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Payment Mechanism for Environmental Services of the Sabana Rubia Paramo, An experience towards Environmental Sustainability

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ABSTRACT

This research strives to know the feasibility of the payment for environmental services (PES) mechanism within the Rubia Páramo savannah páramo, located in the municipality of Manaure Balcón del Cesar, Colombia, with a particular approach that incorporates methods such as contingent valuation, the willingness of local communities to pay (DAP) using logistic model and MCO. The results revealed that 71.73% of respondents know the páramo and value its ecosystem services, highlighting that women with the highest level of education are 1.45 times more likely to pay than men. The projected financial value of the estimated DAP is COP$500 per individual, suggesting an annual total of COP$615,792,000 if comprehensive coverage is achieved. The research concludes that, despite the social challenges, the PES could be an effective tool for conservation, especially if institutional trust is strengthened and awareness strategies are implemented.

Keywords: Payment for Environmental Services, willingness to pay, conservation, Barbaric Savannah Paramo, economic valuation.

1. Introduction

The need to rethink the traditional dynamics of environmental conservation has become more relevant in the face of the progressive deterioration of strategic ecosystems such as the páramos, for example, in Colombia, these territories not only represent reservoirs of biodiversity, but also crucial sources of water regulation and climate balance, therefore, the present study focuses on the analysis and formulation of a Payment for Environmental Services (PES) mechanism applied to the Sabana Rubia Paramo, located in the municipality of Manaure, department of Cesar. The interest in this research responds to both

academic and professional concerns, aimed at supporting public and community decisions from technical tools of environmental economic assessment.

This work arises from the imperative of strengthening alternatives that promote sustainability in rural territories, where agricultural pressures, economic informality and weak institutionality threaten the ecological integrity of the landscape based on the recognition of PES as an economic incentive, either in kind or in money, aimed at promoting conservation through voluntary agreements between key actors. According to the Ministry of Environment and Sustainable Development – MINAMBIENTE, these mechanisms are based on five pillars: incentive, beneficiaries, stakeholders, preservation and restoration actions, and contractual agreements, with established modalities that focus on environmental services such as water regulation, biodiversity conservation, greenhouse gas capture, and the cultural and recreational benefits associated with territory.

The legal framework that supports this initiative is solidly structured in the Political Constitution of 1991, particularly in its articles 79, 80 and 339, which stipulate the right to a healthy environment and the obligation of the State to conserve areas of special ecological importance, in turn, regulations such as Decree-Law 870 of 2017 and Decree 1007 of 2019, together with resolutions 1084 of 2018 and 1628 of 2015, provide the technical and methodological guidelines for implementing PES schemes, including the calculation of opportunity cost and priority territorial coverage. This framework is complemented by instruments such as CONPES 3886 of 2017, which sets the guidelines for the National PES Program, and CONPES 3850 of 2015, which links these mechanisms to the Colombia in Peace Fund, recognizing their relevance in post-conflict contexts.

From a methodological approach, the research adopts a quantitative paradigm, as proposed by Hernández and Mendoza (2018), based on the measurement of variables, the use of statistical instruments and the analysis of hypotheses, with an explanatory scope, since it seeks to elucidate the causes that determine the willingness to pay on the part of the community. as well as to estimate the financial viability of the scheme in a rural environment with marked socioeconomic particularities. For this purpose, the contingent valuation technique is used, validated by logistic regression and multiple linear regression, thus allowing robust estimates on the willingness to pay and the monetary value assigned by the inhabitants to the ecosystem services of the páramo.

The target population includes the municipalities of Manaure Balcón del Cesar, Robles La Paz, San Diego, San José de Oriente and Betania, territories located within the area delimited by Resolution 1628 of 2015. From a simple probabilistic and random sample, a structured survey was applied that allowed to collect the environmental perception, territorial knowledge and willingness to pay on the part of the communities directly benefited by the provision of water and other ecosystem services. This information feeds the development of econometric models validated with STATA and Python software, following the quality standards required for environmental assessment analysis.

