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REVERSE LOGISTICS CHAIN OF POST-CONSUMPTION AUTOMOTIVE TYRES IN TERESINA-PI

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ABSTRACT

Tyres are solid waste that requires proper disposal to avoid environmental and health damage or to not serve as breeding grounds for disease vectors such as Dengue, Chikungunya and Zika. Concerns with these types of materials motivated legislation such as CONAMA No. 416/2009, which prevents environmental degradation caused by unserviceable tyres and seeks the correct destination, and the National Solid Waste Policy, law 12305 which, by its validity, establishes the indispensability of the structuring and implementation of reverse logistics, besides bringing the shared responsibility of the production chain. Because of the concern with the post-consumption of tyres, as the environmentally correct disposal, it was sought to analyze how the reverse logistics of post-consumption automotive tyres occurs in the city of Teresina - PI, through field research in those involved in the chain, such as tyre repair shops, dealers, resellers, tyre retreaders and recycling company. Tyre retreading, besides being more economical for consumers and ecologically correct, is an alternative to post-consumption tyres that have the proper structure for retreading, also avoiding the use of litres of oil, as well as the release of CO2. In the three renovators visited in the city of Teresina, 91,560 litres of oil were not used monthly, with a non-release of 247,615.09 cubic meters of CO2 and the annual forecast of 1,098,720 litres of oil with 2,971,381.13 cubic meters of CO2 not being emitted.

Keywords: Reverse tire logistics; tire reform; tire recycling.

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1. INTRODUCTION

According to ANIP - National Association of the Tire Industry, in 2016 67,870.35 tyres were produced by category (in thousands of units) divided into cargo, pickup truck, ride, motorbike, agricultural, industrial and aircraft. In the third quarter of 2017, there was a growth in production of 9.4% when compared to the previous year, highlighting the production of passenger tyres with 12.4% and 14.5% for light commercial vehicles (ANIP, 2017).

The growth in tyre production coupled with the increase in the vehicle fleet justifies the concern with their post-consumption so that tyres can obtain environmentally appropriate disposal. According to IBGE data (2021), Brazil has about 211.2 million inhabitants with 107,948,371 vehicles registered by December 2020 (DENATRAN, 2021).

Unserviceable tyres, when discarded in nature, constitute a serious environmental problem, since they can cause both environmental damage and harm to people's health. With the introduction of the National Solid Waste Policy (2010), the responsibility was shared among manufacturers, importers, distributors, traders, citizens and the holders of management services for this waste in the Post-Consumption Reverse Logistics.

The practice of reverse logistics for unserviceable tyres understood as the reverse cycle from the point of consumption to the final disposal of these objects is a possible solution to avoid such problems (Sousa and Rodrigues, 2014). For Valle and Souza (2014), reverse logistics consists of the process of recovery of post-sale or post-consumption waste, collecting, performing pre-treatment, processing and distribution, with a view to destination to the production chain.

In 2016 the production of tyres moved the economy and in this sector, there were 24,200 direct jobs. The indirect ones were 115 thousand jobs and 38 thousand points (ANIP, 2016). The post-consumption of tyres also mobilizes the economy. According to the Brazilian Association of the Tyre Retreading Segment (2018), retreading is considered an economic, safe and environmentally friendly option.

In Brazil, tyre retreading does not enter the tyre recycling statistics (Lagarinhos et al., 2016). The appropriate destinations of tyres can be recycling and retreading. According to the Brazilian Association of the Retreading Segment (2016), in 2016 Brazil is ranked second in the world market in the sector, behind only the United States.

The tyre retreading segment is the way to avoid environmental problems, disease vectors and decrease the number of tyres thrown into the environment, since rubber, when thrown into nature, takes millions of years to decompose. Recycling is another aspect that can be used in the post-consumption of tyres, providing raw materials for the manufacture of other products and can serve as fuel.

According to the IBGE - Brazilian Institute of Statistical Geography (2021), the state of Piauí had a fleet of 1,196,192 vehicles in 2018. In the capital Teresina, this number is 492,946, representing 42.21% of the vehicles of the state. Given the importance of the fleet of the capital of the state of Piauí, as well as the Brazilian status as the second-largest country in the retirement sector, the need to know how the environmentally appropriate disposal of post-consumption automotive tyres occurs in the city of Teresina arises.

In this sense, this research aimed to analyze the reverse logistics chain of post-consumption automotive tyres in the city of Teresina and, therefore, it was made the mapping of the agents involved, in addition to the description of the reverse logistics process and, finally, it was proceeded to the evaluation of the agents' contribution to the reverse logistics chain of post-consumption automotive tyres in the city of Teresina.

Therefore, with the identification of the links involved, as well as their responsibilities, it becomes possible greater participation of society, since, with the perception of its role, it may contribute with a greater post-consumption automotive tyres destination at collection points, thus avoiding the improper disposal. As well as the collection points, which will dispose of a higher amount than that delivered either to the recycling company or to the tyre retread companies.

2. THEORETICAL FRAMEWORK

Post-consumption automotive tyres, when not intended for retreading or recycling, are more likely to be discarded in nature. ANIP (2017) estimates that 100 million tyres are abandoned in landfills, dumps, streams, lakes and rivers in Brazil, causing environmental impacts, serious public health problems and waste management. Such disposal becomes unfeasible, since "tyres have low compressibility, do not biodegrade and form bulky waste that takes up a lot of space. In addition, when buried they tend to rise and come out to the surface" (LAGARINHOS et al., 2016).

Through reverse logistics, which is an instrument of shared responsibility, establishing a strategy to collect, transport and disseminate knowledge to give an appropriate destination to the tyre no longer useful should be a constant practice in companies. Reverse logistics is focused on the equation of product return, giving an appropriate destination to them, to recapture economic, social and environmental value. This process is conducted to comply with the legal determination, in the provision of services to custom-

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ers, in the supply chain and to end customers using technical assistance (MELLO et al., 2016).

