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Environmental impact assessment of the cocoa post-harvest stage in a farm located in the Department of Santander, Colombia

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Abstract

The production of cocoa has become a strategic sector for the global economy, showing steady growth in recent years. However, the different stages that make up the production chain can generate various environmental impacts. Therefore, the objective of this research is to identify and quantify the environmental impacts associated with the cocoa post-harvest stage in a farm that produces approximately 152 kg of dry cocoa beans per month and an average of 1,824 kg per year across three hectares cultivated with this crop, located in the department of Santander, Colombia. Therefore, the technical and environmental conditions present throughout the different phases of the process are characterized. Subsequently, based on the information collected, the environmental impacts associated with each of the activities involved are identified and finally evaluated using the Arboleda methodology (EPM). As a result, 13 direct impacts and 15 indirect impacts generated during the post-harvest stage on the farm are identified. Likewise, the assessment classifies the project as having a medium environmental impact, indicating the need to implement management plans for the activities carried out on the farm in order to reduce their environmental impact.

Keywords: Cocoa post-harvest, environmental impact assessment, environmental impacts.

1. Introduction

Colombian cocoa stands out in international markets due to its sensory characteristics, particularly flavor and aroma [1], [2]. Likewise, cocoa production in Colombia contributes significantly to the growth of the national agricultural sector, positioning it among the three most economically relevant products in the country [3] In this context, the department of Santander has consolidated itself as one of the main producing regions nationwide, largely due to its favorable climatic conditions for crop development [4], [5]. It is important to highlight that during the cocoa post-harvest stage, negative impacts are generated within the productive process, representing a challenge to the sustainability of the cocoa value chain [6], [7]. Among the identified impacts, the generation of by-products such as cocoa pod husk (CPH) stands out; these residues are often disposed of in open fields without adequate management, leading to the proliferation of pests and alterations in crops [8], [9]. Additionally, the generation of liquid by-products such as mucilage during the fermentation stage may cause contamination of soils and surface water sources [10], [11], [12], along with the emission of offensive odors and the presence of sanitary vectors [13], [14] .

Studies focused on the cocoa sector have primarily characterized the by prducts generated from a qualitative perspective For this reason, it is necessary to complement these approaches through the analysis and quantification of the impacts derived from real practices implemented on producing farms, allowing the establishment of relationships between the activities carried out and their direct and indirect effects on the local environment [15], [16].

The objective of this study is to accurately and contextually evaluate the environmental impacts generated by the different activities carried out during the cocoa post-harvest stage, considering the production conditions of the "San Cristóbal" farm, located in the Quinales district of the municipality of El Playón, in the department of Santander, Colombia. To this end, the post-harvest processes implemented on the farm were characterized to identify the impacts associated with each activity and to quantitatively evaluate the direct and indirect impacts using standardized methodologies such as the one proposed by Arboleda, which considers parameters including the class, presence, duration, evolution, and magnitude of each impact [17], [18]. As a result, a global assessment of the project was established using mathematical calculations that support the formulation of environmental management plans aimed at mitigating the negative impacts derived from current practices, contributing to environmental improvement on the farm and strengthening applied knowledge in environmental management within the cocoa agroindustry.

2. Research method

This research adopts a methodological approach aimed at evaluating the environmental impacts associated with the cocoa post-harvest stage under real production conditions. For this purpose, the method combines direct field observations with a detailed technical description of post-harvest practices, and additionally incorporates the application of a recognized environmental impact assessment methodology. In this way, primary information related to the activities carried out on the farm is collected, while simultaneously ensuring that the evaluation accurately reflects the actual operational context of the production system.

Based on the above, the study initially defines the study area and subsequently describes each post-harvest activity in a sequential manner, establishing procedures used to identify, classify, and evaluate the direct and indirect environmental impacts generated throughout the process [19]. This methodological design allows a systematic analysis of the interactions between productive activities and environmental components, thereby providing consistent and verifiable results that support the evaluation of sustainability in cocoa production systems [20], [21].