The content of the work is structured according to the three specific objectives. First, a technical and social diagnosis is developed on the environmental goods and services of the Sabana Rubia Paramo, identifying their ecological functions, the actors involved and the current pressures on their territory, being an analysis that addresses an ecosystem and community perspective. Secondly, the formulation of the PES scheme is presented, based on the current regulatory framework and technical criteria of prioritization, cost-efficiency and equity, being an integrative component with results of the survey, econometric analysis and the proposal of agreements between actors. In the third and final instance, the contingent economic value that the community would be willing to contribute voluntarily for the conservation of the páramo is estimated, taking as a reference the median of the declared contribution and adjusting the projections based on the coverage of the aqueduct service and the frequency of payment expressed by the respondents.

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2. Theory

In the field of environmental economics, it is essential to understand how goods and services are classified according to their availability and access, which translates into the way they are used within markets, in this sense Fernández and Salazar (2015) mention that goods can be classified into four main categories: rivals, non-rivals, excluding and not exclusive. This differentiation has a direct impact on markets, as it determines the way in which goods and services are exchanged and how their value is assigned. Rival goods are those whose use by one person limits their availability to others, while non-rival goods can be harnessed by several individuals without reducing their supply. On the other hand, exclusionary goods allow access to be restricted, unlike non-exclusive goods, which are available to everyone. This classification is fundamental to understanding the distribution of and access to ecosystem services, which, by their very nature, cannot be efficiently exchanged in conventional markets.

As for ecosystem services, these represent the benefits that nature provides to humanity. According to the FAO, they are essential for regulating natural cycles and sustaining life on the planet. Biodiversity is a key pillar within this concept, as it ensures the proper functioning of ecosystems and, therefore, of the services they provide. FAO groups them into different categories: supply services, such as food, fresh water and medicinal resources; regulatory services, including climate control, carbon sequestration and erosion protection; support services, such as habitat for species and conservation of genetic diversity; and, finally, cultural services, which encompass intangible benefits such as tourism or spiritual values linked to nature. Despite their importance to human survival, their value is often underestimated due to their immaterial nature.

On the other hand, the total economic value encompasses both the use and non-use value that environmental goods contribute to society. The Alexander Von Humboldt Institute points out that, given their relevance, people would be willing to pay to access these limited resources. These are divided into use value (such as water or food) and non-use value (such as the cultural or spiritual significance of an ecosystem). Economic valuation helps to make visible the financial importance of these services, facilitating their conservation through tools that adequately protect them.

Based on these principles, environmental economic valuation has become a key area for the protection of ecosystems. This methodology is divided into two main approaches: the revealed preference methods and the stated preference methods. The former analyze real behaviors in the market, such as the travel cost method or hedonic prices, which measure how much people are willing to pay for goods linked to the environment. The latter, such as contingent valuation or conjoint choice experiments, estimate this disposition through surveys in hypothetical scenarios. Contingent valuation, in particular, is one of the most widely used techniques, as it recreates a fictitious market to assess how society values nature protection.

Payment for Environmental Services (PES) is an economic instrument designed to promote conservation by compensating those who contribute to maintaining ecosystems. These rewards can be monetary or in-kind, and seek to minimize conflicts over land use while driving sustainability. According to the Ministry of Environment, the PES is made up of five pillars: the incentive for those who conserve, the beneficiaries of these supports, the actors involved, the preservation and restoration actions, and the agreements that formalize the commitments. Its modalities include the protection of watersheds, the conservation of biodiversity, carbon sequestration and the safeguarding of cultural and recreational values.

The amount of the incentive in a PES is calculated considering the opportunity cost of land in strategic ecosystems, that is, the profits that would be lost by prioritizing conservation over other productive activities. Decree 1007 of 2018 establishes that this value must be based on these costs and apply the principle of cost-effectiveness to optimize the available resources and expand the protected area. This approach ensures that funds earmarked for conservation are used efficiently.

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In the legal field, Colombia has a solid regulatory framework to implement PES. Articles 79 and 80 of the 1991 Constitution recognize the right to a healthy environment and the State's obligation to protect natural resources. Other regulations, such as Decree-Law 870 of 2017 and Decree 1007 of 2018, detail the technical guidelines to execute these schemes, defining their conditions and principles. These regulations are complemented by policies such as CONPES 3886 of 2017, which promotes PES at the national level, and CONPES 3850 of 2015, which links them to the Colombia in Peace Fund, facilitating the financing of projects in areas of strategic interest.