Lagarinhos (2011) studied the reverse logistics of used tyres in Brazil, from the point of collection to final disposal, assessing the current scenario and proposing changes on most systems implemented by manufacturers, importers, resellers and distributors and by pre-treatment companies. The study used, as a method, field research at collection points, pre-treatment companies, tyre repair shops, co-processing, sorting and selection companies, reformers and recyclers, associations that represent manufacturers and international entities that work with tyre recycling, to evaluate the models used and compare them with the system implemented in Brazil. After analysing the results, the research showed that the National Solid Waste Policy makes reverse logistics necessary as a means of applying shared responsibility for the product life cycle, whereby all those involved in the chain contribute towards minimizing solid waste volumes and the impacts caused to health.

Considering these aspects, this study presents some researches developed in the context of the waste tyres reverse logistics in the capital of the state of Piauí, such as the work of Nascimento (2014), who analyzed the quality control inserted in the planning of the waste tyres reverse logistics in Teresina - PI, which aimed to describe how the quality control is inserted into the planning of the waste tyres reverse logistics in the rubber industry in Teresina. This investigation has as the method field research, with an application of a semi-structured interview script in the rubber industry, because from it it was possible to map the reverse flow of unserviceable tyres. Thus, it was observed that it is necessary to verify the quality of the unserviceable tyres, once that these will be used in recycling to, later, be employed in rubber industries, in the manufacturing of types of cement and asphalt.

In this sense, the new tyre companies are looking for ways to reduce the emissions of pollutant gases resulting from the manufacture of tyres. Rhodia, a Solvay Group company, presented in June at the Pneu Show Congress (2018) how high-performance silica added to rubber compounds can reduce car fuel consumption by up to 7%, as well as carbon emissions into the atmosphere.

According to MinasPetro - the retail trade union for petroleum products in the state of Minas Gerais (2020), in 2019, 140 billion litres of fuel were sold in the Brazilian market. The volume represents an increase of 2.89% compared to 2018 when 136 billion litres were sold. Soon, allied to the growth of fuels, we have the emissions of pollutant gases, in the incomplete combustion of the carbides present in vehicle engines, releasing hydrocarbon vapours, as well as carbon monoxide from explosion engine vehicles, and nitrogen oxide.

Another example of a reverse logistics chain for tyres is the manufacturer Continental, which in the year 2014 presented the cultivation of dandelion as an alternative to traditional natural rubber, which is used in the tyre production process.

In the composition of tyres, as has been seen, natural and synthetic rubber are combined. Natural rubber is preferable to synthetic rubber since, according to Ministry of Agriculture data, a lower amount of energy is used in its production of 13 Gigajoules when compared to synthetic values which are 108 and 175 Gigajoules.

The concern with the emission of pollutants gases in the atmosphere, as well as the use of energy generated in units of the final disposal of solid waste, helped in the enforcement of the National Policy on Solid Waste (2010), encourages the use of plans for national, state and municipal solid waste, presenting gradual goals that reduce, reuse and recycle waste and rejects. It also aims at sharing the responsibility, promoting the use of waste, directed to its productive chain.

Figure 1 shows the structure of the tyre. By observing it, it is possible to have a better understanding of the items that constitute it. All items shown are of fundamental importance. According to ANIP - Associação Nacional de Indústrias de Pneus, the main items are the tread, which is the part of the tyre that comes into contact with the ground, the carcass and the bead that connects the tyre and makes the connection with the wheel.

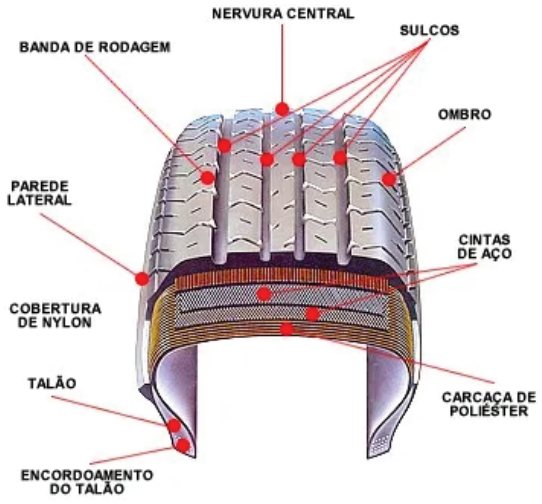

Figure 1. Tire structure.
Encordoamento do talão - Bead stringing

Talão – Slip
Cobertura de Nylon - Nylon Cover
Parede lateral – Lateral Wall
Banda de rodagem – Tread
Nervura central - Central Nerve
Sulcos – grooves
Ombro – Shoulder
Cintas de aço - steel strapping
Carcaça de poliéster - Polyester carcass

Source: Brazil Tires (2009).

According to Lagarinhos and Tenório (2008), post-consumer automotive tyres that have the tread presented grooves and protrusions, making it possible to adhere to the ground, can be reformed. The structure must also not be compromised by cuts and deformations.

According to INMETRO's (National Institute of Metrology, Standardization and Industrial Quality - INMETRO) Ordinance No. 444 of November 19, 2010, there are three types of tyre retreads: retreading, recapping and remoulding. In retreading, the rubber of the tread and shoulders is replaced; in recapping, the tread is changed, and in remoulding, the tread, shoulders and sidewalls are replaced, with the outside of the tyre being coated with a new layer of rubber.

The main means of transporting goods in Brazil is by road. Of the retreaded tyres, "75% are destined for road transport of cargo, 12% for handling own cargo and the remainder concerns the transport of passengers" (SILVA et al., 2010). According to ABR - Brazilian Association of the Tire Retreading Segment, tyre retreading "is the second or third cost in transport using commercial tyres (cargo)", it also states that "the retreaded tyre has mileage performance similar to the new one, with 73% lower cost to the consumer".

