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# End-of-Life Tire Management Model for the Ecuadorian Land Force

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**Summary**
The management of end-of-life tires (NFU) represents a critical challenge for environmental and operational sustainability in the Ecuadorian Land Force. This study addresses the problem by designing a management model based on principles of social responsibility and circular economy. Applying a quantitative approach and a Principal Component Analysis (PCA) on a sample of 350 staff, three key dimensions were identified: management, environment and recycling. The results reveal deficiencies in the application of regulations, inadequate infrastructures for storage and recycling, and limited technical training among operators. However, more than 59% of respondents express a willingness to collaborate in NFU recycling and donation activities, which underscores the opportunity to implement sustainable strategies. The proposed model emphasizes the need to strengthen training, improve infrastructure, foster regulatory compliance, and develop economic incentives to maximize the recycling and reuse of NFUs. This comprehensive approach aims to minimize environmental and health impacts, while contributing to the Sustainable Development Goals. The research concludes with recommendations to validate and expand the model in other institutional contexts.
**Keywords**: Circular economy, Sustainable management, Industrial recycling, Environmental regulations, Social responsibility

## 1 Introduction

Environmental pollution is one of the most determining factors in the acceleration of climate change, directly affecting global climate systems. The burning of fossil fuels, deforestation, and the uncontrolled emission of greenhouse gases (GHGs) have increased the average global temperature, causing extreme weather events such as more intense hurricanes, prolonged droughts, and melting of the poles (Sawyer et al., 2024).

The emission of carbon dioxide ($CO_2$), methane ($CH_4$), and nitrogen oxides ($NO_x$) contributes to the greenhouse effect, trapping heat in the atmosphere. This phenomenon has led to an average increase of 1.2 °C since the pre-industrial era, negatively impacting ecosystems and biodiversity. In addition, air, land, and water pollution affects human health, with millions of premature deaths attributed to pollution-induced respiratory and cardiovascular diseases (Heinrich et al., 2024).

To mitigate these impacts, it is necessary to adopt strategies that involve both individuals and companies. Thus, people must reduce their personal carbon footprint by using public transport, bicycles or electric vehicles; actively participate in recycling and waste reduction programs; and adopt plant-based diets, as the livestock industry is one of the largest sources of methane (Romarate et al., 2024).

For their part, companies can implement certified environmental management systems, such as ISO 14001, to monitor and reduce their emissions; adopting circular economy models that reuse and recycle materials, minimizing waste; and investing in renewable energy sources such as solar and wind, decreasing dependence on fossil fuels (Rahmani &Aboojafari, 2024).

Above all, the participation of governments through public policies is vital to develop policies that promote clean energy and subsidies for green technologies; establishing regulations that limit GHG emissions and promote sustainable practices in industrial sectors (Green, 2024); and promoting environmental education is key for individuals to understand their role in mitigating climate change. Workshops, campaigns, and awareness programs can encourage collective actions to reduce pollution (Romarate et al., 2024).

Thus, the management of end-of-life tires (ELF) is a critical challenge for the Ecuadorian Land Force due to the permanent nature and high amount of this waste generated by the intensive use of land and air vehicles in its logistical and administrative operations. Globally, it is estimated that 300 million tires are discarded annually in the United States alone, of which a percentage ends up incinerated or deposited in landfills, generating serious environmental and health impacts (Medina & Severino, 2014). In Ecuador, approximately 60,000 tons of NFU are generated annually, of which only a fraction is recycled or retread, while the rest accumulates in landfills or is exposed to the environment, according to recent studies (León, 2024).

One of the most obvious problems is the lack of adequate infrastructure for the storage and technical treatment of NFUs, which leads to their accumulation in the open air. This practice encourages the proliferation of disease vectors such as dengue and the contamination of soil and water bodies due to the leaching of toxic compounds and microplastics (Chiluisa, 2015). In addition, tire incineration, a method used in some industrial sectors, releases harmful gases such as carbon dioxide, sulfur oxides, and fine particles, exacerbating climate change and affecting public health (Tipán, 2020).

Ecuadorian regulations, including the Environmental Management Law and the TULSMA framework, establish principles of extended producer responsibility and the proper management of solid waste, but their implementation faces practical limitations, such as lack of resources and inter-institutional coordination. In this context, the Ecuadorian Land Force faces additional challenges operating in an environment where regulations are often not fully complied with, and logistical capabilities for the recycling and reuse of NFUs are limited (Constituent Assembly, 2008).

In addition, studies indicate that there is a shortage of economic incentives to encourage tire recycling, limiting the creation of related industries and contributing to the waste of valuable materials such as steel and rubber. The absence of a classification and technical monitoring system for NFU in logistics units aggravates the problem, increasing the risk of environmental contamination and affecting the sustainability of military operations (Piedra, 2020).

The accumulation and improper disposal of tires contribute to the contamination of soil, air and water, generating adverse effects such as the proliferation of disease vectors and the emission of polluting gases. Through a comprehensive approach based on Ecuadorian and international environmental regulations, this study aims to establish a roadmap towards the implementation of responsible practices that support both the environment and the community.

The management of NFU by the Ecuadorian Land Force is at a critical point that requires the adoption of a comprehensive model based on principles of social responsibility and circular economy. As this study is part of the research project "Land Force end-of-life tyre management (ELF) within the framework of Social Responsibility", this model must specifically address existing structural and operational problems, ensuring efficient and sustainable waste management.

In the Ecuadorian context, regulations such as Article 15 of the Constitution (2008) and the Environmental Management Law underline the importance of clean technologies and renewable energies. The Land Force, as part of the national defense system, has the obligation to lead environmental management initiatives, in line with its organizational mission of sustainability.

Precisely, this article focuses on developing a management model for NFUs that integrates principles of organizational social responsibility and environmental sustainability. By addressing variables such as storage, classification, final disposal, recycling, and environmental management, this model seeks to minimize the negative impacts of NFUs on the environment. Therefore, this work is structured with the introduction, theoretical and referential framework, methodology, results and conclusions.

## 2 Theoretical Framework

The development of a management model for NFUs is based on theories of corporate social responsibility (CSR) and circular economy. According to Vidal et al. (2005), CSR implies the commitment of organizations to society, seeking to improve the quality of life through ethical and sustainable practices. This principle guides the proposal of a model that not only complies with legal regulations, but also contributes to environmental sustainability.

At the international level, models such as the Integrated Waste Management Programme of Aragon (GIRA) in Spain highlight the importance of principles such as efficient recycling, the reuse of by-products and extended producer responsibility (Araujo et al., 2020). These concepts are essential to ensure that NFUs are managed effectively, transforming an environmental problem into an economic and social opportunity.