2.1 Study area

The environmental impact assessment of the cocoa production process is carried out in the municipality of El Playón, located in the department of Santander, Colombia (Figure 1).

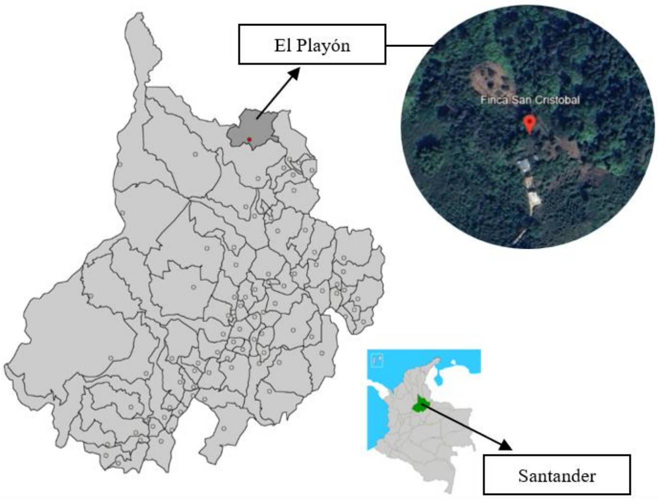

Figure 1. Geographical location of the study area: El Playón, Santander. Source: [22]

The study area presents an average temperature of 25 °C, a relative humidity of approximately 80%, and annual precipitation ranging between 1600 mm and 2000 mm [22], [23]. The primary economic activity in this area is based on the exploitation of the primary sector, with agriculture particularly cocoa cultivation representing 80.1% of total production [24], [25], [26] . Additionally, the environmental impact assessment of the post-harvest process was carried out specifically in the rural district of Quinales, at the "San Cristóbal" farm, which covers 17 hectares, three of which are dedicated to cocoa cultivation, with approximately 2950 plants currently in production.

2.2 Description of the Cocoa Post Harvest Stage

The cocoa post-harvest stage in the study area consists of four main phases, as shown in Figure 2, which include the harvesting of the fruit from the crop, the opening of the pod (depulping), the fermentation process, and the drying of the beans.

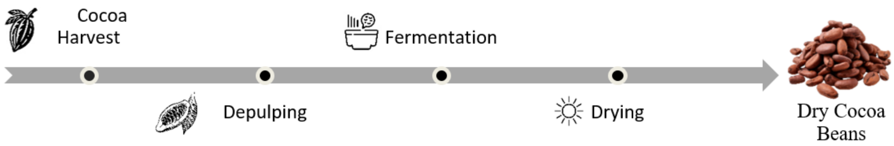

Figure 2. Phases of the cocoa post-harvest process

The final product requires additional processes to enable the commercialization of the beans; therefore, an area is needed where the beans can be inspected and packaged, so they may be stored until the sacks are transported.

2.2.1 Cocoa harvesting

Cocoa harvesting is carried out in the field by selecting fruits that have reached their optimal stage of maturity. This activity involves the use of knives or machetes, as well as sacks for cutting and temporarily storing the cocoa pods. In addition to the fruit, leaves and plant branches are also obtained as a result of separating the pods from the tree.

The production at the "San Cristóbal" farm is approximately 815 cocoa pods per week, with an estimated weight of 480 kg of fruit (with an average pod weight of 0.589 kg). The cocoa pods are transported from the plantation to the area designated for pod opening using sacks or carts, and are then carried by a motor-cargo vehicle to the location where cutting and depulping are performed.

2.2.2 Pod opening and depulping

Once the fruit has been harvested, cocoa pods are manually opened to extract the pulp and beans, as illustrated in Figure 3.

