SUSTAINABILITY OF AGRICULTURAL PRODUCTION UNITS IN THE WESTERN CORDILLERA OF THE ECUADORIAN ANDES †

[SUSTENTABILIDAD DE LAS UNIDADES PRODUCTIVAS AGRÍCOLAS EN LA CORDILLERA OCCIDENTAL DE LOS ANDES ECUATORIANOS]

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SUMMARY

Background: In this research, the sustainability of the productive systems of the parish of El Tingo La Esperanza, Ecuador was evaluated to make a diagnosis considering 25 sustainability indicators corresponding to the social, economic and environmental dimensions. **Objective**: To evaluate sustainability in the different groups of agricultural production units (APU). **Methodology:** Structured interviews were conducted with 109 producers of the Agricultural Production Unit (APU) to determine indicators of sustainability and clustering of APU using Ward's method. Subsequently, the sustainability attributes were determined in each group to calculate the General Sustainability Index (IGS); and finally, the influence of the attributes in each APU group was analyzed using Principal Component Analysis (PCA). **Results:** There is a high variability among the sector's production systems, represented by 5 groups of APU. Sustainability applying 25 indicators allowed us to observe that there is weak sustainability in the sector in all dimensions, especially in the environmental dimension. The evaluation of the General Sustainability Index (GSI) shows that APU1 are sustainable and resilient, while in APU2 sustainability is affected by difficulties in the production system, APU 3, 4 and 5 have very low sustainability values; especially the APU3 which lives in critical conditions; in the same way, the PCA shows that APU3 is not associated with any sustainability attribute. **Implication:** The producers of El Tingo La Esperanza parish especially those belonging to APU 3, 4 and 5, require special attention in improving their diversity, productivity and association capacity to improve their quality of life and therefore their sustainability. **Conclusion**: To design an effective strategy for the development of the parish, the diversity of the APU, their sustainability and critical points must be taken into account.
Key words: Indicator; Attributes; Sustainability; Ecuadorian Andes.

RESUMEN

Antecedentes: En esta investigación se evaluó la sostenibilidad de los sistemas productivos de la parroquia El Tingo La Esperanza para realizar un diagnóstico considerando 25 indicadores de sostenibilidad correspondientes a las dimensiones social, económica y ambiental. **Objetivo**: Evaluar la sostenibilidad en los diferentes grupos de unidades de producción agrícola (UPA). **Metodología**: Se realizaron entrevistas estructuradas a 109 productores agrícolas para determinar indicadores de sostenibilidad y agrupamiento de las UPA utilizando el método de Ward. Posteriormente se determinaron los atributos de sustentabilidad en cada grupo para calcular el Índice General de Sostenibilidad (IGS); y finalmente, se analizó la influencia de los atributos en cada grupo de UPA mediante Análisis de Componentes Principales (PCA). **Resultados**: evidencian una alta variabilidad entre los sistemas productivos del sector, representados con 5 grupos de UPA. La sustentabilidad aplicando a 25 indicadores permitió observar que en el sector existe una débil sustentabilidad en todas las dimensiones, especialmente en la dimensión ambiental. La evaluación del Índice General de Sustentabilidad (IGS) evidencia que las UPA1 son sustentables y

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resilientes, mientras que en las UPA2 la sustentabilidad se ve afectada por dificultades en el sistema productivo, las UPA 3, 4 y 5 presentan valores muy bajos de sustentabilidad; sobre todo las UPA3 que viven en condiciones críticas; de la misma manera, el ACP que la UPA3 no se encuentra asociada con ningún atributo de sustentabilidad. **Implicaciones:** Los productores de la parroquia El Tingo La Esperanza especialmente los que pertenecen a las UPA 3, 4 y 5, requieren una especial atención en mejorar su diversidad, productividad y capacidad de asociación con el fin de mejorar su calidad de vida y por ende su sustentabilidad. **Conclusión:** Para diseñar una estrategia efectiva para el desarrollo de la parroquia se deben tener en cuenta la diversidad de las UPA, su sustentabilidad y puntos críticos.

Palabras clave: Indicador; Atributos; Sustentabilidad; Andes Ecuatorianos.

INTRODUCTION

Farming systems play an essential role for human survival as they provide raw materials, food, fuels and other ecosystem services (Zhang *et al.,* 2023). However, the agricultural sector currently faces challenges in feeding a growing population while protecting the environment, maintaining farmers' livelihoods, mitigating and adapting to climate change (Sgroi, 2022). Therefore, understanding the use and management of productive resources in agricultural systems is essential in decision-making for natural resource management (Karamian *et al.,* 2023). Under this approach, the sustainable development of agricultural systems is crucial to ensure food security, agricultural production efficiency and resilience and adaptation to climate change (Tao *et al.,* 2023).

The evaluation of the sustainability of an agricultural system must define physical, economic, environmental, social and political elements (Cruz *et al.,* 2016; Samian *et al.,* 2015; Silva *et al.,* 2020); as well as the involvement of all actors (Carmona *et al.,* 2013; Dlouhá *et al.,* 2022) in a way that reflects their reality in the area. There are several methodologies for the construction and evaluation of sustainability, but their application is complex due to their different dimensions (Sarandón, 2002; Sarandón *et al.,* 2006) and the holistic need for the analysis of different simultaneous dimensions in a productive system (Sarandón and Flores, 2009). In recent years, the methodologies developed around sustainability are based on indicators (Lewandowska-Czarnecka *et al.,* 2019; Pean *et al.,* 2015; Sgroi, 2022). They are essential tools to address resource management and planning (Moreira *et al.,* 2022); in addition, they provide a comprehensive vision of the availability and access of current and future resources (Cansino-Loeza *et al.,* 2020) and for decision-making and policy formulation in favor of the sustainability of natural and productive systems (Yuan and Lo, 2020).