The Sabana Rubia Paramo, located in the municipality of Manaure, Cesar, is a key ecosystem for the region. Not only does it regulate the water cycle, ensuring supply to nearby populations, but it is also home to a great diversity of species. However, its conservation is at risk due to pressures such as the advance of agriculture and informal economic activities.

Against this backdrop, Payment for Environmental Services (PES) is a promising alternative. This model seeks to reconcile the protection of the páramo with the development of local communities, allowing those who care for it to receive economic benefits in return. Thus, the implementation of a PES scheme in Sabana Rubia would not only help preserve this valuable ecosystem, but would also improve the living conditions of its inhabitants, generating income through conservation.

For this mechanism to work, it is essential to have a good understanding of the theoretical, legal and social aspects that underpin it. Only then can its long-term success be guaranteed.

3. Materials and Methods

The study to design the PSA of the Sabana Rubia Páramo followed a mixed-sequential methodological approach (Hernández & Mendoza, 2018). This process combined different techniques to collect and analyze information, ensuring that the objectives set out in the research were met. The population corresponds to the communities settled in the vicinity of the study area that corresponds to that established in Article 1 of Resolution 1628 of 2016 "By which zones of protection and development of renewable natural resources and the environment are declared and delimited and other determinations are made", Polygon 4. Serranía del Perijá in Table 4 of Annex 1. Its extension corresponds to an area of 267,414.58 hectares, an area in which the Sabana Rubia páramo is included.

The sample is simple, probabilistic and parametric random for the known population, according to Bencardino (2012), it is given by the following mathematical formulation:

$$n = \frac{Z_{\alpha}^{2} Npq}{e^{2}(N-1) + Z_{\alpha}^{2} Npq} \qquad (1)$$

Where

n = Sample size by simple random selection.

N = is the size of the population or universe (total number of possible respondents).

p = is the success factor (usually assumed as 50%).

q = is the failure factor (calculated as follows, q = 1 – p; which in this case would be 50%).

Zα = is a constant that depends on the level of trust we assign. The confidence level indicates the probability that the results of our research are true: 95.5% confidence is the same as saying that we can be wrong with a probability of 4.5%. Zα values are obtained from the table of the standard normal distribution N(0,1).

The initial phase of the research consisted of identifying the actors involved in its preservation. To this end, several documentary activities were carried out that included the search for scientific information in digital repositories as a bibliographic review of previous studies on the region under study, supported by entities such as CORPOCESAR, the Alexander Von Humboldt Institute (IAvH) and IDEAM, which

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made it possible to obtain a relevant documentary base on the management of the páramos in the region.

To assess the population's willingness to pay (DAP), advanced statistical and econometric methods were used, including the logit model and multiple linear regression (MCO). These allowed us to analyze how factors such as gender, age, educational level, occupation and income influence people's valuation of ecosystem services.

The results not only revealed the key variables affecting DAP, but also facilitated a descriptive analysis using graphs. These visualized overall trends in responses and helped identify patterns in participants' environmental practices. A relevant finding was the connection between knowledge of the territory and the valuation of ecosystems, which reinforces the importance of environmental education in conservation.

The research also included an analysis of the logit model (see equation 2), which made it possible to estimate the probability of willingness to pay.

$$P(Y = 1|X_1, \ X_2, \dots, X_n) = \frac{1}{e^{-(\beta_0+\beta_1*x_1+\beta_2*x_2+\cdots+\beta_n*x_n)}} \qquad (2)$$

Where

P(Y = 0|X1, X2, ..., Xn) = is the probability that the dependent variable Y is equal to 1 (e.g., the probability that an individual is willing to pay for environmental services).

β0 = is the model intercept, which represents the probability of Y= 1 when all independent variables are equal to zero.

β1, β2, ... , βn = are the coefficients of the model that indicate the marginal effect of each independent variable X1, X2, ..., Xn on the probability that Y = 1.

The study validated the model using key statistical tools such as sensitivity, specificity, ROC curve and optimal cut-off point, which allowed to accurately measure how much inhabitants value the conservation of these ecosystems. To determine the economic value of this willingness to pay, the multiple linear regression (MCO) method was used, taking into account determining factors such as socioeconomic status, interest in acquiring land, and the time they would be willing to contribute to the PES system.