Figure 3. By-products generated during the cutting and depulping stage

Depending on the cocoa variety and the size of the fruit, each pod may contain between 20 and 50 beans. In addition, this activity involves the use of manual tools such as machetes or knives, which leads to the generation of organic residues, with cocoa pod husk (CPH) being the most representative by-product of the process [27].

Under the conditions evaluated at the study farm, pod opening and depulping require approximately four hours of labor for the processing of 815 cocoa pods, resulting in the generation of about 365 kg of CPH. These residues are disposed of directly in the field without the application of management practices or control measures to regulate the decomposition process.

2.2.3 Fermentation

The fermentation process constitutes one of the most determining stages in the final quality of cocoa beans, as it is during this phase that the precursors responsible for the characteristic flavor and aroma of the product are developed. For this research, in the study area, bean fermentation is carried out in two wooden fermentation boxes, which are covered with banana leaves to maintain the temperature and promote the necessary microbiological conditions to obtain properly fermented beans for the drying process to continue [28].

Based on the above, this stage is divided into two clearly defined sub-phases. First, during Sub-phase 1, freshly depulped beans are placed in the first fermentation box, where a considerable loss of liquid residues corresponding to the mucilage occurs. Under these conditions, this residue has an approximate weight of 39 kg and drains through the bottom of the wooden boxes; however, this by-product is discharged directly onto the soil, which may generate environmental impacts associated with its high organic load. Subsequently, in Sub-phase 2, gaseous emissions are produced as a result of the metabolic activity of the microorganisms responsible for fermentation, during which yeasts degrade the sugars present in the cocoa pulp, producing ethanol and carbon dioxide [29].

As a consequence of these processes, temperature increases and characteristic fermentation odors are generated, which may attract animals and vectors such as flies, thereby creating sanitary and environmental risks in the area of influence. Additionally, this phase has an approximate duration of six days, during which the beans must be turned every 24 hours using wooden paddles, in order to prevent material agglomeration and mold formation. Finally, the process concludes when the beans acquire a brown coloration as a result of the oxidation of polyphenolic compounds. Figure 4 schematically presents the sub phases that make up the cocoa bean fermentation process.

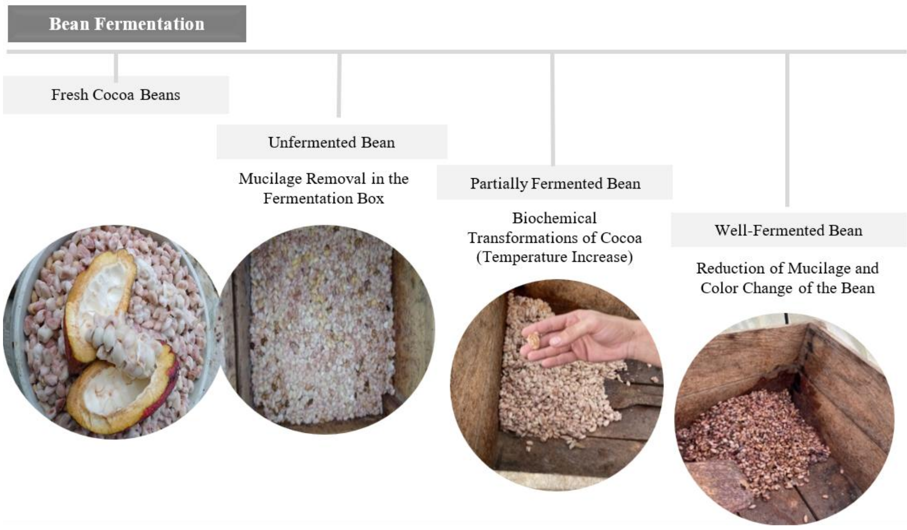

Figure 4. Sub phases of the cocoa bean fermentation process in the study area

2.2.4 Drying

The method used for cocoa drying corresponds to a conventional technique based on the direct exposure of the beans to solar radiation. Under this approach, the procedure lasts approximately between 6 and 10 days, and its duration depends directly on the meteorological conditions present in the area, such as incident solar radiation, ambient temperature, and relative humidity. During this phase, a black plastic sheet is placed on the ground surface, on which the previously fermented beans are spread. Controlled periodic turning is carried out in order to promote the uniform removal of moisture contained in the beans.