According to Souza and Oliveira (2014), in the period from 2005 to 2014 81.65 million truck/bus tyres and 61.5 million car tyres were reformed. A total of 5,200 million litres of oil were no longer used.

According to ABR - Brazilian Association of the Tire Retreading Segment (2016), in the retreading process, for each unit of tyre retreaded, a saving of 50 litres of oil is generated for a cargo tyre and 18 litres for a passenger tyre. Every year, about 7.6 million trucks and buses, 8 million cars, 2 million motorbikes, 300 thousand off-road and agricultural tyres are retreaded in the country. With 1,257 companies generating services, totalling about 5,000 micro and small companies aggregated.

Given the similar performance to new tyres, as well as the reduced price, retreaded tyres are an alternative for consumers whose tyres are not in good condition for use. They can be taken to a tyre renovation company for inspection, with a view to possible retreading. If they are not suitable for the process, they can be sent to a recycling company.

By performing the reverse cycle of the tyre, besides saving the final consumer money, the volume in litres of oil in its production is reduced, thus reducing the emission of pollutants released in this process, such as carbon dioxide, which is also an environmental gain.

3. METHODOLOGICAL PROCEDURES

For the application of the article, the formula presented in (1) was chosen, as proposed by Bolfarine and Bussab (2005), for the calculation of finite sample size.

$$n = \frac{NZ^2p(1-p)}{Z^2p(1-p)+e^2(N-1)} \quad (1)$$

Where:

n is the population of variables for the calculated sample;

N is the population;

Z, the standardised normal variable associated with the confidence level;

p, the true probability of the event;

e, the sampling error.

The population consists of 187 enterprises presented by the Teresina Municipal Zoonosis Center in 2016, and the research has a 95% confidence level and a 7% sampling error. Therefore, the sample value is 73 enterprises, which were divided into 27 tyre repair shops, 5 dealerships, 37 tyre resellers, 1 recycling company and 3 retreading/recapping companies.

With this study, it is possible to identify the reverse chain of post-consumption automotive tyres in the city of Teresina-PI, which is responsible for the representativeness of tyre disposal in the state of Piauí, 2.22% of the percentage/country in the year 2015, representing 28.24% of the total 7.86% of the Northeast region, occupying the first place, according to the data disclosed by the Report of Tires CONAMA Resolution No. 416/09 (IBAMA, 2016).

In conducting the exploratory research qualitative and quantitative procedures were used through the collection of numerical information on storage and collection capacity, production (reform), oil saved in the production of new tyres, CO2 emissions avoided in companies, through the observation of the reverse logistics system in some of the reverse chain agents located in Teresina.

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To collect information from research participants, three different interview scripts were used. The first script was applied at collection points to gather information about the identification of collectors, collection frequency, the existence of a storage place, description of the procedure for keeping, types and volume of tyres received, partnership with destination/disposal companies, knowledge of the National Policy for Solid Waste - PNRS, environmental risks and the risk of using the tyre beyond its life cycle.

The second interview script was applied to the retreading/recapping companies and sought to verify the regularity of the companies with the environmental agencies, the partnership with a destination/discarding company, volumes, destination locations and transportation of unserviceable tyres, the retreading/recapping process of post-consumption tyres, care for non-contamination, knowledge of the PNRS, criteria for recycling, compliance with INMETRO Ordinance No. 554 of 2015 (new requirements for tyre retreading), reused volume, difficulty in complying with the PNRS, verification of inspection, marks received.

The third interview script was applied to the recycling company and gathered information on the partnership established for the collection of tyres, the regularity with the environmental agencies, volumes, care, capacity and time limit for storage, processes performed at the collection point, whether storage follows the CONAMA/2009 legislation, final destination, destination of the recycling product, the amount paid by importers.

Data on tyres reformed monthly and annually in the companies was used so that it was possible to compare the reduction in litres of oil and the decrease in CO2 emissions when compared to the manufacture of new tyres. For the calculations, research was carried out on the website of the Brazilian Association of Retreading, (ABR) the number of litres in a barrel of oil, as well as the emission of cubic meters of carbon dioxide equivalent.

4. RESULTS

The collection points studied during this research consisted of dealerships, tyre repair shops and auto centres (tyre resellers) that offer the tyre exchange service requested by users of automotive vehicles. From these, information was collected on the volume of post-consumption tyres generated and the main parties responsible for the collection. Figure 2 describes the number of tyres generated by each type of collection point.

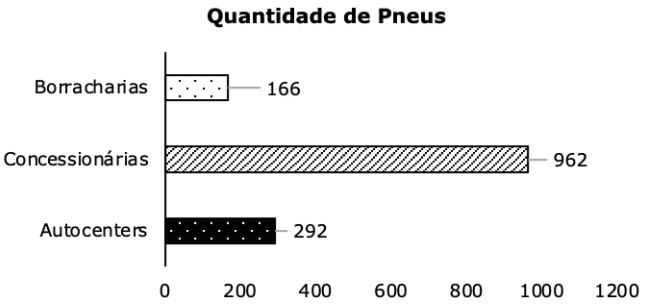
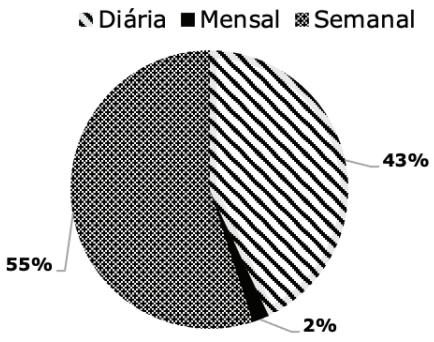


Figure 2. Monthly average of unserviceable tyres in tyre repair shops, dealerships and resellers.
tire-repair shops
dealers
autocenters
Source: The Author(s) (2018).