A key aspect of the study was understanding how local communities view this payment for environmental services scheme. The interviews and surveys applied revealed concrete obstacles: from initial mistrust and lack of clear information to institutional problems that hinder participation. The detailed analysis of the testimonies helped to better understand both the resistance and the expectations that the inhabitants had regarding the program. This information was enriched by the application of Mendelow's (1981) stakeholder matrix, a tool that organized participants according to their level of interest and influence, allowing the design of specific strategies to achieve their commitment to the conservation project.

The analysis also exposed the main challenges that the implementation of the PES would face, including financing problems due to low revenue, informality in local economic activities, and mistrust of institutions. Added to this are environmental pressures, such as the expansion of the agricultural frontier, low environmental awareness and the constant movement of population in the area, factors that threaten the stability of the model in the long term. In the face of these challenges, the study proposed concrete measures to reduce risks and ensure that the mechanism operates sustainably.

Monthly and annual collection projections were made under different scenarios of coverage, frequency and participation, which made it possible to identify the implications for the operational management

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of the PES and evaluate the economic feasibility of the scheme, considering both the social and environmental context of the region.

4. Results and Analysis

The analysis of the results obtained from the economic valuation survey applied to the communities that are supplied with water for consumption as a result of the Sabana Rubia Páramo provided key information on the perception and disposition of the inhabitants regarding the conservation of this ecosystem. With a sample, which included 796 people from the municipalities of Manaure Balcón del Cesar, San José de Oriente and Betania, Robles La Paz, San Diego and Agustín Codazzi, representing 36.56% of the population of 102,632 inhabitants, a relatively low figure due to the floating population and also small due to the existing distrust towards the research process. Despite the fact that some of these localities have a significant coverage of the aqueduct service, as can be seen in the coverage data in Table 1, most of the respondents positively value the ecosystem services provided by the páramo, especially water production.

Table 1. Aqueduct coverage in the populations under study

Locations	Aqueduct Coverage
Agustín Codazzi	0,95
Manaure	0,75
San José Oriente and Betania	0,75
Robles La Paz	0,75
San Diego	0,75

Note: Taken from the National Report on the Coverage of Public Aqueduct, Sewerage and Sanitation Services of the Ministry of Housing, City and Territory – MINVIVIENDA and the Superintendence of Residential Public Services – SSPD period 2022.

The level of knowledge about the páramo is remarkable, since 71.73% (Figure 1) of the respondents stated that they were aware of the existence of páramo ecosystems in the Perijá del Cesar mountain range. This knowledge, in turn, translates into a positive valuation of the ecosystem services provided by the páramo, such as climate regulation, biodiversity and, especially, water production.

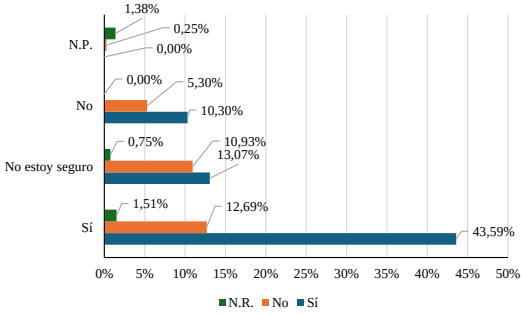

Figure 1. Respondents' Willingness to Pay vs. Everyday Environmental Actions. In original Spanish language

The relationship between knowledge of the territory and willingness to pay is clear: those who understand the relevance of the páramo are more likely to contribute economically to its conservation. This pattern is aligned with the studies of Ripka de Almeida, Adriana et al. (2018), which underline the importance of local knowledge about an ecosystem for the determination of its economic value.

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$$Li = \ln\left(\frac{pi}{1-pi}\right) = -\beta_0 + \beta_1 * Genero + \beta_2 * NivelEducativo + \beta_3 * Ocupacion + \beta_4 * ValorServiciosEcosistemicos + \beta_5 * BeneficioPáramo \quad (3)$$

The econometric model (equation 3), which includes a logistic analysis (logit), made it possible to estimate the probability of willingness to pay and its monetary value, highlighting the relevance of variables such as gender, educational level, occupation, valuation of the ecosystem services of the páramo and knowledge about water benefit.