In this way, for the volume of fruit harvested, an average of 38 kg of dry cocoa beans is obtained per week. These beans must reach the moisture content levels established by current regulations in order to reduce the risk of microbial proliferation, such as mold development, which could compromise product quality. Finally, as shown in Figure 5, the drying process must achieve a moisture content of 7%, a value considered optimal to ensure proper preservation and safe storage of the beans [30].

Figure 5. Cocoa bean drying process by direct solar exposure

2.2.5 Bean storage and transportation under post-harvest conditions

The storage of dry cocoa beans is carried out manually using fique sacks, employing tools such as wooden shovels for filling and handling the product. Subsequently, once the beans have been packaged, they are transferred to the designated storage area, which is equipped with basic services and undergoes periodic cleaning in order to prevent pest proliferation and ensure adequate conservation conditions. Additionally, dry beans are transported from the storage area to the points of sale using pickup trucks, which leads to the generation of noise, fuel consumption, and gaseous emissions associated with vehicle operation.

Regarding the production index, from a weekly harvest of approximately 480 kg of fresh fruit, about 38 kg of dry beans are obtained, corresponding to an average yield of 7.92%. Consequently, the farm produces an estimated 152 kg of dry cocoa beans per month and approximately 1,824 kg per year. Finally, these values reflect an average production of 608 kg of dry beans per cultivated hectare.

2.3 Environmental impact assessment of the post-harvest stage

In the study area, the environmental impacts associated with the post-harvest stage are identified through the integration of qualitative and quantitative techniques, with the purpose of ensuring a comprehensive and systematic evaluation of the process. Figure 6 presents the guidelines used to conduct the assessment of the environmental impacts generated during the stage under analysis, establishing the relationships between the activities carried out, the management practices employed, and the impacts produced [31].

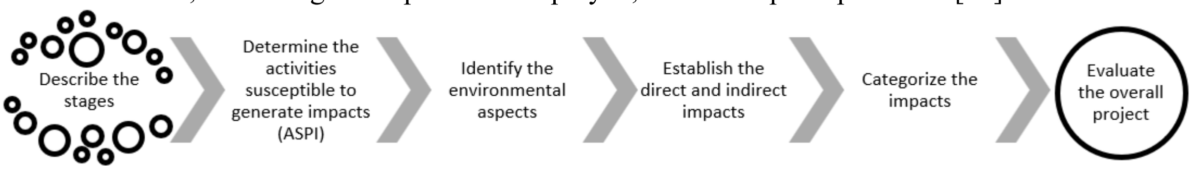

Figure 6. Environmental assessment process Arboleda methodology

Therefore, the description of the post-harvest stage in the study area is first carried out in order to determine the ASPIs and the environmental aspects, and to identify the direct and indirect impacts. Once the impacts have been identified, each of them is evaluated according to the Arboleda method (EPM), in which the class, presence, duration, evolution, and magnitude of the impact are assessed using predefined ranges (Table 1), to finally determine the environmental rating of the project.

Table 1. Environmental impact assessment criteria [31]

