UN Global Compact.

Aligned with the commitment to a sustainable market, companies maintain an Environmental Management System (EMS) certified by ISO 14,001, and one of the requirements of this system is the evaluation of the products life cycle assessment (LCA). Although LCA is related to reverse

logistics and circular economy, it does not define metrics and methods for measuring circularity actions and for these actions to be included in the value perception of the product chain. To ensure and standardize the assessment of LCA in the lubricant oil industry, the API has introduced a methodology and best practices for conducting LCA studies and evaluating the carbon footprints of products (CFP) [47].

LUBRICANT OIL – In the global market, Brazil is one of the countries that engages in the most re-refining of UCLO, a fact made possible only by two important pillars guaranteed by the federal government: normative construction, which developed a mature and well-structured reverse logistics system, and the categorical prohibition of the combustion of UCLO and its use as fuel, determining that the only environmentally appropriate destination is recycling, via re-refining.

In addition to contributing to the domestic supply policy, the re-refining industry plays an important role in environmental protection and decarbonization policies being developed in the country. According to data provided by [2], re-refining emits 7.1 times fewer GHGs than burning UCLO, according to LCA. Figure 10 shows a scheme of emissions, according to the study [2].

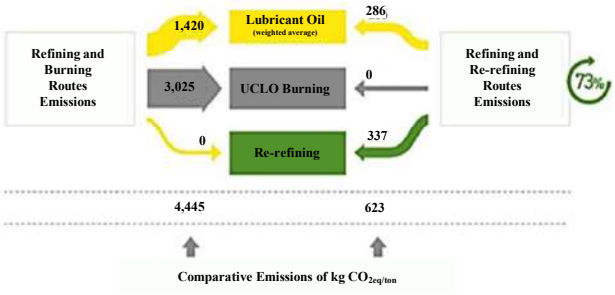

Figure 10. Comparative emissions between re-refining, refining, and burning routes of UCLO [2].

It is important to note that, according to the latest Intergovernmental Panel on Climate Change (IPCC) report, the AR6, which provides the most up-to-date information on the climate crisis and was released earlier this year in 2023, it is imperative to prevent and substitute the use of fossil fuels for energy generation in order to mitigate the rise in global temperatures. Fossil fuel consumption is recognized as the primary contributor to temperature escalation [48].

In 2022, a total of 1,436,419.33 m³ of finished lubricant oil was sold, of which 1,102,687.25 m³ accounted for the calculation base for UCLO collection. A total of 565,728.08 m³ of UCLO was properly collected, representing 51.3%, demonstrating that despite the country's vast geographical dimension with a territorial area of over 8.5 million km², comprising 5,568 municipalities, there is a complex and efficient network for UCLO collection and storage. According to ANP, in 2022, the collection network reached 77% of municipalities, as shown in Table 4 [42, 49].

Table 4. Percentage of municipalities with collection by region in 2022 [42].

Region	Municipalities with Collection
Midwest	87.15 %
Northeast	58.35 %
North	62.28 %
Southeast	87.00 %
South	94.81 %
Total	77.42 %

However, it is noted that despite the collected volume meeting the collection target set by MMA/MME [28], the oil that is not collected and properly disposed of by authorized agents can cause irreversible damage to the environment and human health, as well as represent a loss of base oil with potential for domestic market supply.

Despite the increasing attention given to reverse logistics and the solid and mature regulatory framework regarding UCLO, there are still challenges of various natures to full implementation.

The specific storage requirements for used oil and the uncertainty regarding its composition are barriers faced by UCLO collectors and re-refiners. An example is the mixing of UCLO with non-recyclable or biodegradable oils, chemicals, or even water when present in large quantities. Generators have the responsibility, as established by legislation, to safely collect UCLO in appropriate containers that are accessible for collection and to take measures to prevent mixing with other materials, which would make re-refining unfeasible [14].

Another challenge is that the effectiveness of enforcement has not kept pace with the regulatory maturity of used lubricant oil reverse logistics, and the efficiency of the system is directly impacted by the control of waste movement and disposal. [14] establishes that compliance monitoring and sanctions are the responsibility of IBAMA and the relevant state or municipal environmental agencies. However, other public agents should be more active in order to demand a compliance with the legal obligations of hazardous waste management. Thus, there is a need for better coverage of UCLO reverse logistics enforcement to reach a large number of points requiring inspection and to prevent the illegal disposal of this waste [20, 50].