In Latin America there are many case studies on sustainability that consider indicators for the social, economic and environmental dimensions (Arnés and Astier, 2018). In the Andean region, a 2019 article analyzing social, environmental and economic outcomes in Bolivia, Colombia, Peru and Ecuador during the first two decades of the twenty-first century found that, while progress has been made in some areas, there are still significant challenges to achieving sustainable development in the region (Wanderley *et al.,* 2018). However, there have been efforts to develop region-specific sustainability indicators, for example, in Ecuador, Bravo-Medina *et al.* (2017), Rodríguez *et al.* (2018) and Viteri *et al.* (2018), developed some case studies on small farms in the Amazon region, while Méndez *et al.* (2016) studied the coastal region (Cruz *et al.,* 2016) and (Hernández *et al.,* 2018) studied Andean communities. Other studies have focused on developing indicators to monitor tourism activity in the Galapagos Islands (Hernández and Jiménez, 2015). Case studies have also been conducted to examine the relationship between sustainability indicators and sustainable development outcomes in the Ecuadorian Andes, evidencing that the use of sustainability indicators can: 1) help identify areas for improvement in sustainable development efforts, 2) inform decision-making processes to ensure that future development is sustainable, 3) assess potential conflicts between economic development and environmental conservation and 4) inform strategies to balance these competing priorities (Arnés and Astier, 2018). Overall, sustainability indicators are an important tool for assessing the current state of sustainable development in the Ecuadorian Andes and for informing future efforts to ensure the continued health and well-being of the region (Gudynas, 2003; Palacios and Cuvi, 2017).

Nowadays the sustainability of farms is gaining much importance in the contemporary economy (Lewandowska-Czarnecka *et al.,* 2019), it is worth examining the degree of sustainability in a set of farms with different management methods and of different sizes. That is why in this research the following objectives were proposed: a) Identify the types of APU with Ward's method, under the criterion of the Sarandón methodology, b) determine the General Sustainability Index (GSI) and c) analyze the influence of the critical points in each group of APU using PCA.

MATERIALS AND METHODS

Area of study

The present study was conducted in the geographical area known as El Tingo La Esperanza, located in Pujilí, province of Cotopaxi. Located in the western mountain range of the Ecuadorian Andes, in the upper basin of the Guayas River and with an elevation ranging from 684 to 2227 meters above sea level (Figure 1). It corresponds to a territory of the foothills of the Pacific coast, with a pronounced topography, surface soils and low content of organic material. The average annual rainfall is 2629 mm and presents a rainy (September-May) and dry (June-August) period (Ilbay-Yupa *et al.*, 2021), with an average annual temperature of 19 °C (INAMHI, 2017). The APU of the sector is mainly engaged in agriculture and livestock for subsistence purposes. However, the cultivation of sugarcane (for the production of alcohol and panela) and the breeding of cattle, is the main source of income (Mogro *et al.*, 2020).

Methodology

The methodology is developed in two processes that are summarized in Figure 2. The first is the determination of sustainability indicators and APU grouping using Ward's method. The second was characterized by the determination of the attributes in each APU group and its subsequent evaluation of the GSI; as well as analyze the influence of sustainability attributes in each group of APUs using PCA.

Sample population

The population sample was calculated based on the total population of the parish El Tingo La Esperanza (4051 inhabitants) (INEC, 2010). Consequently, the sample used for the sustainability assessment corresponds to 109 APU, with a confidence level of 95%, probability of the event occurring of 50% and probability of not occurring (50%) and an error (9.25%).

Surveys based on economic, sociocultural and environmental indicators (Table 1) were conducted in eight localities: Siete Ríos, Macuchi, La Esperanza, El Palmar, California, Guayacán, Recta de Vélez and El Progreso. Survey data were collected and subsequently systematized and processed in RStudio V. 4.1.2 (R Core Team, 2020).

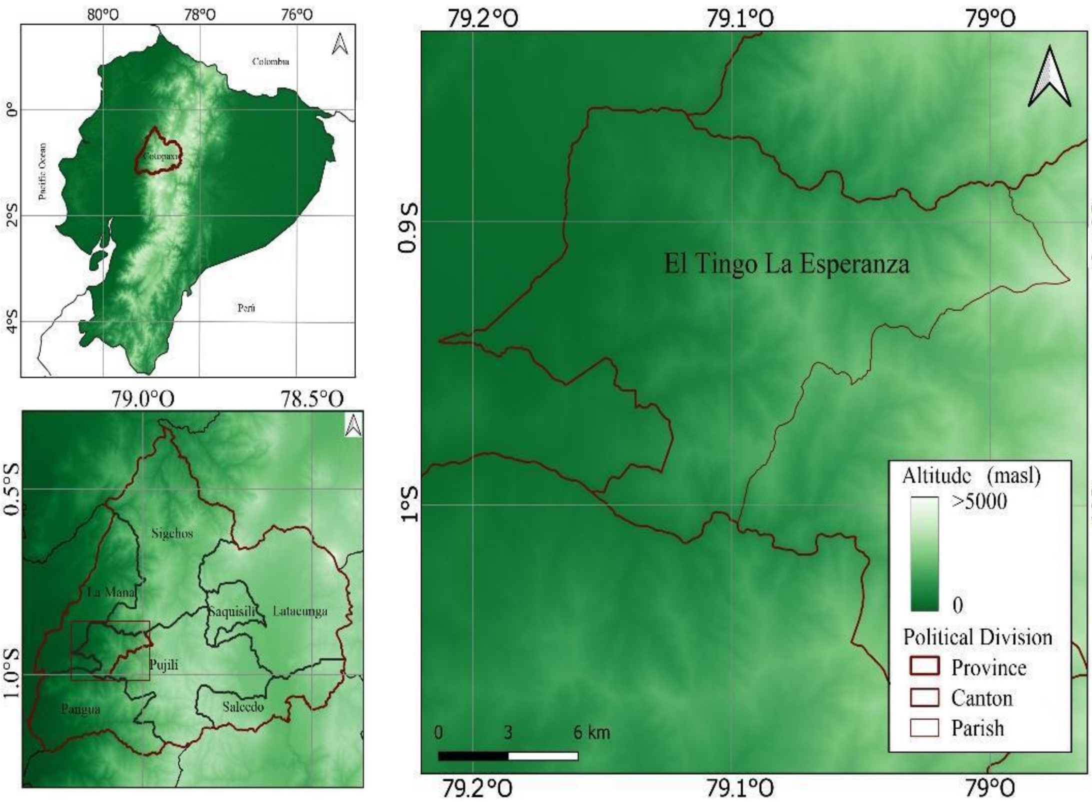

Figure 1. Geographical location of the study area (El Tingo la Esperanza, Ecuador). The figure is the original work of the authors.