Criterion	Description	Range	Value
Class	Relates the characteristics or the qualitative type of effect depending on whether it is considered beneficial or adverse, in relation to the action carried out.	Positive	+
		Negative	-
Presence	It is the certainty that the impact will occur or not, and it is rated in terms of probability.	Certain	1.0
		Very probable	0.7<0.99
		Probable	0.4<0.69
		Somewhat probable	0.2<0.39
		Not probable	0.01<0.19
Duration	Corresponds to the time during which the effect remains in the environment, from the moment it is generated until it returns to its initial conditions, either naturally or through implemented measures	Very long: > 10 years	1.0
		Long: > 7 years	0.7<0.99
		Medium: > 4 years	0.4<0.69
		Short: > 1 year	0.2<0.39
		Very short: < 1 year	0.01<0.19
Evolution	Represents the speed at which the impact develops until it reaches its maximum alteration	Very fast: if it is < 1 month	1.0
		Fast: if it is < 12 months	0.7<0.99
		Medium: if it is < 18 months	0.4<0.69
		Slow: if it is < 24 months	0.2<0.39
		Very slow: if it is > 24 months	0.01<0.19
Magnitude	It is the intensity with which the area of influence or the number of people affected by the impact may be altered.	Very high: > 80%	1,0
		High: between 60% and 80%	0.7<0.99
		Medium: between 40% and 60%	0.4<0.69
		Low: between 20% and 40%	0.2<0.39
		Very low: < 20%	0.01<0.19

For the calculation of the environmental rating (Ca), Equation 1 is applied.

$$Ca = P(7.0 * Ev * M + 3.0 * D), \quad (1)$$

where, Ca = Rating, P = Presence, Ev = Evolution, M = Magnitude, D = Duration.

Consecutively, the environmental rating of direct and indirect impacts determines the importance of the impact as very significant, significant, moderate, or irrelevant, as shown in Figure 7.

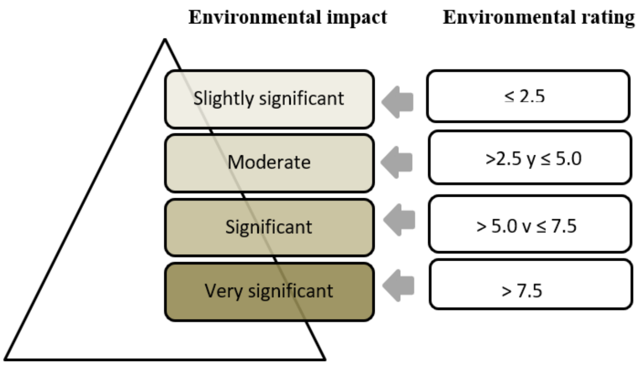

Figure 7. Functional relationship between environmental rating and impact importance. Source: [31]

Likewise, considering the environmental rating of each impact, the overall environmental categorization (CA) of the project is calculated using Equation 2.

$$CA = \frac{(NMs*5)+(Ns*4)+(Nm*2)+(Ni*1)}{Nt}, \quad (2)$$

where, CA: Environmental Categorization; NMs: Number of Very Significant Impacts; Ns: Number of Significant Impacts; Nm: Number of Moderate Impacts; Ni: Number of Irrelevant Impacts; Nt: Total number of impacts evaluated.

In this way, the environmental categorization is established in Table 2, where the total magnitude of the project's impacts associated with the post-harvest stage in the study area is identified.

Table 2. Environmental categorization of the project [31]

Environmental Rating	Environmental Categorization of the Project
1.0 – 1.99	Low-impact projects
2.0 – 3.49	Medium-impact projects
3.5 – 5.0	High-impact projects

3. Results and discussion

This section presents the key findings of the environmental impact assessment conducted during the cocoa post harvest stage. It summarizes the quantities of products and by-products generated, identifies the activities most likely to cause environmental impacts, and analyzes the associated environmental aspects. Additionally, it classifies the 28 impacts detected direct and indirect according to their significance and evaluates them using the Arboleda methodology. Finally, it establishes the overall environmental categorization of the project, providing a clear understanding of the most critical impacts and the environmental implications of the post-harvest process.

3.1 Products and by-products obtained in the study area

In Table 3, the quantitative percentage estimation of the products and by-products generated during the cocoa production process is presented. It was found that among the products and by products generated across the Harvesting, Fermentation, and Drying phases, Cocoa Pod Husk (76%) and Fermented Bean (66%) are produced in the greatest quantities, while Pulp and bean (34%) is the least produced.