Knowing the volumes generated, it is important to know who is responsible for the collection of post-consumption tyres and the frequency with which the collection is performed. It was possible to identify three agents responsible for the collection, being them the City Hall of Teresina, through the Municipal Zoonoses Centre, which is in charge of the collection and handling of tyres to be destined to recycling companies, recycling companies that transform tyres into inputs for the manufacture of other products and other collectors that, according to the respondents, use the tyres to make handicrafts and also to be used in physical/sport training areas.

Thus, Figures 3(a) and 3(b) present the percentage frequency of collection mentioned by respondents.



Daily – montly – weekly
(a)

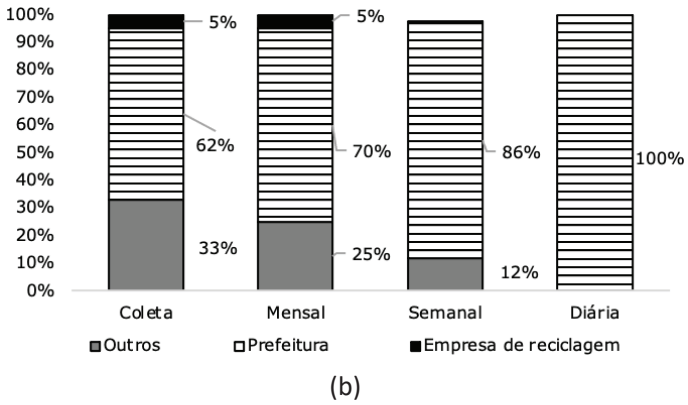


Figure 3. (a) and (b) Frequency of collection of the unserviceable tyres in the visited establishments.
Coleta – Collection
Mensal – montly
Semanal – weekly
Diária – daily
Outros – others
Prefeitura – City Hall
Empresa de reciclagem - Recycling company
Source: The Author(s) (2018).

The information presented in Figures 3(a) and (b) on the frequency of collection of tyres at collection points shows that most of the establishments surveyed have the collection performed weekly, with 55%, and daily, with 43%, which may indicate that during the period when tyres are under the responsibility of generators, the risk of environmental contamination and the possibility of tyres becoming breeding grounds for insects, such as the Aedes aegypti, is low. Respondents also reported that daily collections are performed by the City Hall of Teresina - PMT. It was also possible to obtain the information that the City Hall of Teresina has a partnership with the recycler, reinforcing the idea that in the city the reverse flow of tyres is done according to the provisions of Article 3 XII of PNRS, which deals with shared responsibility. Certainly, waste collected and managed by the Municipal Zoonoses Centre is adequately disposed of when forwarded to the recycling company. Finally, only 2% of the respondents affirmed that the collection is done every month.

The storage of unserviceable tyres is one of the requirements of CONAMA Resolution No. 416/09; therefore, in the visited establishments, the existence or not of a proper place for the storage of post-consumption tyres was addressed. From the total of visited generators, 66.1% presented a proper/covered place, against 33.9% that did not have one, storing the tyres in a space inside the shop. Figure 4 shows the records obtained from the tyre storage locations.

Figure 4. Storage observed in the waste generating agents.
Source: Author(s) (2018).

Respondents were asked about possible care taken with tyres stored in the period before collection: 95% take some care with tyres, such as covering them when they do not have a covered place, being stacked in a reserved place or a proper warehouse for tyres.

The waste generating agents were also asked about their knowledge regarding the importance of proper disposal of post-consumption tyres and the prevention of this waste

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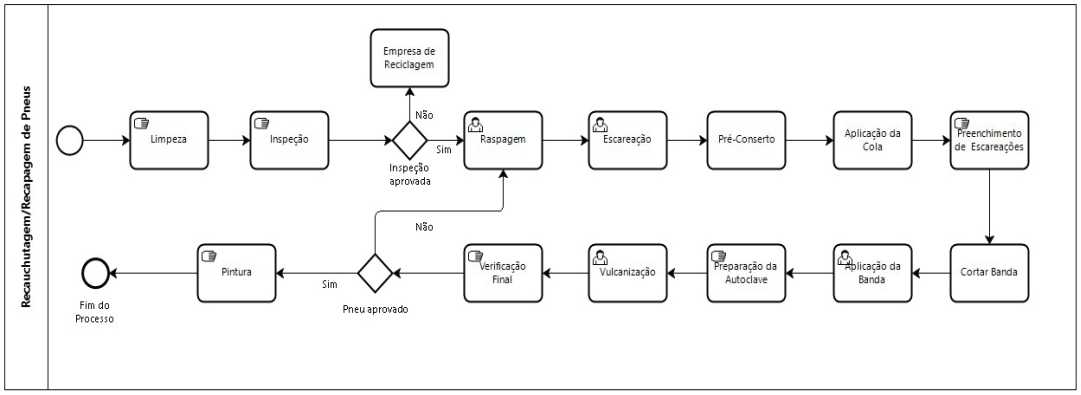

Figure 6. tyre retreading flow of the company visited A

Limpeza – Cleaning / Inspeção – inspection / Empresa de reciclagem - Recycling company / Não – No / Sim – Yes / Inspeção aprovada - Approved inspection / Raspagem – scraping / Escareação – reaming / pré-conserto – pre-repair / aplicação da cola - glue application / preenchimento de escareações - filling of countersinks / cortar banda – cut band / aplicação da banda - band application / preparação da autoclave – preparation of the autoclave / vulcanização – vulcanisation / verificação final - final verification / pneu aprovado - approved tyre / pintura – painting / fim do processo – process end

Source: The Author(s) (2018)