The Integrated Waste Management Programme of Aragon (GIRA) is a pioneering model in the European Union that seeks environmental sustainability through a comprehensive approach to waste management. Its importance lies in its ability to minimize environmental impact through reuse, recycling, and waste reduction, while simultaneously promoting the circular economy. This program has become a benchmark due to its innovative structure and its results in mitigating climate change through the efficient management of industrial and municipal waste (Usón et al., 2013).

The GIRA is designed based on the principles of the waste hierarchy, prioritizing prevention, followed by reuse and recycling, and limiting final disposal in landfills. Its structure includes three components:

1. Operational Components: Selective collection centres for different types of waste; infrastructures for the treatment of organic and non-organic waste; and facilities specialized in the recycling of materials such as plastics, metals and glass.

2. Regulatory Approach: Strict compliance with European directives on waste management; and promotion of extended producer responsibility, obliging manufacturers to manage the complete life cycle of their products.
3. Control and Evaluation Instruments: Life cycle analysis to measure the environmental impact of management strategies; and environmental performance indicators to evaluate the effectiveness of the program (Zabalza-Bribián et al., 2016).
Various studies have analysed and highlighted the achievements of GIRA in terms of sustainability and operational efficiency. For example, Zabalza-Bribián et al. (2016) demonstrated that GIRA reduces greenhouse gas emissions through recycling and composting strategies rather than incineration or landfills. Usón et al. (2013) identified that the specialized treatment of end-of-life tires under the GIRA framework reduces environmental impact, and generates reusable materials for industry. Likewise, recent research has documented that GIRA has fostered the growth of industries related to recycling and reuse, promoting the local economy and generating green employment (Zambrana et al., 2013).
In this regard, Tipán (2019) analyzes the management of end-of-life tires (NFU) in the Ecuadorian Air Force. Using baselines obtained through surveys, a management model is designed based on environmental standards such as the GRI 300 standard, the Spanish GIRA Plan and social responsibility models. The model incorporates the variables of storage, classification, final disposal, environmental management and recycling, and its validity is supported by statistical tests such as Cronbach's alpha and Pearson's correlations. The study identifies three essential dimensions: diagnosis, execution and management regulations. In addition, a pilot test is implemented and a social responsibility guide for NFUs is formulated, suggesting specific goals and indicators. Although the model is viable for the Armed Forces, its validation in other organizational contexts is recommended.
The success of the GIRA in Aragon has inspired other European regions to adopt similar models. In addition, its emphasis on the circular economy is aligned with the UN Sustainable Development Goals, specifically SDG 12 on responsible consumption and production (Usón et al., 2013). Sustainable Development Goal (SDG) 12, entitled "Responsible Consumption and Production", seeks to ensure sustainable patterns in global production and consumption, promoting efficiency in the use of natural resources and minimizing waste generation through circular economy policies.
This objective is based on the need to decouple economic growth from environmental deterioration, encouraging responsible practices between producers and consumers (UN, 2015). Its implementation requires the integration of clean technologies, recycling systems, and the adoption of regulatory frameworks that foster a transition to sustainable economies. The GIRA Plan is a pioneering initiative of the autonomous community of Aragon for the sustainable management of solid waste. This program aligns with the principles of SDG 12 by promoting the waste hierarchy (reduce, reuse, recycle) and ensuring that waste is managed in an environmentally responsible manner. Its structure includes:

- Prevention and minimization: Reducing waste generation through educational and regulatory campaigns.
- Efficient management: Development of infrastructures for the differentiated treatment of waste, including composting and recycling facilities.
- Extended producer responsibility: Encourages manufacturers to take responsibility for the recovery and recycling of their products.

The GIRA has proven to be an effective model for the implementation of circular economy policies, reducing waste destined for landfills and promoting recycling-related industries. Studies show that this programme has improved regional environmental quality and has served as a reference for other European communities (Zabalza-Bribián et al., 2016).
The Integrated Waste Management Programme of Aragon (GIRA) is a model that applies the principles of the circular economy to promote environmental and economic sustainability in waste management. This program prioritizes the reduction, reuse, and recycling of materials, aligning with the objective of closing resource cycles to minimize environmental impact and foster a regenerative economy, since:

1. GIRA integrates strategies to avoid waste generation through sustainable product design and public awareness.
2. It provides facilities to separate and process waste, ensuring the maximum use of materials such as plastics, metals, and organics (Cueto & Escudero-Castillo, 2020).
3. It forces manufacturers to manage the full lifecycle of their products, encouraging responsible practices throughout the value chain.
4. It promotes the research and development of innovative solutions to transform waste into resources.

As a result, GIRA has decreased the amount of untreated waste that ends up in landfills, improving soil and air quality; and it has fostered the development of recycling industries and green employment, contributing to regional economic growth (Dies, 2021). Similarly, the success of GIRA as a circular economy model has served as a reference for similar initiatives in other regions, highlighting its alignment with the Sustainable Development Goals, especially SDG 12 on Responsible Consumption and Production (Beltrán, 2018).

## 3 Methodology

The research adopts a quantitative approach, using the survey already tested in Tipán's project (2019) "Social responsibility management model in the recycling of end-of-life tires for the Armed Forces of Ecuador", as the main instrument to collect data in logistics units of the Ecuadorian Land Force. The survey includes the variables of storage, classification, final disposal, environmental management and recycling, and were applied to a sample of 350 Ecuadorian army officials. The sample was calculated using the formula for finite samples, ensuring a confidence level of 95% and a margin of error of 5%. The study covers the logistics units of Logistics Command No. 25 "Reino de Quito" and Logistics Command No. 72 (Shyris).

The data were processed in the SPSS version 26.0 software, performing descriptive and correlational analyses to identify patterns and relationships between the variables. These relationships are essential to validate the proposed management model. The results allow us to identify strengths and weaknesses in the current management of NFUs, and through the ACP (Principal Component Analysis) and design the NFU management model in the Ecuadorian Land Force.

## 4 Results

### 4.1 Reliability

First, as can be seen in Table 1, Cronbach's alpha coefficient is calculated, with a value of 0.793, which demonstrates a high reliability of the instrument, validating the relevance of the questions to measure the proposed variables.

Table 1

*Cronbach's Alpha Coefficient*

| Cronbach's alpha | N of elements |
|---|---|
| ,793 | 58 |

### 4.2 Descriptives of the GIRA PLAN variables

The results of the surveys applied to the selected sample of military personnel of the Ecuadorian Land Force reveal the following results:

*1. Storage*

The logistics units surveyed indicate that 69.1% generate end-of-life tires (NFU). They also report that, in storage sites, 37.1% of tires are clean, 26.6% are dry, 14% remain in cool environments, and 22.3% do not meet any of these characteristics. Regarding cleaning, 42.3% mention that it should be done with detergent.