Table 3. Products and by-products generated in the cocoa production process

Phases	Products and By-products	Quantity (%)
Harvesting	Cocoa pod husk	76
	Pulp and bean	24
Fermentation	Mucilage	34
	Fermented bean	66
Drying	Dry bean	50
	Removed moisture	50

3.2 Components and activities susceptible to generate impacts (ASPI)

The components of the post-harvest stage and the ASPI are presented in Table 4. In total, six components and seven ASPI were identified, including activities such as cutting and depulping, fermentation, drying, among other.

Table 4. Components and ASPI of the cocoa post-harvest stage in the study area

Stage	Components	ASPI (Activities Susceptible to Produce Impacts)
Cocoa post-harvest	Harvesting	Cutting and depulping
	Fermentation	Fermentation
	Drying	Drying
	Storage	Grain inspection
	Transportation	Packaging Grain transportation
	Administrative management	Personnel hiring

3.3 Determination of environmental aspects

The analysis of the activities and processes implemented in each phase of the post-harvest stage allows the identification of the environmental aspects associated with each ASPI, which are presented below in Table 5.

Table 5. Relationship between components, ASPI, and environmental aspects of the cocoa post-harvest stage

Component	ASPI	Environmental Aspects
Harvesting	Cutting and depulping	Generation of organic solid waste
		Modification of vegetation cover
Fermentation	Fermentation	Odor emissions
		Generation of liquid waste
		Gas emissions
Drying	Drying	Odor emissions
	Grain inspection	Generation of organic solid waste
		Odor emissions
Storage	Grain storage	Energy consumption
		Water consumption
		Odor emissions
	Packaging	Generation of organic solid waste
		Generation of inorganic solid waste
		Consumption of raw materials

Component	ASPI	Environmental Aspects
Transportation	Grain transportation	Gas emissions
		Generation of particulate matter
		Noise generation
		Fuel consumption
Administrative management	Personnel hiring	Job creation

3.5 Environmental impact assessment

A total of 28 environmental impacts were identified, including an increase in the generation of organic solid waste which can lead to deterioration of vegetation cover an increase in liquid waste produced during the fermentation process, which contributes to stronger offensive odors, and the generation of atmospheric pollutants, among other effects that influence the surrounding environment.

Figure 8 provides a general overview of the direct and indirect impacts associated with each phase of the cocoa post-harvest stage. The results indicate that the highest concentration of impacts occurs during the storage phase, particularly in the grain packaging process. However, when analyzing the waste generated in each phase, it becomes evident that during the cutting and depulping activity, a significant volume of cocoa pod husk is produced, representing a relevant environmental aspect due to its magnitude.

Accordingly, Table 6 presents a detailed list of the impacts associated with each ASPI and environmental aspect, organized by the phases of the cocoa post-harvest stage.

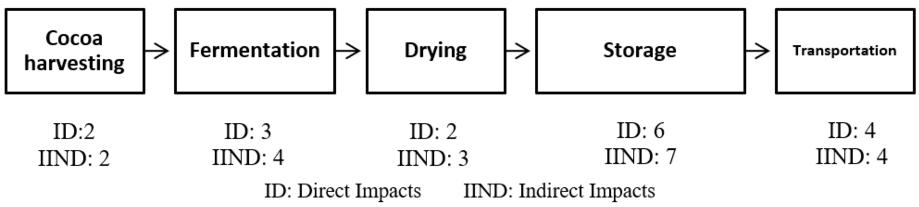

Figure 8. General summary of the impacts caused during the post-harvest stage

On the other hand, Figure 9 shows the amount of CPH generated during the process, as well as the cocoa beans that were not properly dried and were discarded due to the presence of mold, which increases the generation of organic solid waste. Likewise, positive impacts were identified, among which the increase in employment opportunities and the improvement of the economic conditions of families involved in the productive sector stand out.