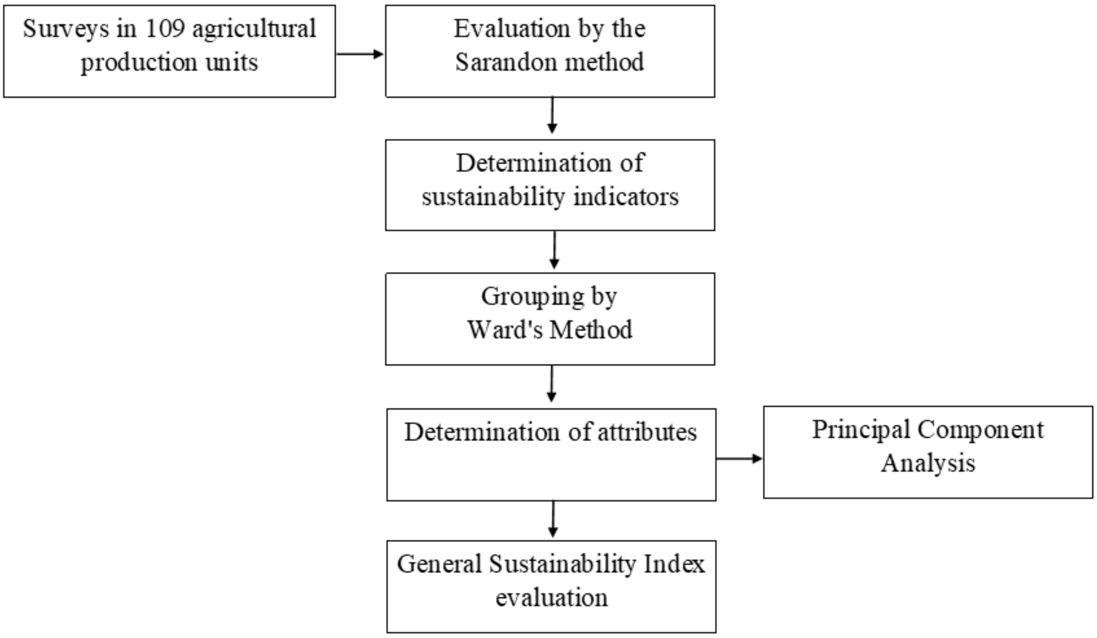

Figure 2. Methodological scheme to evaluate the Sustainability of Agricultural Production Units in the western cordillera of the Ecuadorian Andes.

Sustainability Assessment

Sustainability was evaluated under the criteria of Sarandón, 2002 and Sarandón *et al.*, 2006, considering: three dimensions: economical, environmental and social (Pinedo-Taco *et al.*, 2018; Collantes and Rodriguez 2015), eight attributes and twenty-five indicators (Table 1). The information of the evaluated indicators was standardized, obtaining a transformation on a scale from 0 to 4; where 0 is the lowest or smallest value; 1 very low level, 2 low level, 3 medium level and 4 high level. Escala is based on the recommendations given by Sarandón and Flores (2009). This methodology is widely used due to the ease of measurement, comprehensibility and information provided by APU (Sarandón, 2002; Conceição *et al.*, 2005; Machado Vargas *et al.*, 2015; Painii-Montero *et al.*, 2020).

Classification of APU

The classification of APU recommended by Huaringa *et al.*, 2023, with similar characteristics according to the twenty-five sustainability indicators was carried out using the cluster technique. Which generates a hierarchical grouping by multivariate categorical information, to analyze, elucidate and represent a data set of $p > 1$ variables in a sample of n observations; that is, the focus is aimed at investigating two or more characteristics of a group of individuals (Pardo and Campo, 2007). Hierarchical methods deal with the grouping of clusters to form a new group, starting with groups of individuals present in the study and grouping them to form all cases in the same group (González de Miguel *et al.*, 2009).

The data ordered by hierarchies, allows to determine the role of relevance of the variables studied, therefore, with statistical difference (Núñez-Colín and Escobedo-López, 2011), where, the average is effective when the distribution of information is symmetrical, since it is greatly influenced by extreme values, in those cases, the use of the median as a measure of central tendency is more robust (Mishra *et al.*, 2019), this assertion was considered to obtain the grouping of the APU and represent in an explanatory diagram, since the variability in the information is evident.

General Sustainability Index (GSI)

Sustainability indices were calculated for the following dimensions: economic (KI), environmental (EI) and sociocultural (SCI) for each of the APU groups. Subsequently, the general sustainability index (GSI) was calculated, considering the mathematical expressions detailed below:

$$\mathrm{IK} = \frac{2\left(\frac{A1+A2+A3+A4+A5+A6}{6}\right)+\left(\frac{B1+B2}{2}\right)}{3} \quad (1)$$

where, A1, A2, ..., A6, represent the indicators belonging to the attribute of food self-sufficiency; at the same time B1 and B2 are indicators of the economic risk attribute.

Table 1. Indicators grouping economic, environmental and socio-cultural dimensions.

Dimension	Attribute	Indicator
Economic	Food self-sufficiency	A1. Productive crops
		A2. Surface for self-consumption
		A3. Pest incidence
		A4. Diversification of production
		A5. Yield
		A6. Monthly net income
	Economic Risk	B1. Sales diversification
		B2. Product Distribution
Environmental	Conservation of soil life	A1. Crop management
		A2. Crop residue management
		A3. Irrigation water system
	Risk of erosion	B1. Predominant Slope
		B2. Soil conservation
		B3. Soil typology
	Diversity management	C1. Functional biodiversity
		C2. Use of agroforestry
socio-cultural	Meeting basic needs	A1. Housing
		A2. Access to education
		A3. Access to health
		A4. Services
	Contributions to the production system	B1. Participation in productive work
		B2. Production system acceptance
		B3. Collaborating parties
	Social integration	C Participation in organizations
		D. Ecological Awareness

$$EI = \frac{2\left(\frac{A1+A2+A3}{3}\right)+\left(\frac{B1+B2+B3}{3}\right)+\left(\frac{C1+C2}{3}\right)}{4} \qquad (2)$$

where, A1, A2 and A3, are the indicators of the attribute of conservation of life in the soil; B1, B2 and B3, corresponds to the erosion risk attribute and C1 and C2, are the indicators of diversity management.

$$SCI = \frac{2\left(\frac{A1+A2+A3+A4}{4}\right)+\left(\frac{B1+B2+B3}{3}\right)+C+D}{4} \qquad (3)$$

where, A1, A2, ..., A4, corresponds to the indicators of the attributes of the satisfaction of basic needs; B1, B2 and B3 are the indicators of the contribution in the production system; C and D are attributes of participation in organizations and ecological awareness respectively.