On the other hand, the data reveals that 63.1% of the stored tires do not have sidewall markings, 76.9% are not protected with dark-colored covers, 56.3% are stored indoors, while 43.7% remain in areas without a roof or cover. In addition, 68% of the units do not periodically turn the tires to protect them from sunlight.

In conclusion, the logistics units of the Land Force do not apply adequate storage techniques or provide technical treatment to the NFU. This contributes to increased environmental pollution and inefficient use of discarded tires, exacerbating the problem of sustainable tire management.

According to the data analyzed, 74.3% of the sample of surveys applied in the logistics units indicate that there are adequate routes for the access, mobility, loading and disembarkation of tires. Likewise, 62% indicate that ventilation and temperature conditions are normal, and 64.9% confirm that the facilities comply with the required distance from natural ecosystems and hazardous substances. In addition, 59.7% say that the tires are far from materials that could affect the rubber. However, 56.6% mention that there is an excessive piling up of end-of-life tires (NFU), while 48.3% consider that there are favorable conditions for tires to accumulate water, compared to 51.7% who think the opposite.

In conclusion, although essential aspects such as accessibility, climate and protection of ecosystems are met, technical management is still deficient, with an excessive accumulation of NFU that represents a moderate environmental risk.

*2. End-of-Life Tire (NFU) Classification*

64.3% of those surveyed state that the stored tyres have exceeded their useful life. 59.7% indicate that those tires that are not suitable for retreading or tread replacement are delivered to authorized managers. However, 60.6% of those surveyed say they do not know managers who carry out recycling and reuse activities for end-of-life tyres (ELT).

This situation reflects the absence of specific standards established by the Ground Force to carry out a proper classification of NFUs. The lack of clear guidelines limits the efficient management of this waste and makes it difficult to use it in sustainable processes that contribute to the care of the environment.

*3. Final Disposition*

The institution allocates end-of-life tyres (NFU) mainly for recycling (46.9%), followed by sale (21.7%), delivery to authorised managers (16.3%) and sending them to landfills (15.1%). It should be noted that components such as the valve (61.1%) and the valve cover (61.4%) are not recycled in most cases. Meanwhile, tire rubber is sold to specialized managers (23.7%), reused for other services (22.3%) and, to a lesser extent, discarded in municipal collection centers (20%).

In terms of recycling methods, the most useful process identified is the obtaining of tire dust through mechanical processes (28.6%), followed by retreading and the manufacture of spare parts for vulcanizers (24%). However, the practice of burning or incinerating tires is recognized as the most harmful to the environment, with a negative impact reported by 69.7% of respondents.

Likewise, a significant percentage of the NFU is destined for recycling and sale, and the lack of use of components such as valves and caps persists. In addition, retreading and reuse for spare parts represent viable alternatives, while burning tires remains a major source of environmental pollution.

*4. End-of-Life Tire Management (NFU)*

38% of those surveyed store tyres in warehouses, while 32% do so without a cover, outdoors. A worrying 65.7% state that they are unaware of adequate procedures for the management of end-of-life tyres (ELT). On the other hand, 83.7% consider that the Ministry of Environment and Water (MAAE) should regulate the management of tires, although 66.6% are unaware of the existence of any institutional planning based on an Organizational Social Responsibility (RSO) model for the recycling of NFU. In addition, 56.9% indicate that they do not apply any technical management method for recycling.

As for environmental regulations, 20.6% do not apply any, 54.1% are limited to basic aspects and only 25.4% follow the regulations issued by the MAAE. Regarding outdoor storage, 19.2% do not practice it, 52.3% do it in a basic way, and 28.6% implement it. Regarding the classification of UFE outdoors, 15.7% do not carry it out, 45.7% do it partially, and 38.6% do it adequately.

In terms of technical final disposal, 18% do not apply any method, 50.2% adopt basic practices, and 31.7% implement appropriate techniques. Likewise, 78.9% do not know the current volume of NFU in military units. 69.4% say they have not received training in environmental management and preservation related to NFU, which prevents the promotion of an organizational culture oriented towards environmental conservation. Finally, 66.3% are unaware of the possible uses of NFUs under a management model that reduces pollution.

Technical treatment for the storage and handling of NFU is not implemented in 70% of cases. There is a deficit of knowledge and procedures, while management regulations require clearer regulation by the MAAE. Additionally, 74.7% do not apply environmental regulations in their entirety, 71.5% do not implement adequate storage, and 61.4% do not classify NFUs in a technical way. Likewise, 68.2% do not carry out an adequate technical final disposal. These findings highlight the urgent need to foster an organizational culture that prioritizes the sustainable management of NFUs and environmental conservation.

*5. Environmental Regulations*

74.6% of those surveyed in the logistics units report not knowing the current environmental regulations, while only 35.5% consider that they help to conserve the environment. On the other hand, 53.6% affirm that they apply basic practices for environmental preservation. 59.4% stated that they did not know of a management system that avoided environmental pollution, although 76.3% identified pollution as a critical problem. Only 36.3% of those surveyed are aware of the Constitution of the Republic of Ecuador and only 12.6% are aware of TULMAS (Unified Text of Environmental Legislation).

Compliance with environmental regulations is considered mandatory by 79.4% of the logistics units. Meanwhile, 66.9% indicate that the exposure of end-of-life tires (NFU) to the open air generates environmental pollution, and 60.9% say they are unaware of specific health effects related to this practice. Among those who identify impacts, 44.9% mention allergies and 40.6% respiratory diseases as derived problems.

35.1% of the NFU become contaminated water deposits, and 31.7% indicate that tires are conducive to rodent reproduction. 48.3% of those surveyed agree that the exposure of NFU to the open air represents a problem of environmental pollution. Also in terms of environmental collaboration, 59.1% support the management and recycling of NFU as an effective measure for environmental protection. Likewise, 54.6% would be willing to give up end-of-life tires without receiving financial compensation, while 39.2% would contribute moderately to the donation without any payment.

In summary, the lack of knowledge about current environmental regulations (74.6%) and management systems to reduce environmental pollution (59.4%) is relevant. However, most logistics units recognize the obligation to comply with environmental regulations (79.4%) and the negative impact of exposing NFU to the open air, including related health problems. There is ample scope to foster a culture of environmental protection, supported by the interest of 59.1% in managing and recycling tyres and 54.6% in donating them without expecting financial benefits.