Figure 9. Residuals obtained in the cocoa production process

Table 6. Direct and indirect impacts caused by each environmental aspect

Stage	Component	ASPI	Environmental Aspect	Impacts	
				Direct Impacts	**Indirect Impacts**
Post-harvest	Harvesting	Cutting and depulping	Generation of organic solid waste Modification of vegetation cover	*a*. Increase in the amount of organic solid waste b. Deterioration of vegetation cover	a1. Increase in vector-borne diseases b1. Loss of individual plant species
	Fermentation	Fermentation	Odor emissions Generation of liquid waste Gas emissions	a. Increase in offensive odors b. Increase in the amount of liquid waste c. Air pollution due to gases	a1. Community disturbances b1. Contamination of drinking water sources b2. Modification of water uses c1. Increase in respiratory diseases
	Drying	Drying	Odor emissions	a. Increase in offensive odors	a1. Community disturbances
		Grain inspection	Generation of organic solid waste Odor emissions	a. Increase in the amount of organic solid waste b. Increase in offensive odors	a1. Increase in vector-borne diseases a2. Increase in offensive odors b1. Community disturbances
	Storage	Grain storage	Energy consumption Water consumption Odor emissions	a. Increase in offensive odors b. Increase in energy consumption c. Increase in water consumption	a1. Community disturbances b1. Deterioration of natural resources c1. Alteration of the availability and quality of water resources
		Packaging	Generation of organic solid waste Generation of inorganic solid waste Consumption of raw materials	a. Increase in the amount of organic solid waste b. Increase in the amount of inorganic solid waste c. Increase in the consumption of raw materials	a1. Increase in vector-borne diseases a2. Increase in offensive odors b1. Deterioration of landscape visual quality b2. Loss of soil and water quality c1. Increase in the amount of organic solid waste
	Transportation	Grain transportation	Gas emissions Generation of particulate matter Noise generation Fuel consumption	a. Air pollution due to gases b. Atmospheric pollution by particulate matter c. Noise pollution d. Increase in fuel consumption	a1. Increase in respiratory diseases b1. Increase in respiratory diseases c1. Increase in hearing-related illnesses d1. Increase in greenhouse gas emissions
	Administrative Management	Personnel hiring	Job creation	a. Increase in the demand for employment	a1. Improvement in quality of life a2. Economic improvement for families involved in the activity

Table 7 presents the list of direct and indirect impacts that affect the abiotic, biotic, and socioeconomic components of the environment. These impacts may be repeated across different activities; however, they are established as the overall impact of the project.

Table 7. Environmental impact assessment matrix – Arboleda method

No.	Direct and Indirect Impacts	Ca	Environmental Impact
1.	Increase in the demand for employment	10.00	Very significant
2.	Increase in the amount of organic solid waste	10.00	Very significant
3.	Deterioration of vegetation cover	3.43	Moderate
4.	Increase in the amount of liquid waste	6.02	Significant
5.	Increase in offensive odors	8.65	Very significant
6.	Atmospheric pollution by gases	4.38	Moderate
7.	Increase in energy consumption	6.02	Significant
8.	Increase in water consumption	8.60	Very significant
9.	Increase in the amount of inorganic solid waste	8.60	Very significant
10.	Increase in the consumption of raw materials	7.20	Significant
11.	Atmospheric pollution by particulate matter	5.58	Significant
12.	Noise pollution	8.37	Very significant
13.	Increase in fuel consumption	7.30	Significant
14.	Improvement in quality of life	5.91	Significant
15.	Economic improvement for families involved in the	5.91	Significant
16.	Increase in vector-borne diseases	3.17	Moderate
17.	Loss of individual plant species	1.84	Slightly significant
18.	Contamination of drinking water sources	4.76	Moderate
19.	Modification of water uses	4.62	Moderate
20.	Community disturbances	5.32	Significant
21.	Increase in respiratory diseases	3.28	Moderate
22.	Alteration of the availability and/or quality of water	2.09	Slightly significant
23.	Deterioration of landscape visual quality	2.50	Slightly significant
24.	Loss of soil and/or water quality	3.80	Moderate
25.	Generation of waste	10.00	Very significant
26.	Deterioration of natural resources	4.53	Moderate
27.	Increase in hearing-related illnesses	4.32	Moderate
28.	Increase in greenhouse gas emissions	7.90	Very significant