In this research, indicators referring to the following attributes were considered to be twice as important: food self-sufficiency, conservation of soil life and satisfaction of basic needs (Table 1).

$$GSI = \frac{KI+EI+SCI}{3} \qquad (4)$$

where, KI, EI, SCI correspond to each of the dimensions of sustainability.

The results of the GSI were analyzed considering that a APU is sustainable if GSI > 2; but in addition, the three dimensions cannot have a value less than 2 (Painii-Montero *et al.*, 2020).

Principal Component Analysis

The assessment of the influence of economic, environmental and sociocultural indicators on the APU classified above was performed using principal component analysis (PCA). This analysis allows to explain the variables that are intercorrelated, and reduce the proportionality of a set of observations (Subba Rao *et al.*, 2020). It is very useful in the dimensionality of sustainability variables, allowing to identify analogous characters. In addition, it is a valuable tool for sustainability analysis, as it can identify the underlying structure of complex sustainability data and provide insights on how to improve sustainability practices (Ahmed *et al.*, 2021; Zhou *et al.*, 2020).

RESULTS AND DISCUSSION

Evaluation of sustainability in the APU of the parish El Tingo La Esperanza, Ecuador

Based on the context of the sustainability of El Tingo La Esperanza, Figure 3a shows the distribution of the economic development of the inhabitants that make up the productive units, with corn and bananas representing more than 65% of agricultural activity; therefore, it is necessary to consider the importance of these crops, from the point of view of their contribution to the Sustainable Development Goals (SDGs) set by the United Nations (Tanumihardjo *et al.,* 2020). However, sustainability processes, aligned with the way of production, with soil and water management and environmental certifications. Crops with lower production, but no less relevant, correspond to sugarcane, pastures and citrus fruits (23.8%); since they contribute to the diversification of production systems, as do other non-established products (7.3%) in this study, due to the small size of the productive area (less than 0.1 ha to 1 ha); but that contribute to food security and represent 73.4%; On the other hand, the size of plots of 1 to 5 ha is not very noticeable. The diversification of agricultural production, while important and leading to better food security outcomes, is decisive, from the point of view of the type of crops and area; This is quantifiable to determine the true magnitude of the assertion (Mulwa and Visser, 2020). Phytosanitary management, which accounts for 62.4% of incidence, suggests a lack of access to control technology that leads to the agroecological protection of crops compatible with the expectations of formal markets, (Lefèvre *et al.,* 2020); this is reflected in the low participation of farmers in the use and development of integrated pest management (IPM) technologies, due to the lack of understanding of agroecology (Deguine *et al.,* 2021). The number of species cultivated in each APU ranges from one (46.8%) to five (7.3%), which is common on small farms (Bellon *et al.,* 2020). The lack of mechanisms to improve productivity has an impact on monthly income, which; Consequently, they do not exceed 400 dollars, despite the fact that the number of products sold is varied, mostly three (40.4%) and in some cases more than six (9.2%). There is a need to change the approach to production in terms of agricultural sustainability, as smallholders are dominant in developing countries (Ren *et al.,* 2019), and orient towards the increase of economic income, since it has been proven that positive profit cushions the negative impact of agriculture on the environment (Olanipekun *et al.,* 2019); where, the production of more quality must be sufficient, such that the economic impact is significant and commensurate for the farmer. Attention could be directed to the type of market to which they have access, since most farmers market locally, to intermediaries (59.6%) and associatively (24.8%), this reality significantly limits the ability to access better incomes (Jacome *et al.,* 2020), despite the favorable diversification of production (Bellon *et al.,* 2020).

From the environmental point of view, according to Figure 3b, soil management with the use of organic fertilizers is represented by 43.1% and chemical fertilizers 28.4%; Organic fertilizers may represent a lower agronomic yield, although they contribute more to the improvement of the environment, contrary to the use of synthetic fertilizers (Chew *et al.,* 2019), the use of which has the greatest impact on conventional agriculture (Boschiero *et al.,* 2023). Other practices such as the planting of green manures and vegetation cover are infrequent, although a significant percentage of APU do not use any type of fertilizer (11.9%). Fallow soil is also a common practice (48.6%), so is the burning of waste (33.9%) and the use of waste for livestock feed (14.7%). Soil is an essential factor for environmental protection (Obrist *et al.,* 2017), The practices mentioned in this study contribute to their health, although the evaluation has focused only on improving their fertility, it is important to bear in mind that their holistic action due to their physical, chemical and biological properties, have a direct impact on environmental factors (Hou *et al.,* 2020). Water is constant and technically managed in some APU (39.4%), in others, water is scarce, non-existent or without technical management (60.6%), therefore, advocating for agricultural implementation models, such as agroforestry, no-till and other practices, would favor the sustainable use of water (Abafe *et al.,* 2022) and food security (Mazumder *et al.,* 2023). The slope can exceed 30%, so some APU maintain the soil with trees (67.9%) or carry out some conservation work such as terraces, furrows, contour lines and diversion ditches (84.4%). Steep slopes affect the movement of water, so taking actions to improve the efficiency of this resource could also transcend soil protection (Wang *et al.,* 2018), although no concrete actions have been seen for agriculture in this scenario, at least in developing countries (Piemontese *et al.,* 2020). The soils are compact and clayey, with a good content of organic matter and nutrients, which favors plant diversity, but the planting of short-cycle crops and the slope have an impact on natural diversity. Organic matter improves soil structure and other hydrophysical properties of the soil, which could be diminished by erosion and surface water movement (Aliku *et al.,* 2023).