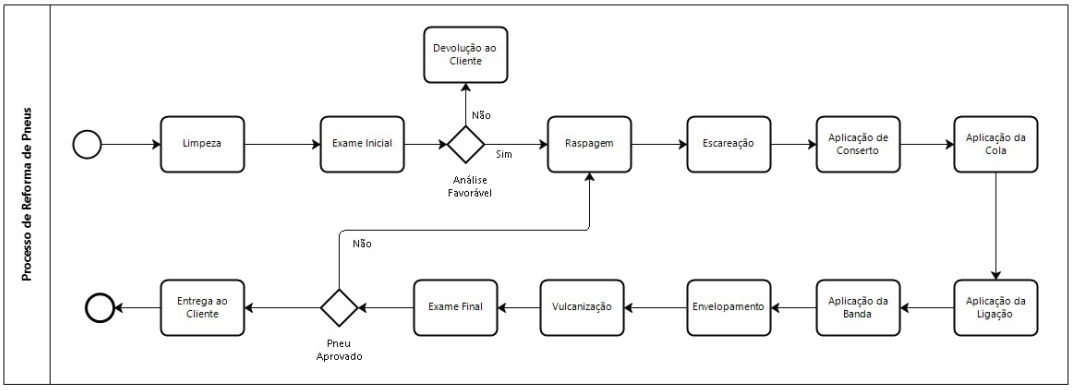

Figure 7. Tyre retreading flow of the visited company B

tyre reform process / limpeza – cleaning / exame inicial – initial exam / devolução ao cliente – customer return / não – no / sim – yes análise favorável - favourable assessment / raspagem – scraping / escareação – reaming / aplicação de conserto - repair application / aplicação de cola - glue application / aplicação da ligação - application of the link / aplicação da banda - band application / envelopamento – enveloping / vulcanização – vulcanisation / exame final – final exam / pneu aprovado – approved tyre / entrega ao cliente - customer delivery

Source: The Author(s) (2018)

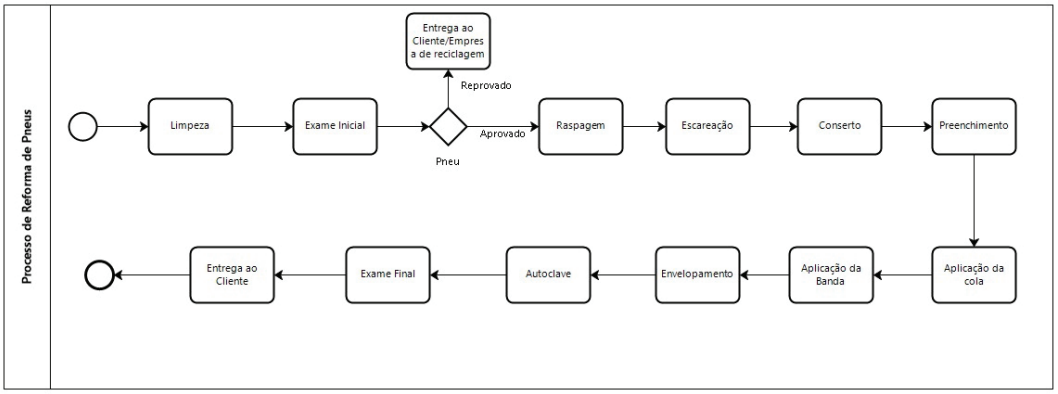

Figure 8. Tyre retreading flow of the company visited C

tyre reform process / limpeza – cleaning / exame inicial – initial exam / entrega ao cliente/empresa de reciclagem - delivery to the customer/recycling company / reprovado – failed / aprovado – approved / pneu - tyre / raspagem – scraping / escareação – reaming / conserto – repair / preenchimento - filling / aplicação de cola - glue application / aplicação da banda - band application / envelopamento – enveloping / autoclave / exame final – final exam / entrega ao cliente - customer delivery

Source: The Author(s) (2018).

from damaging the environment. They also answered about their knowledge regarding the risks of using tyres with worn grooves smaller than 1.6 mm offer to users, that is, at the end of the product's life cycle. The vast majority of agents answered these questions positively, as shown in Figure 5.

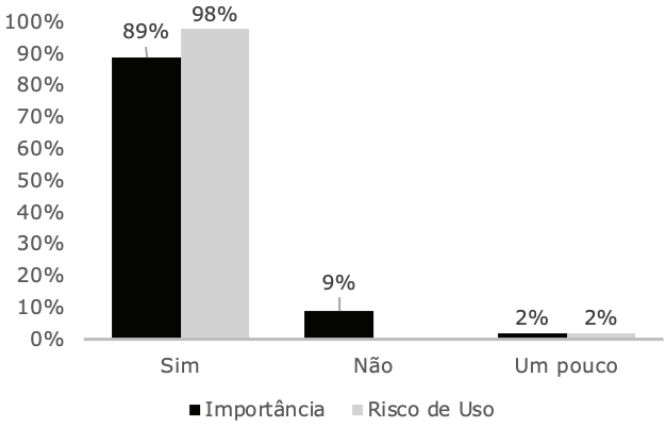

Figure 5. an understanding of the generating agents about their importance in the proper disposal and the risk of using the tyre at the end of the life cycle.
Yes – No – A little
Importance – Risk of Use
Source: The Author(s) (2018).

Without any prior treatment, the vast majority claimed to be aware of the risks. These data can be analysed in Figure 5. The visited establishments, as agents of the reverse chain of tyres, were asked about their knowledge of their role in the correct disposal, of the risks that tyres offer to nature when they are released without any prior treatment.

Almost all the tyres received are automotive tyres. When customers undergo an overhaul after exchanging for new ones, they can take the old ones to deliver them for proper disposal or pass the responsibility to the establishment for this purpose.

During field research at the three refurbishers in Teresina, the post-consumption automotive tyre reform process was evaluated. As can be seen in Figures 6, 7 and 8, which show the tyre retread flowcharts of companies 1, 2 and 3.