Regarding enforcement, it should not be solely carried out by public agents but by all participants in the reverse logistics system, especially the generator. The generator has the responsibility to verify the legal documentation and the compliance of the collector and/or re-refiner to which the

UCLO will be sent, including the delivery of the OCC (oil collection certificate) by an agent duly authorized by ANP, with a publicly available list on the agency's website. Therefore, it is the responsibility of the federal environmental agency to co-manage the system and impose penalties for non-compliance with the established obligations. However, the concept of shared responsibility throughout the product life cycle extends the responsibility of all actors in the chain for the proper disposal of the waste.

Finally, it is extremely important to pay attention to the barriers faced by the sector due to the lack of awareness regarding the proper management of UCLO, which is related to the lack of environmental awareness and education regarding solid waste management in Brazil. It is necessary to expand knowledge among society regarding sustainable development, so that individuals can make responsible choices considering the environmental impacts of their actions. The lack of relevance in this issue hinders people from being active and fulfilling their role as drivers of the system [13, 20].

Improvement proposals for reverse logistics of the lubricant oil – Increasingly, lubricant oil market has the responsibility to influence the energy market, putting into practice their commitment to sustainability. Currently, it is common to see the advancement of ESG (Environmental, Social and Governance) agendas in line with the theme of energy transition. Based on the analysis of the information available in the process, it is possible to identify a series of improvements that can be implemented for the development of circularity.

Despite the regulatory advancements and robust implementation already achieved by the system, there is still much to be accomplished. The management UCLO must be increasingly participatory and shared. There are opportunities for improvement through the continuous dissemination of information and awareness among consumers and generators about the consequences of non-compliance with recycling regulations, for all sectors of the chain. It is necessary for the generator/polluter to monitor the UCLO destination, as they share responsibility for the waste, and there is a need to strengthen the training of environmental licensing agents and enforcement focal points.

The benefits for environmental conservation, economic growth, and social justice provided by the environmentally sound final disposal of the waste through re-refining are emphasized. The co-participation of all sectors involved is extremely positive, and there must be dialogue among all parties in the pursuit of continuously promoting reverse logistics practices and sustainable development.

Aligned with the principles of the circular economy, lubricant oil companies are increasingly exploring market opportunities and offering services to their B2B (business to business) customers, such as lubrication consultancy for the consumer market. These services can extend the product's lifespan. Another aspect is embracing sustainable procurement, which can enhance relationships with suppliers and benefit companies. The ISO 20,400 standard [51], Sustainable Procurement, provides guidelines for sustainable purchasing. It is the first international standard for sustainable procurement and aims to assist organizations in developing and implementing sustainable purchasing practices and policies. Sustainable procurement involves making purchasing decisions that meet an organization's needs while benefiting society and the environment. It ensures that a company's suppliers operate ethically, the products and services acquired are sustainable, and the purchasing decisions help address social, economic, and environmental issues. For example, using re-refined base oil in lubricant production results in a lower carbon product that meets the performance standards for various applications, such as passenger cars, heavy-duty trucks, transmissions, motorcycles, and large marine and stationary gas engines. By utilizing re-refined base oil, not only is the carbon footprint reduced from production to distribution of these finished lubricant products, but it also contributes to sustainability goals. Furthermore, investment in research and development (R&D) is crucial for extending the lifespan of products.

PACKAGING – Stimulating shared responsibility in the reverse logistics sector is a challenging task. Although the issue is addressed in the law and the sector agreement, there are still difficulties in its implementation. The execution is primarily concentrated among manufacturers and importers, while shared responsibility is lacking in other segments that also profit from the sale of lubricant oil. It is necessary to raise awareness among society about the importance of this topic. This process can aid in the implementation of the VDPs model, which still faces resistance from certain retail sectors. Another challenge is reducing the number of environmentally inefficient truck trips. Greater involvement from state and municipal environmental agencies is also needed to promote shared responsibility among all participants in these markets. These agencies should evaluate and facilitate a model that considers the activities of various waste management companies competing with the Jogue Limpo Institute for the collection and disposal of used plastic lubricant packaging towards the system's targets. In the case of plastic packaging, collection is often carried out by other collecting companies not affiliated with the Jogue Limpo Institute, and therefore, their efforts are not taken into account.