In the social aspect (Figure 3c) it is shown that access to housing under basic conditions corresponds to 49.5%, other minimum conditions of habitability correspond to 21.1%, but a considerable number of inhabitants (29.4%) do not have, this situation of vulnerability is significant for sustainable development, it has been shown that the actions are

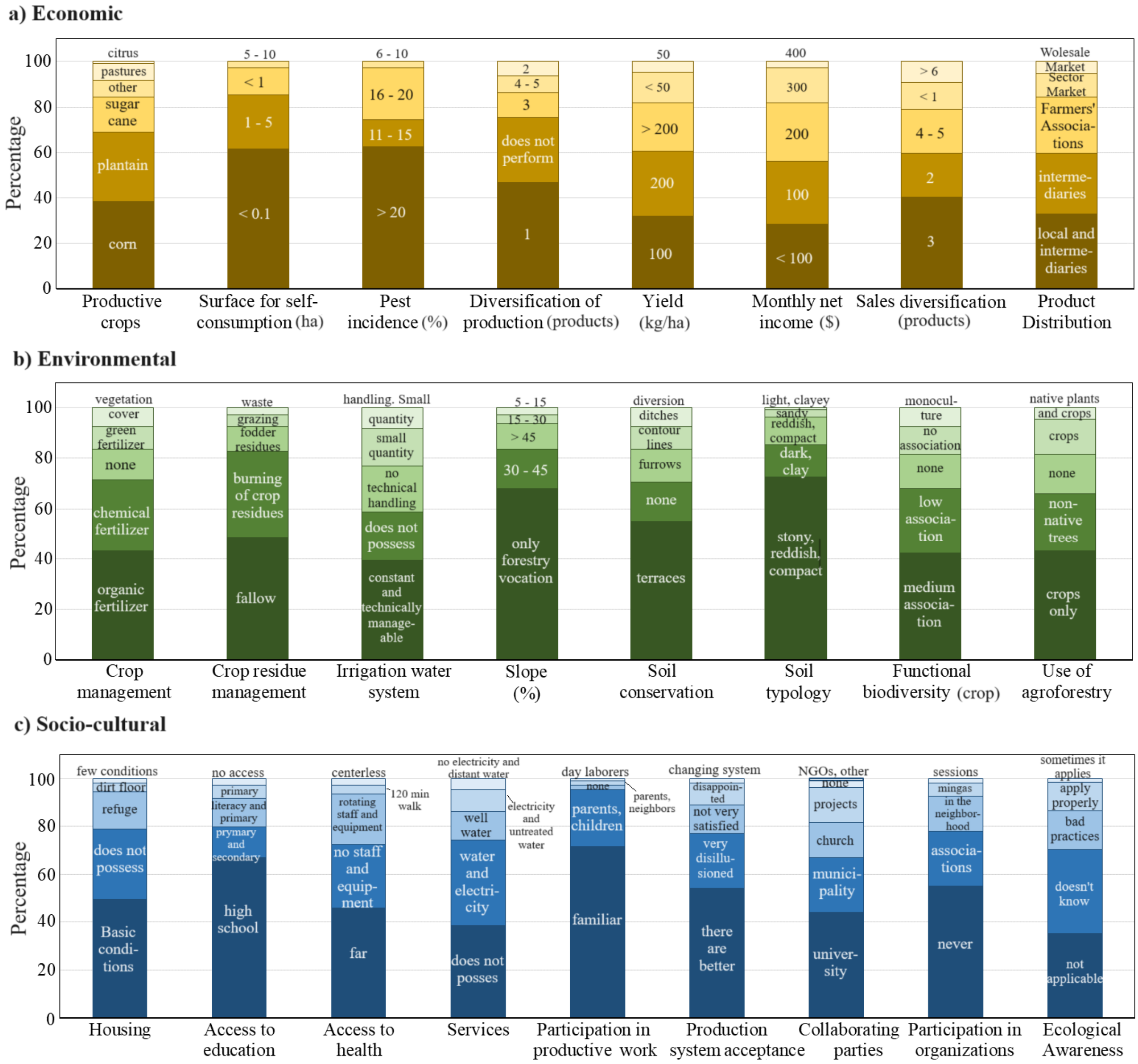

Figure 3. Frequency analysis for the 25 sustainability indicators of the parish El Tingo la Esperanza, Ecuador.

holistic, that is, Favoring the industrialization of products, implementation of livestock activities, use of clean energy, etc. can improve the economic situation of the inhabitants (Lambrechts, 2021; Miani *et al.*, 2023) and, as a consequence, access to housing. Another aspect is education, which is an important element for the implementation of sustainable practices such as agroecology (Barrios *et al.*, 2020), Since 67% have access to secondary education, compared to 2.8% without access to education, the innovation of technology is directly related to education, as demonstrated by the fact that 67% have access to secondary education (Shobande and Asongu, 2022), by explaining that investment in the knowledge of clean technologies can favor actions for the mitigation of carbon emissions and the sustainability of the environment. The members of the APU have access to primary education and literacy (30.3%); however, in terms of education, the deficiency in university admission is evident, which hinders the achievement of the SDGs (Leal Filho *et al.*, 2019). The health centers are located far from the production centers and with inadequate or deficient equipment. 61.5% have access to electricity and drinking water, although the conditions for obtaining water are diverse, which makes it difficult to achieve an adequate standard of living. It is still perceived that there are inhabitants without electricity (38.5%), this situation contradicts concrete actions for sustainability, because the inhabitants will be more aware of meeting their needs, without considering the importance of sustainability, this reality is evident in poor countries, as demonstrated by (Gassner *et al.*, 2019), indicating that policies must be consistent with the reality of those who maintain the agricultural diversity of a region. Most of the productive activities are carried out with family labor (95.4%) and they admit that the form of production should improve. There is a variety of support from the local university and the municipality, which is available to producers organized through associations or integration activities (45%). There is no in-depth knowledge of the importance of ecological management, and its application is deficient, this uncertainty can affect the endowment of resources that may be generated in the future and will have an impact on the resilience of production systems (Stanley, 2020). Finally, it is important to point out that food sovereignty is not only solvable with agroecological actions, but, rather, a compendium of actions that include power relations, rights and participations (Vallejo-Rojas *et al.*, 2022).