The first flowchart represents Company A, which works only with cargo tyres, identifying the stages of its retread process. Company A was the collection point registered by Reciclanip until 2016 and refurbishes 800 tyres per month.

The company receives post-consumption tyres from its customers, as well as those that are left at the auto centres. Afterwards, these will undergo inspection and, if not approved, as can be seen at the beginning of Flow 1, they are sent to the recycling company. Table 1 shows the stages, besides their respective functions.

Table 1. Activities of the tyre retreading process of Company A.

Activity	Função
Cleaning Process in which tyres undergo cleaning and drying to remove humidity, to better analyse the condition of the carcasses.	
Inspection	The operator inspects the post-consumption tyres to choose which carcasses are in conditions for reform or repair.
Scraping	At this stage, the rest of the previous rubber is removed, so that the carcass has the correct dimensions for the application of a new tread.
Reaming	The tyres are again cleaned and prepared for the damages that the carcasses suffered during their use. At this stage perforations and cuts are removed.
Pre-repair	At this stage, pre-consolidation is carried out to restore the affected areas to their original strength.
Glue application	The application of glue will join the new tread to the carcass.
Filling the countersinks	The countersinks are filled, as well as the preparation of the tread for the choice of designs, measures and widths specified by the scraping sector. The tread is then applied to the carcass.
Preparing the autoclave	This stage prepares the tyre for the autoclave which, in this company, has the capacity for 14 tyres.
Vulcanisation	Under temperature and pressure conditions, the components applied to the tyre casing are fused into a single body.
Tyre painting	At this stage, the tyre is painted to look new.
Final inspection	At this stage, the tyre undergoes a thorough analysis and, if it does not meet the company's requirements, it is sent to the recycling company.

Source: The Author(s) himself (2018).

The second flow presented in Flowchart 1 represents company B, which works with cargo and passenger tyres, as well as the tyre retreading process is carried out. The monthly production of retreaded tyres is about 220 passenger tyres and 880 cargo tyres. When comparing the first company with the second, several similarities are identified, the second differing in more modern machines at the same work stations. Given this information, Table 2 presents what differs in the second company.

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Table 2. Activities of the tyre retreading process of Company B.

Activity	Função
Cleaning	At this stage, the tyre is cleaned. The tyre is brushed with a rotating steel brush and then vacuumed. All this process is necessary for a better view of the tyre's state of conservation.
Bonding application	The stage includes the automatic application of the bonding rubber using a machine that eliminates the use of glue in the process, making the quality standard independent of the operator and offering Piauí products the same quality technology used in Europe and the USA.
Enveloping	This is the process of preparation for the autoclave, using a machine to wrap the tyre and then, with the help of a second machine, remove the air present.

Source: The Author(s) (2018).

Company B also returns the tyre to the owner if it does not pass the quality standard that is required. Company B has the INMETRO certification label, guaranteeing the quality of the product.

Company C visited was a small-sized renovation company that receives tyres of any brand and works with tyres from rim 16 to 22. The tyre retreading process is similar to the others mentioned. After the initial examination, if the tyre is rejected, it is either returned to the customer or sent to a recycling company, if it is left at the renovation company anyway. Its monthly production of retreaded tyres is around 200.

Company C works with a boiler, an autoclave with a capacity for nine tyres and more than five matrixes. When applying the glue, a brush is used on the tyre and then the tread is placed. Then the tyre goes to the enveloping and finally to the autoclave. Differently from the other renovation companies visited, if the tyre does not pass the second test, it will not go through the process again: it will be delivered to the customer and he will be informed that in the quality process carried out by the company, the tyre was not approved.

It takes one day from the moment the customer hands over the tyre until it is returned. The residues found in the production process are sent to the recycling company, the tyre powder and the unserviceable ones.

As observed in Flowchart 1, if the tyre is considered unserviceable, it will be directed from the retreading/recoating company to the recycling company. The automotive tyre recycling company in Teresina has partnerships with Reciclanip, with ABIDIP - the non-release of, with the City Hall of Campo Maior and private companies.

The recycling company has the CTF - Federal Technical Registry of IBAMA - Brazilian Institute of Environment and Renewable Natural Resources, which informs the number of tyres collected, the places where they were collected, whether individuals or companies and the destination of unserviceable tyres. The recycling company issues the destination balance to the legal entities that need to give an environmentally adequate destination to the tyres and receives the tyres from Reciclanip's partner brands: Bridgestone, Goodyear, Michelin, Pirelli and Continental.

There is a partnership between the recycling company visited and the City Hall of Teresina for 10 years. The company receives and processes the unserviceable tyres giving an environmentally appropriate destination, also participates in campaigns against *Aedes aegypti* in partnership with the City Hall of Teresina.

The company has two units: the first eco point unit, a place for the delivery and temporary storage of unserviceable tyres, located at Avenida Henry Wall de Carvalho, and receives on average 500 to 600 tyres daily and has a storage capacity of 3000 to 3500 tyres. The second unit has a capacity of 10,000 tyres. When the maximum capacity of the units is reached, Reciclanip is called to remove the excess tyres, using the recycling company CBL, located in Feira de Santana, Bahia.

The tyres that are received at the company are selected by categories, taking into consideration the type of rim, the classification into radial or diagonal tyres, of cars, motorbikes or trucks. The recycling company adopts four types of reuse of the tyres received: granulation, lamination, crushing and tyre artefacts.

The tyres selected for granulation are those of trucks or trailers, which have more rubber; one of the destinations is a company of sports and recreational material in Teresina. The lamination uses common tyres, which undergo the process of scraping and then cutting; they are received by a spring mattress and furniture industry, also in Teresina. Granulation and lamination take place in the second unit.