*6. Recycling of End-of-Life Tires (NFU)*

14.8% of the logistics units do not carry out any type of recycling of end-of-life tires (NFU), while 57.7% apply a basic degree of recycling and only 27.5% implement recycling completely. Regarding the feasibility of recycling, 11.4% do not consider this process viable, 50.6% evaluate it in a basic way, and 38% consider it feasible in their facilities.

In terms of knowledge, 16.5% lack information on tire recycling, 52.1% have basic knowledge and 31.4% have an adequate level of understanding on this subject. In addition, 14.5% are unaware of the possible uses of recycled tyres, while 54% identify basic applications and 31.4% recognise specific uses.

56.6% believe that the development of an eco-friendly management model for NFU recycling is positive. Likewise, 52% perceive that this model should focus exclusively on recycling, followed by 30% who suggest incorporating training and storage activities. In terms of environmental impact, 6.8% are not clear about the effect of a treatment prior to NFU, while 38.3% estimate that this treatment would reduce pollution, and 54.8% are certain that it would be effective in reducing it.

The motivation to deliver NFU to recyclers is linked to financial compensation, as reflected by 50% of respondents, followed by 40% who would deliver the tires in exchange for immediate payment. On the other hand, 51.7% consider recycling NFU for productive activities to be motivating.

In terms of environmental pollution, 44% mention that disused batteries pollute the air in a basic way in the logistics unit, while 45.2% recognize that NFUs contribute to air pollution, a figure that rises to 40.5% when analyzed directly. Similarly, 41.7% determine that common garbage pollutes the air, and 42.9% state that this impact occurs in a basic way.

Finally, 79.4% consider it essential to create an NFU recycling company in the Ecuadorian Land Force, with the aim of taking advantage of the subcomponents of these tires.

In fact, it is observed that the logistics units mostly apply basic recycling practices for end-of-life tires. Although there is motivation to improve the management of NFU, the implementation of an eco-friendly model and the creation of specialized infrastructure are key opportunities to optimize the management of this waste.

In summary, the variables proposed in the end-of-life tire management model such as storage, classification, final disposal, management, environment and recycling do not fully comply with their management in a technical way.

**4.3 Principal Component Factor Analysis (PCA)**

Principal Component Factor Analysis (PCA) identifies a set of variables that correlate with each other to simplify the explanation of a phenomenon by reducing variables or factors (Méndez & Rondón, 2012). In this study, the variables considered are storage, classification, final disposal, management, environment and recycling. The PCA assumes certain conditions: normal distribution of variables, linear relationships, independent observations, and constant variance.

A null hypothesis ($H_0$) is proposed in which the population correlation matrix is equal to the identity matrix, which indicates that there is no significant linear relationship between the variables, making the use of PCA inadequate. In contrast, the alternative hypothesis ($H_1$) states that the population correlation matrix is distinct from the identity matrix, meaning that the variables are suitable for the PCA.

*1. KMO and Bartlett Testing*

The Kaiser-Meyer-Olkin (KMO) and Bartlett tests are fundamental statistical tools that evaluate the suitability of data to perform a Principal Component Analysis (PCA) or factor analysis. These tests help determine whether the relationships between the original variables are strong enough to warrant the use of these methods. The KMO test measures sample adequacy by comparing the observed correlations between the variables with the partial correlations. Its value ranges from 0 to 1, where higher values indicate that the observed correlations are appropriate for PCA or factor analysis.

The KMO index allows you to verify whether the data has enough correlation to apply a factor model. It is used to determine whether variables share a common structure (Field, 2017), and to identify potential problems in the dataset before proceeding to the PCA. Thus, values close to 1 indicate a high sample adequacy; values between 0.5 and 0.7 are considered acceptable; and values less than 0.5 indicate that correlations are insufficient, and PCA would not be adequate (Hair et al., 2019).

To evaluate these hypotheses, KMO and Bartlett tests are used, as shown in Table 2, the significance obtained is less than 5% (0.05), which allows the null hypothesis ($H_0$) to be rejected and the alternative hypothesis ($H_1$) to be accepted. This confirms that the PCA is adequate for the variables studied.

Table 2

*KMO and Bartletta Test*

| | | |
|---|---|---|
| Kaiser-Meyer-Olkin Measure of Sampling Adequacy | | ,815 |
| Bartlett's sphericity test | Approx. Chi-square | 8561,000 |
| | Gl | 1770 |
| | Gis. | ,000 |

Note: a. It is based on correlations

*2. Total Variance Explained*

Total Explained Variance measures what proportion of the total variability in the data is explained by the extracted components or factors. This refers to the percentage of variability in the original data that is captured by the principal components. Each extracted component explains a certain amount of variance, and the cumulative sum of these ratios indicates how well the components synthesize the information contained in the original variables (Hair et al., 2019).

Typically, the first component captures most of the total variance, with successive components explaining decreasing portions of the variance (Field, 2017; Tabachnick& Fidell, 2019). Thus, the cumulative variance indicates the progressive sum of the variance explained by the selected components and a high cumulative value (e.g., 80%) suggests that the selected components adequately represent the original data (Kline, 2014).

As shown in Table 3, the total inertia is equal to 60 components or factors, of which 4 explain 54.35% of the variance of the model, i.e., the model is moderately robust.

Table 3

*Total variance explained*

| Component | Initial eigenvalues | | | Rotation sums of squared charges | | |
|---|---|---|---|---|---|---|
| | Total | % variance | Cumulative % | Total | % variance | Cumulative % |
| 1 | 26,267 | 28,231 | 28,231 | 7,182 | 11,970 | 11,970 |
| 2 | 11,812 | 12,694 | 40,925 | 5,777 | 9,629 | 21,599 |
| 3 | 8,089 | 8,694 | 49,619 | 2,929 | 4,881 | 26,480 |
| 4 | 4,398 | 4,727 | **54,346** | 1,382 | 2,303 | 28,783 |
| 5 | 3,587 | 3,855 | 58,201 | | | |
| 6 | 3,067 | 3,297 | 61,497 | | | |
| 7 | 2,729 | 2,933 | 64,430 | | | |
| 8 | 2,696 | 2,898 | 67,328 | | | |
| 9 | 2,312 | 2,485 | 69,813 | | | |
| 10 | 2,243 | 2,411 | 72,224 | | | |
| 11 | 1,986 | 2,134 | 74,358 | | | |
| 12 | 1,828 | 1,964 | 76,322 | | | |
| 13 | 1,687 | 1,813 | 78,135 | | | |
| 14 | 1,617 | 1,738 | 79,873 | | | |
| 15 | 1,521 | 1,634 | 81,507 | | | |
| 16 | 1,458 | 1,567 | 83,074 | | | |
| 17 | 1,331 | 1,431 | 84,505 | | | |
| 18 | 1,241 | 1,334 | 85,839 | | | |
| 19 | 1,099 | 1,181 | 87,019 | | | |
| 20 | 1,062 | 1,141 | 88,160 | | | |
| 21 | ,988 | 1,062 | 89,222 | | | |
| 22 | ,933 | 1,003 | 90,225 | | | |
| 23 | ,871 | ,936 | 91,160 | | | |
| 24 | ,774 | ,832 | 91,992 | | | |
| 25 | ,668 | ,718 | 92,711 | | | |
| 26 | ,603 | ,648 | 93,359 | | | |
| 27 | ,548 | ,589 | 93,948 | | | |
| 28 | ,466 | ,501 | 94,449 | | | |
| 29 | ,389 | ,418 | 94,867 | | | |
| 30 | ,377 | ,405 | 95,271 | | | |
| 31 | ,307 | ,330 | 95,601 | | | |
| 32 | ,284 | ,305 | 95,906 | | | |