Sustainability dimensions by APU types

Once the three dimensions of sustainability for the APU of the parish of El Tingo La Esperanza were determined, they could be grouped according to similarities identified in the twenty-five indicators (Table 1). Five groups have been chosen to represent the different actions given the economic, environmental and social dimensions; that are carried out in each production unit and that demonstrate different results (Figure 4). Interpreting the groups generated in a cluster diagram (Collantes and Rodríguez, 2015), can make interpretation difficult; therefore, it is important to rely on the similarity index (distance) generated by the diagram and the experience in the study to make the selection, partitioning the level of the generated sets, although this discrimination is a pseudostatistical notion (Núñez-Colín and Escobedo-López, 2011). According to the analysis of Figure 4, the numerical information of each branch is represented by each of the APU, whose horizon line links represent the similarity between one and the other, while the vertical lines suggest the distance between one productive unit and another. This also defines the similarity of grouped subjects, so whole groups may have different degrees of grouping relative to others. Of the groups defined in this study, APU2 represents the highest percentage (49%), followed by APU5 (29%), APU4 (14%), APU1 (6%) and to a lesser extent APU3 (2%). In the APU1, most of the members are men aged 20 to 60 years, whose land areas on average correspond to less than 0.2 ha. In the APU2, there is a greater balance between the number of men and women, with ages exceeding 20 years and with areas of land that, in many cases, exceed 1 ha. The APU1 and APU2 have irrigation water and carry out soil conservation practices in their production systems. In addition, family members have access to primary and secondary schools without difficulty and their housing provides adequate comfort. The APU3 corresponds to a small group, whose levels of sustainability report relatively low indicators, with low economic income, without access to training and a low level of equation. In APU4, the majority of members are women, with the ages of this group fluctuating; However, most of them are over 30 years old, with land extensions greater than one hectare. APU5 contains a uniform number of both genders; Also, areas greater than one hectare and even greater than 5 ha are identified, which contrasts with settlers with land over 0.1 ha. Most of the locals do not exceed the level of secondary education, being relatively low the level of higher education; as well as training in agricultural issues. Education is fundamental and determines a social position and opportunities at the farm level; but, being a scarce resource at the farm level, it determines a stumbling block before decision-making to define concrete sustainability actions (Dalevska *et al.*, 2019).

Sustainability hotspots

The evaluation of the attributes of sustainability in the parish of El Tingo La Esperanza brings together five types of producers, where it is evident that Food Self-Sufficiency (AKI), that is, the ability to produce their own food is sustainable only in the group of APU 1 with a value 2.1. In APU3, serious problems are observed as members of this group fail to sustain their food security. The Economic Risk (BKI), based on resilience to economic crises, indicates that producers of APU1 and 2 are sustainable with values of 2.4 and 2.2 respectively. However, the other groups have deficient values (Figure 04). The Conservation of Soil Life (AEI) is another important indicator where groups of APU2 and 1 are the only sustainable ones with values of 2.7 and 2.2, respectively in contrast to those of the group of APU3 that present a total abandonment of the productive system for not presenting the capacity to protect and preserve the quality of the soil. In the Risk of Erosion (EIB), which results in soil quality, it is partially managed adequately by producers of APU1 with a value of 2.4, unlike the other groups that are deficient and therefore do not present concern for the environment. For Diversity Management (CEI), the group of farmers of the APU2 present a value of 2.5, being the only producers with responsible management alternatives (Figure 5).

In the Satisfaction of Basic Needs (ASCI) such as: food, housing, education, health and work; only the groups of APU2 and 1 are sustainable with values of 3.2 and 2.9 respectively, noting an abandonment of the authorities in the sector. For the Contribution to the Production System (BSCI), APU2 is sustainable with a value of 3.2, evidencing the existence of innovative producers. In the same way, the evaluation of the Integration in Organizational Systems (CSCI) indicates little integration between producers due to inequality in access to basic services and communication routes, specifically roads either because of their poor condition or because they do not exist, hinder communication between the inhabitants. Finally, for the Ecological Awareness indicator (DSCI), all groups are deficient, reflecting the limited capacity to understand and act on the consequences of mismanagement of natural resources in the face of the environmental challenges faced by the area (Figure 5).

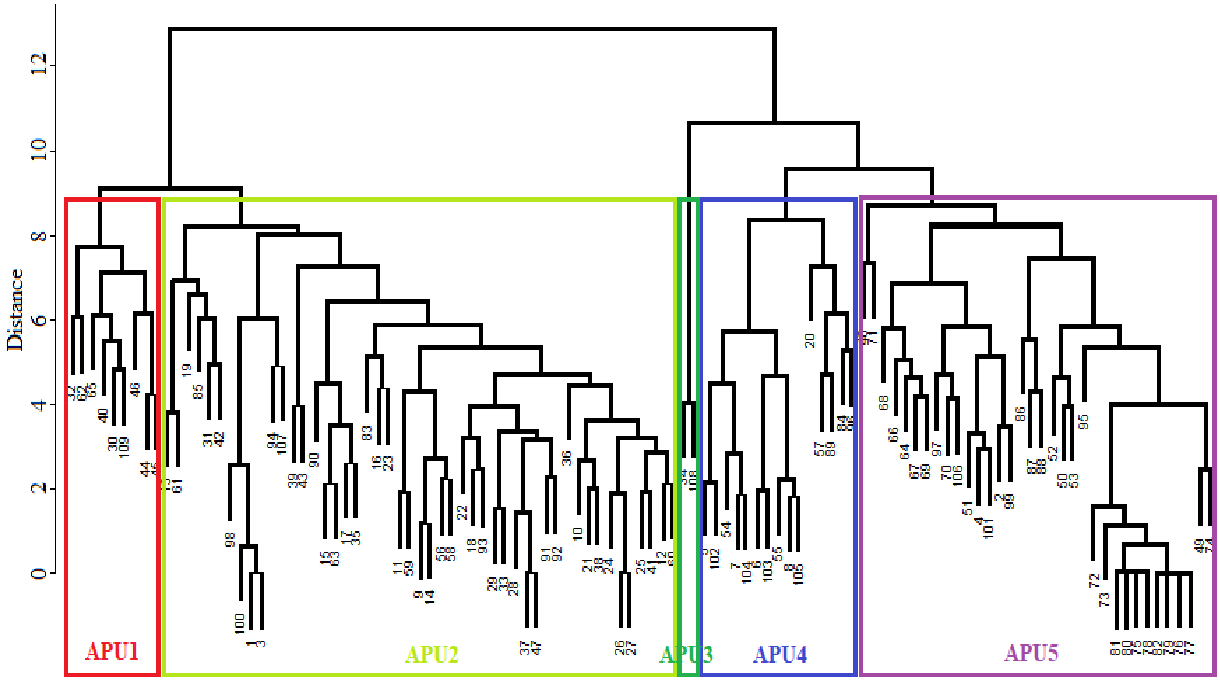

Figure 4. Hierarchical grouping of the five types of APU in El Tingo La Esperanza, Ecuador.