Improvement proposals for reverse logistics of the packaging – The bulk lubricant oil change service for end

consumers or B2B customers offers cost savings of up to 20% compared to the service provided with lubricants in traditional packaging. The change in packaging format does not compromise the product quality, as the technical specifications and quality are validated by the Lubricant Factory through regular testing and the use of security seals to ensure product quality for the customers. Furthermore, the implementation of fractionated bulk trucks would further reduce the service costs.

The incorporation of post-consumer resin (PCR) in plastic packaging closes the loop of reverse logistics, supporting the targets for incorporating recycled content by brand owners and the transition to a circular economy for plastics, while maintaining processability and performance equivalent to packaging made with 100% virgin resin.

Additionally, there is a need to establish a sectoral agreement for the reverse logistics of metal packaging, where we already have a successful program in Brazil managing the reverse logistics of steel packaging (PROLATA Recycling) that can be adapted to serve the lubricant oil sector.

To summarize the discussion carried out with the diagnosis of reverse logistics for lubricating oil and its packaging in Brazil, a SWOT matrix (Table 5) was applied, highlighting the strengths, opportunities, weaknesses, and threats [52] of the process. This enables the development of new strategies to enhance the process, resulting in improved resource management and strategic planning, which are crucial for enhancing the reverse logistics of lubricating oils.

Table 5. SWOT Analysis applied to reverse logistics of lubricating oil and its packaging [53, 54].

Strengths • Competitive advantage for the company • Positive influence on the company's image • Customer satisfaction • Reduction in expenses related to new packaging • Increased profitability • Reduction in reverse logistics costs
Weaknesses • Limited information exchange among supply chain partners • Lack of industrial symbiosis • Lack of strategic planning • Limited adoption of ecodesign • Financial focus rather than sustainability focus • Companies complying only with legal requirements
Opportunities • Environmental education • Environmental gains through waste mitigation • Flexibility to modify packaging due to legal requirements • Reduction of environmental impacts • Packaging recycling promoted by the supplier itself
Threats • Proper packaging and storage of used lubricating oil and packaging • General perception, not connected to reality, that recycled raw materials are of lower quality • Insufficient inspection of the reverse logistics system

CONCLUSION

The regulation of the lubricant market in Brazil is a global reference when it comes to the treatment of UCLO, which in our country can only be legally directed towards re-refining. Thus, the National Petroleum Agency (ANP) regulates and standardizes the market players and their responsibilities, while the Ministry of Environment and the Ministry of Mines and Energy establish increasing collection targets for these waste products.

The strategy to achieve circularity in lubricants and packaging can involve the adoption of the "sell and take-back for recycle" methodology in the business plan. In this business plan approach, the customer remains the owner until the manufacturer takes back the product for recycling with waste valorization.

The effective management of such a system entails ensuring its environmental sustainability as well as its efficacy, so that all stakeholders can also generate economic results. This is a crucial step towards the necessary transition to carbon neutrality and resource efficiency, as it promotes the development of more sustainable products and simultaneously facilitates the transition to a more resilient economy. Some key points that should be considered by companies in the lubricant oil sector are as follows:

1. Financing schemes for investments that enhance circularity;

2. Incentives for integrating sustainability criteria into business strategies;

3. Promotion of industrial symbiosis and new business models;

4. Encouragement of sustainable product design aiming to: (i) increase durability, reusability, and reparability of products; (ii) reduce the use of hazardous chemicals; (iii) decrease premature obsolescence; (iv) increase the content of secondary raw materials; (v) reduce the carbon footprint throughout the product life cycle; and (vi) improve overall energy and resource efficiency;

5. Reduction of packaging usage, especially plastics, through prevention measures and incentives for the production of reusable and recyclable packaging.

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