Figure 1. It was shown that women with more education increase the probability of payment compared to men. In original Spanish language

The results show that women are 1.45 times more likely to be willing to pay than men, and that educational attainment increases this probability by 46.4% for those with university studies compared to those without formal education (Figure 2). This pattern supports the hypothesis that educational level is a key factor in the willingness to participate economically in conservation initiatives, which is in line with what UNESCO (2021) points out, which highlights the impact of educational inequalities on economic decisions related to the environment.

The validation of the logistics model showed that the sensitivity was 90.21%, indicating that the model is effective in correctly identifying people willing to pay. The specificity, on the other hand, was 45.15%, and the ROC curve of 0.76 confirms that the fit of the model is adequate, being criteria that validate the effectiveness of the model as a predictive tool in contexts of economic valuation of ecosystems.

On the other hand, the analysis of the MCO model (equation 4) allowed estimating the monetary value of the EPD at approximately ~COP$500, revealing that the socioeconomic status has a negative relationship with the willingness to pay, that is, people from lower strata are more likely to contribute than those from higher strata.

$$DAP(X/Sí) = \beta_0 - \beta_1 EstratoSocioeconomico + \beta_2 ConocíaSerraníaPerija + \beta_3 CompariaTierraParamo - \beta_4 ActividadTierraParamo + \beta_5 MontoAporteVoluntario + \beta_6 TiempoAporteVoluntario + \beta_7 ModoRecepcionAporteVoluntario \quad (4)$$

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This could be explained by the perception of greater need and direct dependence on ecosystem services in the lower strata, likewise, the willingness to buy land in the páramo showed a positive relationship with the DAP, which indicates that people interested in acquiring land in the páramo are more likely to contribute financially to its conservation.

Conversely, those who consider activities such as agriculture or pastoralism are less willing to pay, suggesting that conservation activities are preferred over productive activities, with findings aligned with the literature on social and environmental capital as determinants in economic decisions about ecosystem conservation (Cervantes, 2014).

When analyzing the willingness to pay (DAP), estimated based on demographic variables such as gender, age, educational level, occupation and daily environmental practices, it is observed that women, people with a higher level of education and those who actively participate in daily environmental actions are more willing to pay for the conservation of the ecosystem, so women's empowerment is an important sociological factor for territorial management. which reveals patterns in respondents' responses about age and occupation: younger people and those with formal jobs show a greater willingness to contribute.

This is consistent with the findings of the World Health Organization (2018), which identifies a correlation between gender, educational level, and willingness to pay for ecosystem services. Although income and occupancy also influence EPD, there does not appear to be a direct and linear relationship, suggesting that other factors, such as benefit perception and environmental education, play a more determining role in willingness to pay.

After analyzing the data on willingness to pay obtained from the survey, a spatial study was carried out to identify areas that could be priorities for conservation and restoration within the territory of the Sabana Rubia Paramo. Using opportunity zoning, areas were identified with characteristics conducive to preservation and others that, due to their high degree of transformation, require restoration. According to the geospatial analysis, areas with low impact, such as those that cover the Páramos and Subpáramos with natural grade, are considered optimal for conservation, since these areas still maintain their ecological integrity and fulfill an essential function in the ecosystem. In fact, 125.69 km² of Páramo and Subpáramo were allocated to conservation due to their low impact and natural condition. In contrast, areas with high impact and transformed degree, such as Grass Mosaics and Agroecosystems, were classified for restoration, since they present a higher degree of alteration, which implies the need for interventions to recover their ecological functionality.

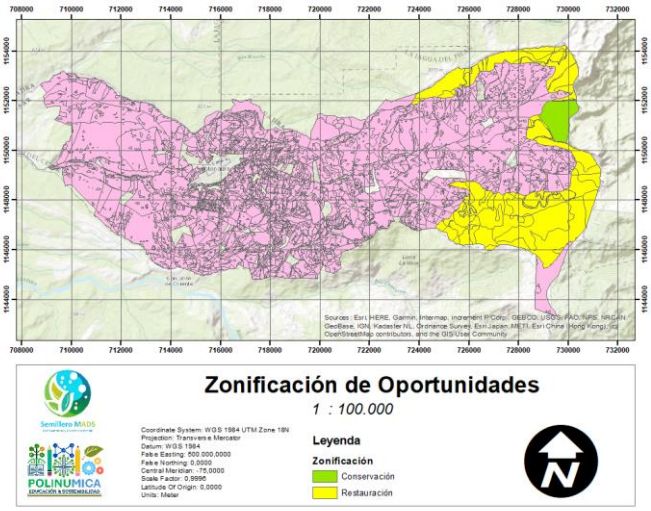

Figure 2. Zoning of opportunities for the conservation and restoration of the Sabana Rubia páramo ecosystem. In original Spanish language