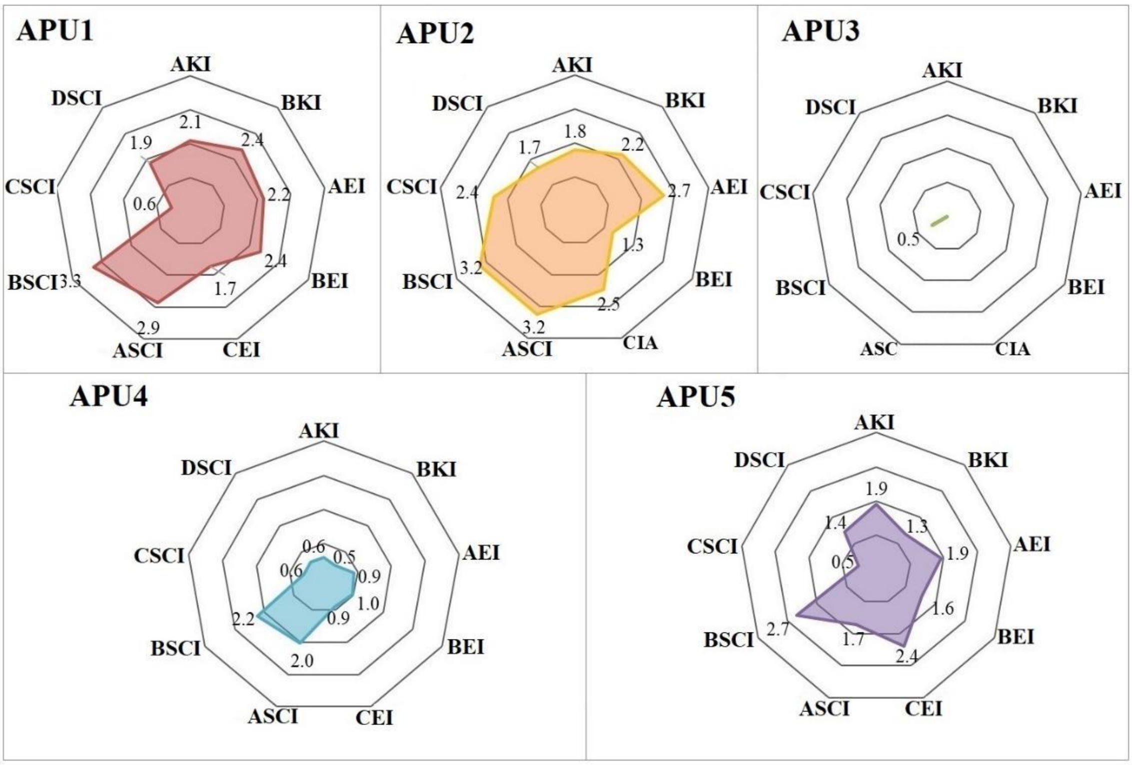

Figure 5. Diagram of sustainability indicators by attribute: Food Self-Sufficiency (AKI), Economic Risk (BKI), Conservation of Soil Life (AEI), Erosion Risk (BEI), Diversity Management (CEI), Satisfaction of Basic Needs (ASCI), Contribution to the production system (BSCI), Integration in organizational systems (CSCI) and Ecological awareness (DSCI).

The low sustainability of the sector has been one of the main causes of the aggression to the environment in the parish of El Tingo La Esperanza, due to the scarce planning on agricultural production, where producers have adopted unsustainable practices, which has caused the degradation of the soil and other resources. In addition, deforestation for the expansion of agricultural exploitation has caused the loss of biodiversity itself that has affected the ecological balance of the sector, causing soil erosion and landscape degradation. Agreeing with Merma and Julca (2012) and Díaz *et al.* (2017), who indicate that the low ecological awareness, the deficient economic income among the inhabitants, derives in a low sustainability that leads to the continuous aggression of the environment.

General Sustainability Index

Sustainability being a fundamental concept of the modern world, in order to understand the balance of natural and social systems, to ensure an optimal quality of life for all. In the parish of El Tingo La Esperanza, five groups of farmers were found, of which the producers of the APU1 are the only sustainable group and that could remain resilient in the face of current environmental and social changes since it obtained values higher than 2 in all its dimensions and with a GSI of 2.19. The farmers of the APU2, although they present a GSI of 2.31 are not sustainable, because in the economic dimension they reach a value of 1.91, which makes it difficult for this group to maintain their sustainable production system. For the group of APU3 there is a general crisis due to the very critical values with a GSI of 0.03 which determines a total abandonment of the productive system in all aspects. Farmers grouped in APU4 and APU5 have a GSI of 0.99 and 1.76 respectively; indicating little development of the agricultural sector in all dimensions due to low income, little diversity, low ecological awareness. These aspects lead to a continuous aggression to nature by economic pressure (Toala *et al.,* 2021).

In the frame of reference of the multicriteria analysis proposed by Sarandón it is evident that it is a flexible method of easy adaptation in the evaluation of the dimensions: economic, environmental and social. The same as in the El Tingo La Esperanza sector present low values, which implies that decentralized governments and governmental and non-governmental organizations support generating policies to promote social equity, to protect and restore natural resources. In the sociocultural dimension, the grouping of producers in society should be promoted to improve their production and marketing channels (Painii *et al.,* 2020).

Sustainability in the Ecuadorian Andes is complex and multifaceted, in a small area like El Tingo La Esperanza five groups of APU have been identified. Two of the five groups show progress in sustainability indicators. However, significant challenges to achieving sustainable development remain (Wanderley *et al.,* 2018). The assessment of sustainability indicators can help identify areas for improvement in sustainable development efforts and can inform decision-making processes to ensure that future development is sustainable (Arnés and Astier, 2018). It helps identify potential conflicts between economic development and environmental conservation and can inform strategies to balance these competing priorities (Arnés and Astier, 2018). Overall, sustainability indicators are an important tool for assessing the current state of sustainable development in the Ecuadorian Andes and for informing future efforts to ensure the continued health and well-being of the region (Gudynas, 2003; Palacios and Cuvi, 2017).