| | | | |
|---|---|---|---|
| 33 | ,275 | ,296 | 96,202 |
| 34 | ,246 | ,264 | 96,466 |
| 35 | ,242 | ,260 | 96,727 |
| 36 | ,228 | ,245 | 96,971 |
| 37 | ,214 | ,229 | 97,201 |
| 38 | ,198 | ,212 | 97,413 |
| 39 | ,187 | ,201 | 97,614 |
| 40 | ,175 | ,188 | 97,803 |
| 41 | ,168 | ,180 | 97,983 |
| 42 | ,157 | ,168 | 98,151 |
| 43 | ,151 | ,162 | 98,313 |
| 44 | ,148 | ,159 | 98,473 |
| 45 | ,136 | ,146 | 98,619 |
| 46 | ,131 | ,141 | 98,760 |
| 47 | ,120 | ,129 | 98,889 |
| 48 | ,116 | ,125 | 99,014 |
| 49 | ,114 | ,122 | 99,136 |
| 50 | ,100 | ,107 | 99,243 |
| 51 | ,097 | ,104 | 99,347 |
| 52 | ,092 | ,099 | 99,446 |
| 53 | ,086 | ,093 | 99,539 |
| 54 | ,082 | ,088 | 99,627 |
| 55 | ,073 | ,079 | 99,705 |
| 56 | ,070 | ,075 | 99,780 |
| 57 | ,062 | ,066 | 99,847 |
| 58 | ,051 | ,055 | 99,902 |
| 59 | ,047 | ,051 | 99,952 |
| 60 | ,044 | ,048 | 100,000 |

*Note:* Prepared by the authors according to the tabulation and treatment of the 350 surveys in SPSS.

*3. Sedimentation Graph*

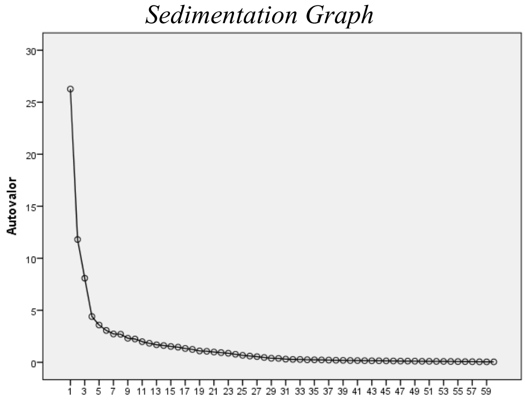
Known as **a Scree Plot**, it is a visual tool and its main purpose is to help determine the optimal number of components or factors to retain in a model. The sedimentation graph shows on the X-axis the main components (ordered from highest to lowest according to the explained variance) and on the **Y-axis** the explained variance or eigenvalues associated with each component (Field, 2017).

The name "sedimentation" comes from the typical shape of the graph, which has a steep slope at the beginning, followed by flattening, resembling a sedimentation curve (Hair et al., 2019; Tabachnick& Fidell, 2019). In this case, the components prior to the inflection point have a significant contribution to the explained variance.

Continuing with the PCA, Figure 1 presents the sedimentation graph, which highlights the presence of the 4 components that represent the social responsibility management model of the NFU of the Ecuadorian Land Force. These results support the robustness of the model and its applicability in the context studied.

Figure 1

*Sedimentation Graph*




*Note:* Prepared by the authors according to the tabulation and treatment of the 350 surveys in SPSS.In original Spanish language

*4. Rotated Component Matrix*

It is a matrix resulting from the rotation process, which seeks to simplify the structure of the factors or components obtained after decomposing the initial matrix of correlations. This process reorganizes the factor loads so that each variable is preferentially associated with a single factor, maximizing strong correlations and minimizing weak ones (Hair et al., 2019).

Rotation can be orthogonal (Varimax) which maintains independence between factors (Field, 2017), and oblique (Promax) which allows correlation between factors (Tabachnick& Fidell, 2019). Each cell in the matrix represents a factor load, which is the correlation between a variable and a factor. Normally, those greater than 0.4 or 0.5 are considered significant, depending on the sample size (Tabachnick& Fidell, 2019).

Considering loads greater than 0.5, Table 4 determines three components for the model of NFU in the Ecuadorian Land Force, since in component 4 there are no loads greater than 0.5. Thus, the three components are made up of the following elements:

COMPONENT 1

- **Management** (degree of application of the Environmental Regulations of the Ministry of Foreign Affairs, degree of Storage of NFU outdoors, degree of Classification of NFU outdoors, degree of existence of Final Disposal of NFUs).
- **Environment** (degree of support for the conservation of the environment), and
- **Recycling** (degree of application of NFU recycling in the logistics unit, degree of feasibility of NFU recycling in the logistics unit, degree of knowledge of some type of recycling for NFU, degree of knowledge of some use that can be given to the recycled NFU).

COMPONENT 2

- **Environment:** (Willingness to donate the NFU for reuse and exploitation without payment).
- **Recycling:** (Preference over the development of a management model for eco-friendly recycling of NFU; degree of environmental pollution with prior treatment to NFU; degree of motivation to recycle NFU in productive activities).

COMPONENT 3

- **Recycling:** (degree to which Waste Batteries pollute the air in your logistics unit, degree to which NFUs pollute the air in your logistics unit, degree to which common Waste pollutes the air in your logistics unit).