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The opportunity zoning map (see Figure 2) clearly illustrates these areas, highlighting in yellow those designated for restoration () and in pink those that are considered priority for conservation. According to the analysis, the areas destined for restoration cover a total of 20.86 km², and are mostly Mosaics of Fragmented Pastures and Forests, which have a medium to high impact and a transformed degree. Likewise, it was observed that forests with low impact and natural grade are essential for conservation, covering 5.24 km² of area. On the other hand, areas of Fragmented Forests with regular impact and transformed degree were considered priorities for restoration, with a total of 0.91 km². These findings provide detailed guidance on how to carry out conservation and restoration strategies in the Sabana Rubia Paramo, aligning with the guidelines established in Decree 1007 of 2018 and Decree-Law 870 of 2017, which define the areas of intervention within the context of the country's environmental management.

The results of the study show that communities face several barriers to participating in payments for environmental services (PES) programs. Many respondents expressed distrust of the institutions that manage these projects and admitted not having enough information about how they could benefit. Some even see PES as a political tool rather than an environmental one, which has created resistance in several groups. These findings are consistent with what was documented by Mendelow (1991), who had already pointed out how distrust in institutions can hinder the application of conservation schemes based on economic incentives.

By applying the Mendelow matrix to analyze the actors involved, it became clear that peasants and community action boards are fundamental pieces for the success of the program, since they show both interest and capacity to influence its development. On the other hand, although mayors' offices and NGOs actively participate in the management of the PES, their decision-making power is more limited, which requires the design of specific strategies to achieve their full commitment. Among the greatest risks detected are financing problems due to low collection, the high level of informality in local economic activities, little trust in institutions and little environmental education. All these factors make evident the urgency of implementing awareness campaigns and improving institutional capacity if the future of the program is to be secured.

Regarding the low-collection economic approaches for different scenarios, monthly revenues of COP$51,316,000 were projected, which is equivalent to COP$615,792,000 per year if a 100% participation were reached, however, these results must be interpreted in light of the social and economic challenges of the region, such as labor informality and lack of environmental education. which could reduce the effectiveness of PSA in the long term. Therefore, the implementation of awareness-raising and strengthening strategies, such as natural conservation contracts, by the institutions in charge of managing the PES to ensure a sustained commitment of the community to the conservation of the Sabana Rubia Páramo and its ecosystem services would serve in an essential way for the nearby populations, in terms of the regulation of guarantees for the protection of water rounds and continuity in the environmental service in modality Water.

5. Discussion

The analysis of the willingness to pay (DAP) for the water regulation service of the Sabana Rubia Páramo shows interesting patterns on the perception and value of this territory, in this sense comparing the results achieved is a fundamental step, so addressing this situation from previous studies, such as that of Pedroza and Pérez (2020). that investigated the Páramo El Verjón, allow us to see that the residents of the area show considerable knowledge about the ecosystem and its benefits, which increases the willingness of the inhabitants to contribute financially to its conservation, which is the result of the study that has been used in this study, which reinforces the validity of the results obtained by correlating local knowledge about ecosystems with the willingness to contribute to its conservation. pay.

In the case of the Sabana Rubia Páramo, 71.73% of respondents stated that they were aware of the existence of the páramos in the Perijá mountain range, which coincides with the findings of Alvarado et

al. (2020), who also highlighted the importance of local knowledge for the implementation of PES schemes in areas of high water relevance.

Regarding water management, it was identified that the population deeply values the regulation of the climate and biodiversity of the páramo, aspects that are crucial for the Páramo de la Vereda Romeral according to Alvarado et al. (2020), authors who also found that the PES schemes in their research were well received by the communities, especially in relation to the protection of water sources, which reinforces the connection of the results obtained with the Sabana Rubia Paramo, which also serves as a water source for several municipalities in the region.