Principal Component Analysis

In Figure 6, the PCA, shows that the first two dimensions of analysis express 90.4% of the total inertia. The foreground represents 77.9%, this percentage is a very high value and, therefore, CP1 shows that the APU of El Tingo La Esperanza are highly influenced by the attributes BKI, BEI, CEI, CSCI, DSCI, BSCI; but a low influence of ASCI, AKI. APU1s are associated with environmental (IEC, CEI) and socio-cultural (BSCI, DSCI) dimensions. But APU2 is associated with three dimensions: economic (BKI), environmental (EIB) and socio-cultural (CSCI). ASCI and AKI hotspots are associated with APU4 and APU5 respectively. In addition, it is noted that the critical points DSCI, BSCI, CEI, AEI, are related to each other, as are CSCI, BKI and EIB. Unlike AKI and ASCI which are independent. In other words, the APU4 achieves (influences) the satisfaction of basic needs such as education, health and basic services, but not food self-sufficiency (surface area for production, incidence of pests and diseases, diversification of production, yield and net income).

This study demonstrates the importance of monthly income, satisfaction of basic needs (housing), ecological awareness and acceptability of the production system. However, these indicators should be monitored to ensure the long-term sustainability of UAPs (Gutiérrez *et al.,* 2017; Cachipuendo Ulcuango *et al.,* 2017). Also, indicators such as soil management, water, biodiversity and agroecological practices must be managed, because they are fundamental indicators in the promotion of sustainable food production (Arnés and Astier, 2018). In addition, they help mitigate the impacts of climate change on food production (Gutiérrez *et al.,* 2017; Mendez *et al.,* 2016; Cruz *et al.,* 2017; Bravo *et al.,* 2017; Hernández *et al.,* 2018).

Table 2. Values obtained for each dimension analyzed in the parish El Tingo La Esperanza, Ecuador.

Índices	APU1	APU2	APU3	APU4	APU5
Economic dimension (KI)	2.18	1.91	0.00	0.57	1.71
Environmental dimension (EI)	2.12	2.27	0.00	0.91	1.96
Socio-cultural dimension (SCI)	2.29	2.75	0.1	1.5	1.62
General Sustainability Index (GSI)	2.19	2.31	0.03	0.99	1.76

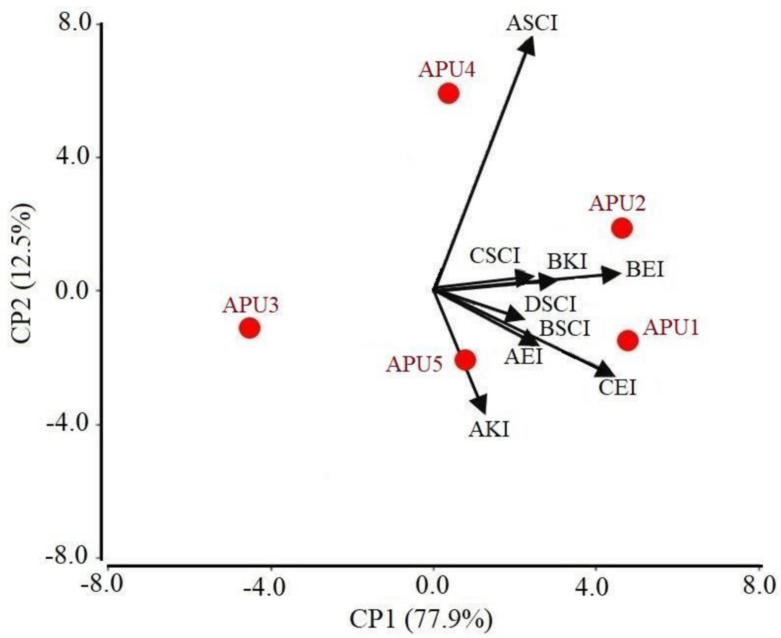

Figure 6. Descriptive scheme of the relationship between grouped APU and significant indicators for the discriminant analysis of sustainability (Food Self-Sufficiency =AKI, Economic Risk=BKI, Conservation of Soil Life=AEI, Erosion Risk=BEI, Diversity Management=CEI, Satisfaction of Basic Needs=ASCI, Contribution to the production system=BSCI, Integration in organizational systems=CSCI and Ecological awareness=DSCI).

The Ecuadorian Andes face several socioeconomic challenges that impact sustainability. These challenges include poverty, limited access to education and health care, and political instability, which can lead to environmental degradation and unsustainable practices (Stiftung, 2013). In addition, economic actors behind development agencies and local governments often prioritize their own interests over sustainability efforts, creating more obstacles to sustainable development (Hernández, 2020). Addressing these challenges is crucial to improving sustainability indicators in the Andes and promoting long-term environmental and social well-being.

CONCLUSIONS

In the parish of El Tingo La Esperanza, there is a lot of variability among the productive systems of the sector, so it was necessary to integrate variables to form similar groups of farmers, based on their technological level, access to basic services; as well as economic income. The grouping of APU by Ward's method resulted in five types of producers, demonstrating that not all of them have the same technology, income; This denotes the lack of capacity for social integration. The sustainability obtained by applying the Sarandón methodology with 25 indicators grouped into three dimensions: 8 for the economic dimension, 8 for the environmental dimension and 9 for the socio-cultural dimension, allowed us to observe that in the sector there is a weak sustainability in all dimensions, especially in the environmental dimension, which indicates a constant aggression against the environment.

The evaluation of the General Sustainability Index shows that APU1 are sustainable and resilient, while those in the APU2 group are affected by difficulties in the production system, the APU in group 3, 4 and 5 have very low sustainability values, with very critical values, especially in the APU3 group; which indicate that the producers of the aforementioned group live in critical conditions and therefore are not associated with any sustainability attribute as explained in the principal component analysis.

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Conflict of interest. The authors declare they have no conflict of interest

Compliance with ethical standards. The research was carried out with the knowledge of the local authorities and with the consent of the people in charge of the APU

Data availability. The authors declare that the information obtained from the people surveyed was used for research purposes between the local government and the Technical University of Cotopaxi. Data is available with the corresponding author upon reasonable request.

Author contribution statement (CRediT). V.M. Garcia-Mora- Conceptualization, Writing – original draft, Data curation and Formal Analysis. Y.V. Mogro – Conceptualization, Investigation. E.J. Jacome – Conceptualization, Methodology, Writing – original draft. M.L. Ilbay-Yupa – Conceptualization, Methodology, Writing – review and editing.

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