3.6 Environmental categorization

In Figure 10, the impacts are categorized according to their environmental rating. The results show three slightly significant impacts, representing the smallest proportion identified. Additionally, eight very significant impacts and eight significant impacts were recorded. Likewise, nine moderate impacts stand out, which constitute the largest number within the classification in the study area.

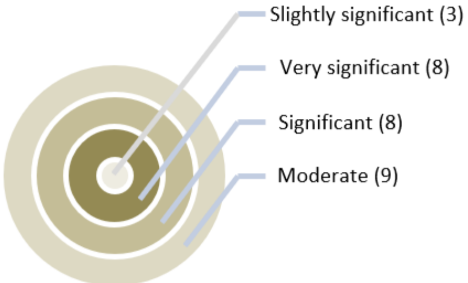

Figure 10. Environmental categorization of the project

In turn, as a result of Equation 2, the project categorization is calculated, yielding a score of 3.32, which indicates that the impacts generated during the post-harvest stage correspond to a Type II project (range 2.0–3.49), that is, a medium-impact environmental project.

4. Conclusions

The application of the Arboleda method allows for the systematic identification of aspects and impacts associated with the post-harvest stage of cacao. As a result, a total of 28 environmental and socioeconomic impacts were identified, of which 13 were classified as direct and 15 as indirect. Furthermore, based on the assessment of the significance of the impacts, eight were categorized as highly significant, eight as significant, nine as moderate, and three as slightly significant.

The analysis demonstrates that the most significant negative impacts are primarily associated with the generation of solid and liquid waste, as well as the emission of unpleasant odors. In this context, according to the evaluation criteria established by the EPM methodology, these impacts present a high level of environmental importance, which implies the need for priority intervention in the environmental management of the cacao production process. However, the environmental impact assessment also reveals significant positive effects on the socioeconomic component, particularly regarding local job creation and the strengthening of the economic conditions of families involved in cacao cultivation and post-harvest activities.

In line with the above, the project's classification indicates the need to formulate and implement environmental management plans aimed at addressing the most significant impacts caused by this economic sector. Among these, the waste management plan is of particular importance, given that waste generation and improper disposal of byproducts represent the most significant impact identified during the harvesting, drying, and storage stages, which also cause offensive odors. In this regard, the proposed measures include the collection and use of byproducts generated during the cacao harvesting and fermentation processes for the development of value-added products such as compost, promoting a circular economy approach, reducing the most significant negative environmental impacts identified, and contributing to the environmental sustainability of the post harvest process at the "San Cristóbal" farm.

Declaration of competing interest

The authors declare that they have no known financial or non-financial competing interests in any material discussed in this paper.

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Author contribution

The contribution to the paper is as follows: Arly Dario Rincón Quintero participated in the development of the project design and methodology; Lauren Mishell Guerrero Barbosa carried out the data collection in the study area; Mauricio Andrés Ruiz Ochoa and Zirley Dayana Ardila Caballero supported the process of identifying and categorizing the environmental impacts; while Jesús E. Contreras-Naranjo, Omar Lengerke, and Camilo Leonardo Sandoval-Rodríguez, as part of the research team, actively contributed to the overall development of the study, strengthening the collaborative work that supported each stage of the research. All authors participated in the analysis and interpretation of the results, as well as in the writing, critical review, and final approval of the manuscript.

Informed consent

Informed consent for the publication of personal data in this article was obtained from the participants.

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