Table 4

*Rotated Component Matrix*

| | Component | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| **STORAGE** | | | | |
| Do your Logistics unit originate end-of-life tires? | -,021 | -,142 | -,128 | -,057 |
| In the case of storing end-of-life tires, which of the following characteristics does the storage site meet: | ,430 | ,226 | -,067 | ,003 |
| In the event that you must clean end-of-life tires, which of the following elements would you use to clean them: | ,345 | ,389 | -,221 | -,076 |
| Is there location marking on the sidewall of the end-of-life tyre? | ,188 | ,008 | -,067 | ,039 |
| Do you wrap the end-of-life tyre in a dark-coloured cover? | ,335 | ,258 | -,201 | ,075 |
| How do you store end-of-life tires with or without rims within your location? | ,039 | ,159 | -,089 | ,028 |
| Do you turn end-of-life tires periodically to prevent them from drying out? | ,331 | ,180 | -,043 | ,055 |
| Convenience of access routes and mobility of embarkation and disembarkation | ,313 | ,069 | ,033 | -,066 |
| There is adequate ventilation and temperature according to normal | ,221 | ,012 | -,031 | -,024 |
| Remoteness of natural ecosystems and hazardous substances | ,310 | -,016 | ,059 | ,001 |
| Away from material that affects rubber | ,318 | -,091 | ,179 | -,058 |
| Excessive crowding | -,049 | -,017 | -,170 | ,109 |
| There are favorable conditions for storing water | ,291 | ,078 | ,045 | ,020 |

| | | | | |
|---|---|---|---|---|
| **CLASSIFICATION** | | | | |
| Did the end-of-life tires exceed their useful life? | -,134 | -,313 | -,120 | -,060 |
| If the end-of-life tyres are NOT SUITABLE for RETREADING or TREAD REPLACEMENT, are they delivered to the MANAGER? | ,375 | ,097 | ,080 | ,000 |
| Do you know of any certified managers for the recycling and reuse of end-of-life tyres (ELUs)? | ,418 | ,104 | ,005 | ,024 |
| **FINAL PROVISION** | | | | |
| Tires that are no longer in use in their final disposal, the Institution uses them to: | -,014 | -,001 | ,014 | -,054 |
| Is the valve on the end-of-life tyre RECYCLED? | ,368 | ,108 | -,039 | ,118 |
| Is the end-of-life tire valve CAP RECYCLED? | ,325 | ,080 | ,031 | ,108 |
| How do you dispose of end-of-life tires? | ,210 | ,238 | -,240 | ,037 |
| With the knowledge of end-of-life tire recycling methods, what is the most advisable recycling method to obtain the best utility? | ,074 | ,316 | -,470 | -,023 |
| Of your opinion on the burning or incineration of end-of-life tires? | ,150 | ,188 | ,052 | -,059 |
| **MANAGEMENT** | | | | |
| You store tires out of use: | -,020 | ,014 | ,142 | -,043 |
| Do you know if there are procedures for the management of land tires that have ended their useful life in your logistics unit? | ,321 | ,073 | -,100 | ,002 |
| Do you consider it important for the Ministry of the Environment of Ecuador (MAE) to regulate the issue of end-of-life tires? | -,019 | -,252 | -,022 | ,003 |
| Do you know if within the institutional planning there is a management model of Organizational Social Responsibility (RSO) in the recycling of NFU in accordance with current environmental regulations? | ,423 | ,040 | ,020 | ,003 |
| Do you apply any management method for the recycling of end-of-life tyres? | ,437 | ,009 | ,039 | ,068 |
| Indicate the degree of application of the environmental regulations of the Ministry of the Environment of Ecuador MAE for the management of tires | **-,628** | ,256 | ,227 | -,327 |
| Indicate the degree to which end-of-life tires are stored outdoors | **-,574** | ,319 | ,273 | -,331 |
| Indicate the degree to which end-of-life tyres are classified in the open | **-,712** | ,243 | ,144 | -,316 |
| Indicate the degree to which there is technically an end-disposal of end-of-life tyres | **-,686** | ,224 | ,189 | -,432 |
| Do you know the total volume of end-of-life tires that exist in military units today? | ,399 | ,149 | -,138 | -,027 |
| Have you received training and coaching in the field of environmental management and preservation in your logistics unit currently? | ,461 | ,303 | -,182 | ,067 |
| Do you know about the uses that can be provided to end-of-life tires (NFU) through a management model to reduce environmental pollution? | ,429 | ,006 | -,013 | -,083 |
| **ENVIRONMENT** | | | | |
| Do you know about the current regulations in force in relation to environmental provisions? | ,336 | ,008 | -,011 | ,093 |
| Indicate to what extent you help to conserve the environment | **-,566** | ,424 | ,006 | ,122 |

| | | | | |
|---|---|---|---|---|
| Do you know if your Logistics Unit has a management system that prevents environmental pollution? | ,459 | ,012 | -,022 | ,017 |
| Indicate what environmental problems you know about and are familiar with | -,091 | ,144 | ,050 | ,008 |
| From the list, indicate which regulations you know | ,001 | ,112 | -,059 | ,398 |
| Do you consider that environmental regulations are mandatory in your Logistics Unit? | ,074 | -,259 | -,117 | -,050 |
| Do you rule that the environment is contaminated by exposing end-of-life tires in the open air or outdoors in your Logistics Unit? | -,103 | -,352 | -,187 | ,014 |
| In your current job, does your logistics unit know of any type of affectation to diseases related to health and environmental pollution, due to the accumulation of End-of-Life Tires (NFU)? | ,255 | ,095 | -,042 | -,124 |
| Indicate which health conditions | ,012 | ,052 | ,018 | ,214 |
| Indicate type of contamination | ,031 | ,066 | -,137 | ,033 |
| Do you know the level of environmental pollution when exposing end-of-life tires in the open air or outdoors? | ,328 | ,112 | -,280 | -,080 |
| Indicate to what extent you would be willing to collaborate with the environmental protection of the country by managing and recycling your tires | ,035 | **,797** | -,056 | ,013 |
| Would you be willing to donate the End-of-Life Tires (NFU) for reuse and use without payment? | ,132 | **,847** | -,027 | -,109 |
| **RECYCLING** | | | | |
| Indicate to what extent the recycling of end-of-life tyres is applied in the logistics unit? | **-,663** | ,441 | ,001 | ,095 |
| Indicate the degree of feasibility of recycling end-of-life tyres in the logistics unit? | **-,562** | ,419 | -,118 | ,184 |
| Indicate to what extent you are aware of any type of tire recycling? | **-,775** | ,136 | ,034 | ,324 |
| Indicate to what extent do you know of any use that can be given to recycled tires? | **-,706** | ,288 | ,122 | ,305 |
| What do you think about the development of a management model for the eco-friendly recycling of end-of-life tires? | -,087 | **-,575** | ,124 | -,102 |
| How do you think the tire recycling management model should work? | -,093 | -,027 | -,095 | ,071 |
| To what extent environmental pollution would be reduced with a pre-treatment of End-of-Life Tires (NFU) | ,043 | **,847** | ,102 | ,195 |
| To what extent you are motivated by the economic income from the delivery of end-of-life tires? | -,234 | ,375 | ,350 | ,407 |
| To what extent it motivates you to recycle your end-of-life tires for productive activities | -,121 | **,767** | ,099 | ,159 |
| Indicate the extent to which Battery Waste pollutes the air in your logistics unit | -,048 | ,417 | **,739** | ,153 |
| Indicate the extent to which end-of-life tires (ELUs) pollute the air in your logistics unit | -,012 | ,385 | **,796** | ,045 |
| Indicate the extent to which Common Waste pollutes the air in your logistics unit | ,012 | ,369 | **,793** | ,049 |
| Would you be interested in creating an end-of-life tire (NFU) recycling company in the Land Force to take advantage of the subcomponents (steel, textile fiber, rubber, etc.) of end-of-life tires? | -,061 | -,360 | -,019 | ,054 |