In the crushing process, the passenger car tyres initially undergo a visual inspection, then they go to the four-axle crusher, in which there is no separation of the materials present in the tyres. The shredded tyres are co-processed at Votorantim, in Sobral, Ceará. The company has a truck to transport the crushed tyres.

The company does not make use of the other materials that make up the tyre, failing to use the metallic components, which could be separated before shredding and sold to local steel mills.

The investigated unit stores the tyres in covered locations, as indicated by CONAMA Legislation 416/2009. The period allowed for the unserviceable tyre to be stored in the recycling Company is one year.

Tyre artefacts, presented as the fourth recycling process, are made in Teresina, with a variety of objects, such as chairs and tables, which are two of the most common examples. At the visited unit there are such artefacts.

5. DISCUSSION

As seen, post-consumption automotive tyres that are collected in tyre repair shops, dealerships and resellers in the city of Teresina can be destined for retreading or recycling, depending on the conservation status and internal structure. The highest volume of post-consumption tyres collected was at dealerships, then auto-centres and, lastly, tyre repair shops, with the city hall being the most responsible for the collection, as well as the frequency of collection.

Tyres with adequate internal structure and tread showing grooves and protrusions can undergo the retreading process. According to ABR (2015), 50 litres of oil are saved during retreading for a cargo tyre and 18 litres for a passenger tyre. Given these values, Table 3 identifies the quantities of tyres reformed by each company visited, in addition to the savings in litres of oil that is no longer used in the manufacture of a new one.

Table 3. Tyres retreaded monthly in the visited companies.

Companies	Tyre Type	Monthly production	Litres of Oil
Company A	Load	800	40.000
Company B	Touring	220	3.960
Company B	Load	880	44.000
Company C	Tyre Type	200	3.600

Source: The Author(s) (2018).

As can be analyzed in Table 3, company A presents the monthly production of 800 reformed tyres, bringing to the environment a saving of 40,000 litres of oil. On the other hand, company B produces load and ride tyres, totalling 1100 and, therefore, saving 47,960 litres. Furthermore, Company C produces 200 tyres, between retreads and repairs, saving 3,600 litres of oil.

Together, the three renovation companies studied save 91,560 litres of oil per month, which are no longer used in the manufacturing of new tyres, acting in the post-consumption of tyres. Furthermore, around 2,100 retreaded tyres are returned to the market. Table 4 shows the results of the three companies considering the annual forecast.

Table 4. Production forecast of retreaded tyres annually in the companies visited.

Companies	Tyre Type	Annual Production	Litre of Oil
Company A	Load	9.600	480.000
Company B	Tour	2.640	47.520
	Load	10.560	528.000
Company C	Load	2.400	43.200

Source: The Author(s) (2018)

In the analysis of the results presented in Table 4, the three companies are identified, as well as the amount produced by the type of tyre reformed and the economy in litres of oil. Company A, with the annual production of 9,600 tyres and savings of 480,000 litres of oil, company B, with 13,200 tyres and 575,520 litres of oil saved and company C, with 2400 tyres and mitigation of 43,200 litres of oil. Therefore, the volumes in litres of oil saved in the tyre retreading process of the three companies total 1,098,720 litres annually.

According to ABR (2013), retreaded tyres save the emission of greenhouse gas (CO2) in nature, that is, each barrel contains 159 litres of oil and emits 430 cubic metres of carbon dioxide (ABNT; Petrobrás, 2014). In Table 5 the amount in cubic meters of CO2 that is not released into the atmosphere is calculated.

Applying the value in litres of oil saved monthly and annually by the volume per barrel, 91.560 barrels are identified in the month and 1.098.720 barrels of oil in the year. Then, it was multiplied by the value of 430 cubic meters, which is equivalent to 1 barrel, thus, the values of CO2 emissions that ceased to be released into nature are found.

Table 5. Prediction of litres of oil saved and CO2 in the production of retreaded tyres in the companies visited.

Period	Savings in litres of oil	Emission of CO2 (m3)
Monthly	91.560	247.615,09
Annual	1.098.720	2.971.381,13

Source: The Author(s) (2018).

As can be seen in Table 5, together with the saving of oil comes the reduction of CO2 in the atmosphere, that is, every month 247,615.09 m3 of CO2 would be saved, and on an annual basis, 2,971,381.13 m3 of CO2. In Brazil, according to

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ABR (2013), 1,630,000,000 m3 of CO2 are no longer released every year.

The sector also provides a turnover of around four billion reais a year, a total that comprises the tyre retread itself, the raw material and the equipment, in addition to helping in the collection of one billion reais in taxes (R$ 300 million/year of PIS and Cofins, R$ 500 million/year of ICMS, and R$ 200 million/year of ISS) (PNEWS, 2017).

When analyzing the process in the three retreading companies visited and in other companies in the market, such as Pneus Bahia, located in São José dos Campos - SP, it can be seen that local companies meet the market requirements, offer a quality product and the trend is that an improvement occurs.

Despite the benefits for both the environment and the consumer of reusing tyres, retreaders and retreaders face difficulties in complying with the PNRS and other laws, due to the lack of support required by the authorities. They face costs when sending unserviceable tyres to the recycling company, such as petrol costs, driver's costs, costs of storing tyres for the production process, among others.

The recycling company visited also faces setbacks with shopkeepers who want to sell the tyres and receive the environmentally correct disposal balance offered by the company, without taking into account the costs that it has as a private company.

In Brazil, there is AREBOP (National Association of Tire and Rubber Artifact Recycling Companies), which seeks to encourage, enable and organize this sector. Table 6 shows the number of national recycling companies that are part of the association, as well as the Brazilian regions where they are located.

Table 6: Recycling companies associated with AREBOP per Brazilian regions

Region	Number of Companies
South	5
Southeast	7
Northeast	1
Central-West	1

Source: AREBOP (2017).