Although Lombana (2019) focused his research on the substitution of cultivation areas for conservation processes in La Hidráulica, the similarity with the case of the Sabana Rubia Páramo is clear, since, in both studies, the willingness to receive economic incentives to change land use is high. In this research, it was observed that those inhabitants who are involved in activities such as agriculture and pastoralism have a reduced willingness to participate in the PES scheme, which coincides with the findings of Lombana, who also found that productive activities tend to detract from interest in conservation initiatives.

The analysis of the economic valuation carried out by Mayorga and Caro (2018) on ecosystem services in Samacá, Boyacá, offers an interesting framework to understand how environmental services are valued in rural regions, since, as in Samacá, the identification of key actors and the quantification of conservation benefits were essential elements for the design of this PES. although, in the case of the Sabana Rubia Paramo, the estimated opportunity cost per hectare was lower than that of Samacá, given that productive activities are not as intensive in terms of land exploitation, so it is a finding that, although it challenges each other, confirms the need to adapt PES strategies to the specific socioeconomic characteristics of each region, as these authors suggest.

In the analysis of socio-ecological systems, Sandoval's (2018) study has been fundamental to understanding how social and political factors affect the implementation of PES. This study reveals that distrust in institutions and lack of information are significant barriers to community participation in conservation programs, since lack of trust is something that has also been pointed out by Mendelow (1991) in his analysis of actors, where communities with greater power and interest are more likely to get involved in participatory processes such as PES schemes. In the Páramo Sabana Rubia, key local actors, such as community action boards and peasants, are the most inclined to participate in the program, but their participation is limited by misinformation and institutional mistrust, which coincides with the barriers identified in the studies analyzed.

The CVC's Association Agreement No. 115 of 2016, which implemented a compensation system for environmental services in the páramos of Valle del Cauca, provides key experiences to adapt the PES to the Sabana Rubia Paramo. This agreement prioritized the identification of critical areas for conservation and restoration, an approach similar to that used in the Sabana Rubia study, where both areas with potential for preservation and others that need urgent intervention due to their advanced deterioration were detected.

The results of the geospatial analysis in Sabana Rubia were revealing: natural forests, with low human impact, emerged as vital spaces to protect, while agroecosystems, highly transformed, require immediate restoration actions to recover their ecological functions. This distinction is essential to design effective conservation strategies in the páramo.

On the other hand, Ripka de Almeida et al. (2018) underline the relationship between local knowledge and the willingness to pay for ecosystem services as fundamental before initiating any consistent and social process. In the Sabana Rubia Paramo, it was observed that those individuals with a higher level of education and greater knowledge about the benefits of the páramo are more likely to contribute economically to conservation, also reflected in the econometric model developed, which shows that women with a higher level of education are 1.45 times more likely to be willing to pay than men. and

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that educational level increases this probability by 46.4% for those with university studies, a finding coinciding with and supported by UNESCO (2021), which highlights the impact of educational inequalities on economic decisions related to the environment.

The socioeconomic study revealed an interesting pattern: people from lower strata show greater interest in participating in the PSA. This seems to indicate that these groups value the services provided by ecosystems more, probably because they depend directly on them for their livelihoods. These findings coincide with what Cervantes (2014) proposed on how social and environmental capital influences economic decisions related to conservation.

Another relevant fact was that those who showed interest in buying land in the páramo were also more willing to support the PES scheme. This reinforces the idea that economic incentives, especially those linked to productive activities, play a key role in the success of these conservation programs, as other studies on the financial feasibility of PES have shown.

The geospatial zoning of the Sabana Rubia Páramo identified priority areas for conservation and restoration, with an area of 5.24 km² dedicated to conservation due to its low impact and natural condition, while 20.86 km² were assigned to restoration, which implies the territorial imbalance in a protected area such as the Serranía del Perijá Natural Park. however, this zoned approach coincides with the principles established in Decree 1007 of 2018 and Decree-Law 870 of 2017, which guide the implementation of conservation and restoration projects in strategic ecosystems.

The research made it clear that while other approaches could be explored, the reality is that applying a PES scheme in the Sabana Rubia Páramo will not be easy. Problems such as distrust of institutions and labor informality represent important obstacles. However, the study also showed that with a good awareness campaign and adequate institutional strengthening, this mechanism could become an effective solution to protect this strategic ecosystem.