*Note:* Prepared by the authors according to the tabulation and treatment of the 350 surveys in SPSS.

*5. Rotated Space Component Chart*

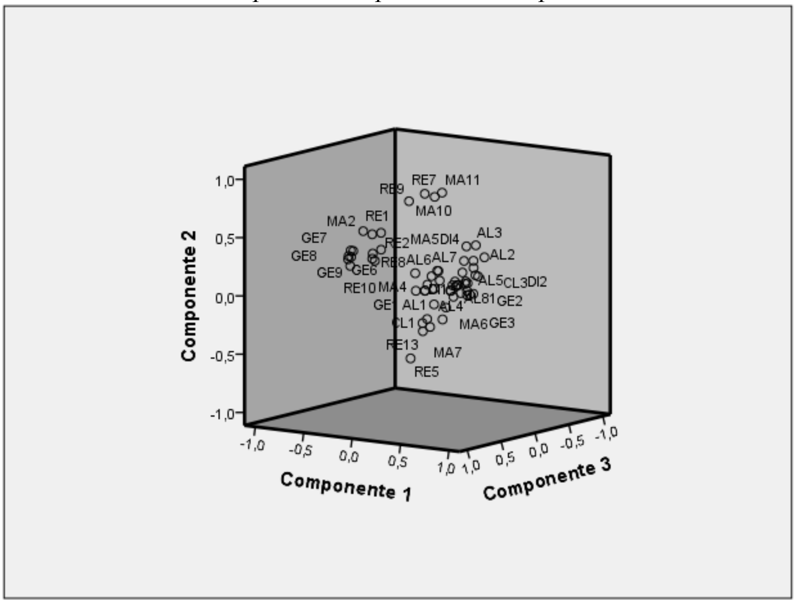
It is a visual representation of the main components or factors in a two- or three-dimensional space, once the factor loads have been rotated. This graph is commonly used to illustrate the relationship between variables and factors or components. The graph is based on factor loads, which are the correlations between the original variables and the extracted factors. When the loads are rotated (by orthogonal or oblique rotation), they are redistributed for ease of interpretation.

The interpretation of the rotated component graph is performed based on the positions of the variables. A variable located near an axis indicates a strong association with that component. Variables that are grouped together usually represent a common construct or a latent factor. In oblique rotations, the angles between factor vectors reflect correlations; a small angle indicates a strong correlation between factors (Hair et al., 2019).

Figure 2 shows the presence of the three components mentioned in the previous section.

Figure 2

*Component Graph in Rotated Space*




*Note:* Prepared by the authors according to the tabulation and treatment of the 350 surveys in SPSS. In original Spanish language

**4.4 Structure of the Management Model for End-of-Life Tires in the Ecuadorian Land Force**

Next, an analysis and interpretation of the model generated through the results of the Principal Component Analysis (PCA) applied to the 350 surveys on recycling and Corporate Social Responsibility (CSR) of end-of-life tires (NFU) in the Ecuadorian Land Force is presented. The identified components are grouped into three main dimensions: Management, Environment, and Recycling.

**Component 1:**

*1. Management*

The analysis shows that this component mainly reflects the institutional capacity to implement good practices for the management of NFU, highlighting the importance of infrastructure and compliance with environmental standards. It mainly reflects operational and regulatory aspects. Strengthening regulatory compliance and improving storage and sorting infrastructure is critical. Low values in this component could suggest priority areas for intervention. Therefore, this dimension assesses practices related to the application and compliance with standards and processes established for the management of NFUs. The elements included are:

- *Degree of application of the Environmental Regulations of the Ministry of Foreign Affairs:* This indicator measures alignment with the regulations of the Ministry of the Environment of Ecuador. A high degree of implementation reflects an adequate integration of regulations into management practices, which strengthens institutional sustainability.
- *Outdoor NFU Storage Grade:* A common practice that exposes NFUs to deterioration and creates environmental hazards. High values in this indicator could reflect challenges in the storage infrastructure.
- *Degree of classification of NFU outdoors:* This aspect is linked to the capacity of the logistics units to carry out a correct segregation of the NFU before its final disposal. Poor sorting could limit the recycling and reuse of tyres.

- *Degree of existence of Final Disposal of NFUs:* This element measures whether adequate processes are in place for the final disposal or recycling of NFUs. A low value could indicate a lack of clear mechanisms or insufficient infrastructure.

*2. Environment*

This component addresses the perception about the contribution of NFU-related activities to environmental conservation. It highlights the environmental perception of civil servants, which influences the willingness to participate in sustainable activities. Educational initiatives can strengthen this component. A high value in this component could reflect positive environmental awareness among staff and recognition of the efforts made in logistics units. However, if the values are low, they could indicate the need for awareness campaigns and environmental education.

- *Degree of support for environmental conservation:* This indicator measures officials' perception of how current management and recycling practices of NFU contribute to protecting the environment.

*3. Recycling*

This component assesses the feasibility and knowledge about NFU recycling within logistics units. It shows the opportunity to implement practical solutions based on existing knowledge. However, greater institutional support may be required to make recycling a routine and viable activity. A high value in this component would indicate a solid knowledge base and feasibility for recycling implementation. Low values could evidence the need for technical training and greater logistical support to develop sustainable strategies.

- *Degree of application of NFU recycling in the logistics unit:* Indicates whether there are active recycling practices in the unit, reflecting the level of implementation of circular economy strategies.
- *Degree of feasibility of NFU recycling in the logistics unit:* Evaluates the perception of the real possibilities of implementing recycling, considering factors such as infrastructure, human resources, and institutional support.
- *Degree of knowledge of some type of recycling for NFU:* This indicator measures the level of technical knowledge of officials about the options available to recycle NFU.
- *Degree of knowledge of any use that can be given to recycled NFUs:* Assesses whether officials are aware of the possible uses of products derived from recycling, such as rubber reused for pavements or industrial products.