Table 6 shows that the Southeast region has seven registered recycling companies. In the South of Brazil, there are five companies. The Centre-West and Northeast regions both have one tyre recycling company, for a total of fourteen associated companies.

The Brazilian Association of Importers and Distributors of Tires (ABIDIP) seeks partnerships of importers with recycling companies so that they can collect the tyres. The association has associated recycling companies in the states of Piauí, Rio Grande do Sul and Paraná.

According to ABIDIP (2018), importers must meet the collection target of 70% of all imported tyres, considering the deadline of 3 months from the import registration. Then, the importer pays the recycler for the tyres to be recycled and removed from the environment. It was also agreed with shopkeepers so that they become collection points for their customers and then direct the tyre to recycling points.

For greater cooperation between the links of the reverse logistics of unserviceable tyres, consumers, when exchanging an unserviceable for a new one, should they take the unserviceable tyre with them, must commit to delivering it to the collection point closest to the final destination, since if it is left at the establishment, the latter must give an environmentally correct destination, delivering it to the recycling company.

Given the presented reverse logistics structure in Teresina, Flowchart 2 presented the links involved in the chain. Just like City Hall's alliance with the Municipal Zoonosis Centre, which delivers post-consumption tyres to the recycling company, the latter also receives tyres from the company for retreading. Upon reaching maximum capacity, it directs Reciclanip to take the surplus.

Thus, it was possible to observe that the reverse logistics of post-consumption tyres in the city of Teresina is increasingly following an environmentally correct destination. Using Flowchart 2, the main disposal links of post-consumption tyres presented by the retreading/recapping companies with the remoulding of tyres and by the recycling company are visible. The city has a satisfactory reverse logistics structure for tyres. As seen, the links involved understand their roles in the chain.

However, it is necessary to increase the number of collection points, as well as the number of tyre recycling and renovation companies, since, with this growth in the links of the reverse logistics of tyres, it is possible to use a larger amount of tyres. Moreover, it is avoided that these do not follow a proper destination.

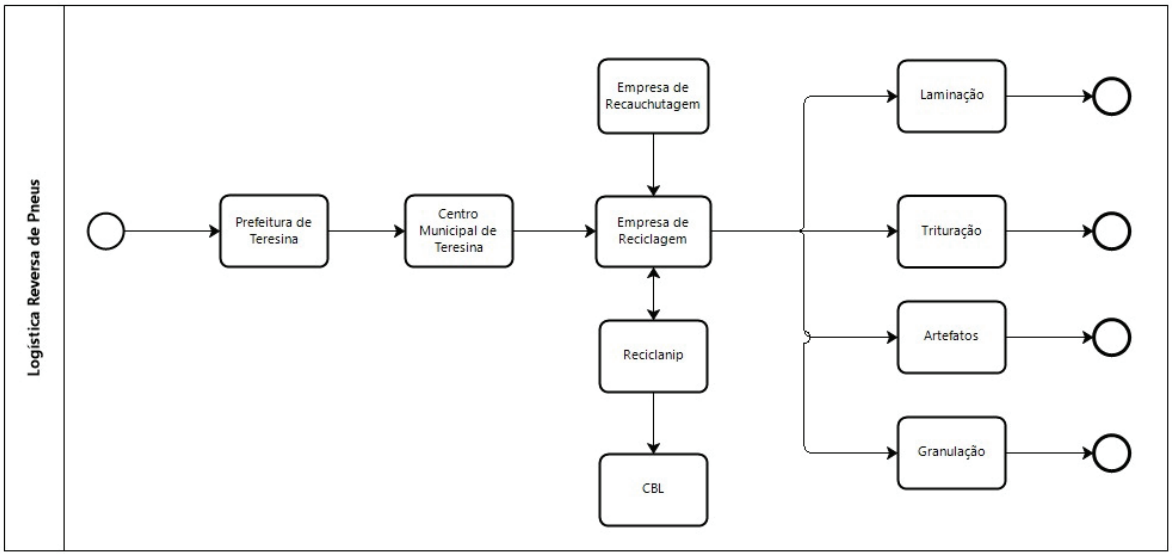

Figure 9. Reverse logistics in Teresina
reverse logistics for tyres / teresina city hall / teresina municipal centre / retreading company / recycling company / Reciclanip / CBL / Lamination / grinding / artifacts / granulation
Source: The Author(s) (2018).

6. CONCLUSION

Therefore, tyre retreading, besides being more economical for consumers and ecologically correct, since it is an alternative to post-consumption tyres that have the appropriate structure for retreading, also prevents the use of a larger volume of litres of oil, as well as mitigates the release of CO2 in nature.

Therefore, with the development of this market in the capital of Piauí, it is feasible the movement of the local economy, greater competition in this sector, the proper disposal and avoid that tyres are thrown into nature without any prior treatment or that they serve as breeders of diseases.

With the use of retreaded tyres on a larger scale, it will be possible to save on raw materials and reduce the emission of atmospheric pollutants. Through the action of the three renovators visited in the city of Teresina, 91,560 litres of oil ceased to be used monthly, 247,615.09 cubic meters of CO2 ceased to be released. The annual forecast is a saving of 1,098,720 litres of oil and 2,971,381.13 cubic metres of CO2 not being emitted.

In this way, retreading automotive tyres reduces the impact on nature and its resources. Retread companies contribute to the consumers who pay a lower price, comply with the laws in force, besides being a profitable business. Therefore, with more information on retread processes, tyre retreaders will help consumers to have an alternative to extend the useful life of post-consumption automotive tyres, at a low cost compared to the purchase of a new tyre.

For future research, an in-depth study of the reverse logistics chain of post-consumption automotive tyres in the state of Piauí is suggested, with the purpose of better understanding how the state performs the reverse chain and its integration with the Northeast region since Piauí is representative in the disposal of post-consumption tyres in the region.

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