6. Conclusions

The study on Payment for Environmental Services (PES) in the Sabana Rubia Páramo demonstrated two important things: first, that it is possible to implement this mechanism in such a vital ecosystem for the region, and second, that the methodology developed could be applied in other páramos of the country with similar characteristics. The results fully coincide with the objectives set at the beginning, confirming that, despite the typical challenges of rural areas and their socio-economic complexities, PES can become a real alternative to conserve strategic ecosystems such as moorlands.

To reach these conclusions, rigorous quantitative methods, including econometric models and contingent valuation, were used to help accurately calculate the willingness to pay (DAP) of the inhabitants. This data provides a reliable starting point for those who want to replicate the experience in other territories.

One of the most significant advances was to design a practical operating model that, in addition to protecting the páramo, generates concrete economic benefits for the communities that inhabit it by participating in the conservation of the ecosystem, while ensuring the protection of biodiversity and the water regulation that this páramo provides, and that is aligned with the sustainable development goals for rural development. responding to the growing need to incorporate communities in conservation efforts through economic incentives.

The study has also managed to transcend the limits of the descriptive analysis, since not only were the needs to recover the key ecosystem services provided by the Sabana Rubia Páramo identified, but also the economic valuations associated with these services were quantified, which according to the results obtained, the proposed PES model presents a strong component of economic viability, with a projected collection that could reach COP $615,792,000 per year in an ideal scenario with a DAP$500.

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This data reinforces the financial sustainability of the scheme, while highlighting the importance of having a system of adequate incentives, based on the opportunity cost and cost-effectiveness of productive activities that would be partially replaced by conservation practices. Thus, this study is not only adjusted to the needs of the region, but is also in tune with national trends in terms of the promotion of economic mechanisms that favor the conservation of ecosystems.

One of the biggest challenges that emerged during the research was the low participation of key actors, especially local institutions and some community groups. The root of the problem seems to lie in the deep distrust of the entities that would administer the PES, a pattern that had already been detected by previous studies. As Mendelow (1991) points out, this distrust of institutions is usually one of the main obstacles when trying to implement participatory schemes, since it directly affects the dynamics of power and interest among the actors.

The qualitative analysis, supported by the matrix of actors, revealed a paradoxical situation: although peasants and community action boards have a great interest and capacity to influence the process, their involvement is limited by two key factors. On the one hand, the lack of clear information on how the PES works and, on the other, the view that these schemes are more of a political tool than a real conservation mechanism. These findings highlight the urgency of improving awareness campaigns and working to rebuild trust in institutions, two elements without which it would be impossible to guarantee that the model works in the long term.

The study on willingness to pay showed revealing differences between different population groups, which helped to better refine the incentive system. A striking finding was that women with more education are willing to pay 1.45 times more than men, confirming that female empowerment and academic training play a key role in the success of these programs.

A contradictory fact was also detected at first glance: the lower strata showed less willingness to pay, although paradoxically they are the ones who depend most on these ecosystems. This coincides with what is documented by Cervantes (2014), who explains that communities with fewer economic resources tend to value more the environmental services that guarantee their daily survival, even if they have less capacity to contribute economically to their conservation.

From a technical perspective, the use of contingent valuation methods and the logit econometric model allowed the validation of the hypotheses raised, providing robust estimates of the EPD and the factors that influence it. With the validation of the logistic model, estimating a sensitivity of 90.21% and a ROC curve of 0.76, it is confirmed that the methodology used is adequate for this type of analysis and the capacity of the statistical tools applied to capture the willingness of the inhabitants to contribute to conservation is highlighted, then, this methodological component reinforces the reliability of the results obtained, ensuring that the projections of collection and participation in the PES scheme are realistic and based on revealed preference data (Annex 1 of resolution 1084 of 2018 of the Ministry of Environment and Sustainable Development).

The impact of this study is particularly relevant in the national context, given that Colombia is the country with the largest number of páramos in the world, which gives it a global responsibility in the conservation of these ecosystems. This work not only contributes to the development of public policies for the protection of the páramos, but also offers a model that can be replicated in other regions of the country. As PES parameters are adjusted to the particularities of each ecosystem, this type of research has the potential to serve as a basis for the creation of environmental conservation policies that not only benefit ecosystems, but also the communities that depend on them.

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