**Component 2:**

*1. Environment*

- *Willingness to donate NFU without payment for reuse and use:* This indicator reflects the level of acceptance by employees to cede NFU without receiving financial compensation, with the purpose of promoting its reuse in productive or recycling activities. A high value in this element indicates a positive disposition towards the reuse of NFUs, which can be interpreted as a commitment by officials to environmental conservation and the circular economy. If values are low, there could be cultural, economic, or perceived barriers to the benefits of donating NFU, indicating the need to raise awareness of the positive impact of these actions.

*2. Recycling*

- *Preference on the development of a management model for eco-friendly recycling of NFU:* Assesses the acceptance of officials regarding the implementation of a structured and sustainable system for the management and recycling of NFU. High values reflect an interest in adopting organized and sustainable solutions for recycling, which shows alignment with principles of sustainability and social responsibility. Low values could indicate disinterest, lack of knowledge or distrust in the viability of such a model.
- *Degree of environmental contamination with prior treatment of NFUs:* This indicator measures the perception of the environmental impact associated with initial management processes of NFUs before their recycling or final disposal. High values suggest significant concern about the polluting effects of current practices, which could be a barrier to the implementation of sustainable strategies if not addressed. Low values indicate a lower perception of the environmental impact, which could require awareness-raising actions to evidence the negative consequences of improper management.
- *Degree of motivation to recycle NFU in productive activities:* Evaluates the willingness and enthusiasm of employees to get involved in activities that reuse NFU in production processes, such as the manufacture of derived materials. High values reflect a genuine interest in and willingness to participate in recycling initiatives, which represents an opportunity to strengthen the circular economy within logistics units. Low values could be due to a lack of incentives, information, or resources available for these activities.

**Component 3:**

- *Degree to which Battery Waste pollutes the air in your logistics unit:* This element reflects the perception about the environmental impact of battery waste on air pollution. High values in this component indicate that officials perceive battery waste as a major source of pollution, likely due to the release of toxic gases or vapors of chemicals such as sulfuric acid and lead. A high perception of contamination can be associated with improper disposal or storage practices for used batteries. If the values are low, there could be less awareness of the risks posed by these wastes to the air and environmental health.
- *Degree to which NFUs pollute the air in your logistics unit:* This indicator measures the perceived impact of end-of-life tires on air quality. Although NFUs do not emit gases on their own, improper burning or accumulation under improper conditions can release toxic substances such as volatile organic compounds (VOCs) and particulate matter. High values reflect a significant concern about the mismanagement of NFUs, such as their open-burning practices, which is an environmentally unsustainable practice. Low values could suggest a more appropriate management or less direct exposure to these practices in the logistics units.

Figure 3

*Dimensions of the Management Model for End-of-Life Tires in the Ecuadorian Land Force*


*Note:* Prepared by the authors as a result of the GPA.In original Spanish language

**5 Conclusions**

The management of end-of-life tires (NFU) in the Ecuadorian Land Force reflects a deficit in the knowledge and application of environmental regulations, with more than 70% of the logistics units ignoring current guidelines or applying them in a basic way. This shows a disconnect between regulations and their practical implementation, which limits the effectiveness of sustainable actions. The facilities for the storage and final disposal of NFU have serious deficiencies, such as excessive accumulations and conditions that favor environmental pollution. More than 65% of tires are stored improperly, creating significant risks to public health and the environment.

There is a lack of technical knowledge about NFU recycling and reuse among officials. Only 31.4% demonstrate an adequate level of understanding about potential applications of recycled NFUs, underscoring the need for training programs to foster circular economy practices. While 57.7% of logistics units apply basic recycling practices, less than 30% implement complete recycling. This reveals a gap in institutional capacity to adopt more advanced strategies that maximize the reuse of resources.

More than 59% of the employees surveyed are willing to collaborate with recycling activities and donate NFU without financial compensation. This high level of acceptance indicates a favorable basis for implementing eco-friendly initiatives, as long as they are accompanied by adequate infrastructure and regulation.

The descriptive results of the survey on the management of end-of-life tires NFU, applied to the 350 members of the Ecuadorian Land Force, reflect as strengths the basic awareness of the environmental impact and the importance of recycling, partial implementation of sustainable practices, such as mechanical recycling and reuse, and the widespread interest in improving the management of NFU through structured models. On the other hand, the weaknesses are synthesized in a lack of technical, regulatory and procedural knowledge on the management of NFU, inadequate storage, with excessive accumulations and conditions that favor pollution, limited connection with recyclers and lack of infrastructure for specialized recycling, and poor application of environmental regulations and institutional planning.

The results of the survey reflect as strengths the basic awareness about the environmental impact and the importance of recycling, partial implementation of sustainable practices, such as mechanical recycling and reuse, and the widespread interest in improving the management of NFU through structured models. On the other hand, the weaknesses are synthesized in a lack of technical, regulatory and procedural knowledge on the management of NFU, inadequate storage, with excessive accumulations and conditions that favor pollution, limited connection with recyclers and lack of infrastructure for specialized recycling, and poor application of environmental regulations and institutional planning.

The application of the Principal Component Analysis made it possible to unveil a management model for end-of-life tires of the current situation in the Ecuadorian Land Force. The process began with the information collected through the survey that contains six dimensions of CSR and NFU, since it is an instrument validated in a previous study applied to the Ecuadorian Air Force. In this way, the ACP generated a model for the Ecuadorian Land Force that is represented in three components: 1) Management, Environment and Recycling; 2) Environment and Recycling; and 3) Recycling.

In order to strengthen recycling and social responsibility practices in the management of end-of-life tires, some improvement actions are proposed, such as: 1) Training and awareness: Implement educational programs on the sustainable management of NFU and current environmental regulations; 2) Specialized infrastructure: Create internal recycling companies and improve storage conditions in logistics units; 3) Regulation and planning: Establish clear guidelines for the classification, storage and final disposal of NFU, in collaboration with the MAAE; and 4) Incentives and motivation: Design economic and social strategies to promote active participation in recycling and reuse activities.

Finally, this work leads to the recommendation to carry out a longitudinal analysis on the evolution of knowledge and management practices of NFU in the Ecuadorian Land Force, integrating environmental and social metrics. This approach will make it possible to evaluate the impact of interventions in terms of pollution reduction, recycling efficiency and generation of green employment, linking them to the Sustainable Development Goals.

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