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ARTICLE

Strategic Site Selection for Agricultural Innovation: Utilizing AHP to Enhance Rural Development in Colombia's Cabuya Industry

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ABSTRACT

The strategic deployment of agricultural technologies is essential for promoting rural development in contexts marked by inequality, such as Colombia. This study examines the site selection of a prototype machine for extracting fiber, juice, and bagasse from giant cabuya (Furcraea foetida), a crop with underutilized potential for generating economic and environmental benefits. To address this challenge, the Analytical Hierarchy Process (AHP) was applied as a multicriteria decision-making framework that integrates infrastructure, social capital, and economic outlook. The methodology combined hierarchical modeling with expert assessments gathered through workshops and interviews with producers, associations, and local stakeholders in four major cabuya-producing regions. A total of 36 paired comparison matrices were constructed to evaluate alternatives, ensuring validity through consistency ratios below established thresholds. Results indicate that La Guajira is the most suitable location for deploying the prototype, followed by Antioquia, Nariño, and Santander. These findings highlight the advantages of using multidimensional criteria to inform decisions, moving beyond narrow productivity-based or politically influenced approaches. This study contributes to agricultural innovation and policy design by showing how AHP supports transparent, participatory, and evidence-based allocation of resources. The model not only improves governance and reduces

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biases but also provides a replicable tool for aligning technological investments with local socio-economic capacities, thereby fostering sustainable and inclusive rural development.

Keywords: Multicriteria Decision-Making; Agricultural Technology; *Furcraea foetida*; R&D Technology Transfer

1. Introduction

Agricultural innovation is increasingly recognized as a critical driver of sustainable rural development, especially in countries like Colombia, where disparities in regional development and agricultural productivity remain pronounced. The deployment of novel technologies, such as prototype machines for extracting fiber, juice, and bagasse extraction from giant cabuya *(Furcraea foetida),* not only modernizes production but also holds the potential to transform local economies through employment generation, value addition, and environmental sustainability. The optimization of such deployment through scientific methods ensures that these technologies reach regions where they can maximize socioeconomic returns. Likewise, by incorporating socio-economic and environmental criteria into decision-making models, this approach provides valuable insights that align with public policy goals focused on rural sustainability and technological empowerment.

Selecting the optimal location to deploy a prototype machine developed as part of an extensive research process is a decision that demands thorough consideration. Beyond social and economic aspects, environmental and cultural factors must also be considered. According to Jones-Garcia and Krishna [1], factors such as agroecological conditions, the farming community, and the technology itself significantly influence the transferability and acceptance of technologies.

Policymakers must adopt strategies that align with long-term goals, weighing the many possible alternatives to choose the best approach [2]. Such challenges are evident in Colombia, where inefficiencies in the agricultural technology transfer process—especially delays in prioritizing regional needs—have hindered timely innovation adoption by farmers [3].

Conflicts often arise between technology recipients and decision-makers due to changing social, economic, and environmental conditions in different regions. Such changes may necessitate reconsidering the initial decision. Additionally, political transitions can alter governmental priorities, impacting pre-established plans. Despite these complexities, decision-makers must aim to present optimal scenarios that benefit society.

The 2030 Agenda for Sustainable Development has transformed decision-making frameworks, emphasizing the role of agricultural development in alleviating poverty, ending hunger, and safeguarding natural resources [4]. As the rural sector is home to many of the world's most impoverished communities [5], tools such as Multi-Criteria Decision Analysis (MCDA) are crucial for informed decision-making.

MCDA methods, including the AHP, are widely recognized for their utility in addressing complex decision-making problems, particularly in agriculture [6,7]. However, there are a multiplicity of methods that are used, given a kind of familiarity and affinity with a specific method [8].

The global agricultural sector is experiencing a profound and accelerated transformation, driven by the intersecting forces of climate change, shifting demographic trends, and increasingly sophisticated consumer demands. In this context, the development and deployment of agricultural technologies cannot be viewed in isolation, but must be situated within broader economic, institutional, and political frameworks. As demonstrated by Roa-Ortiz and Cala-Vitery [3], applying a dynamic governance approach to the analysis of agricultural technology transfer policies in Colombia reveals the critical importance of adaptable and inclusive governance structures. Their model underscores how effective governance can enhance coordination among stakeholders, streamline decision-making processes, and ultimately improve the adoption and scaling of technological innovations in rural territories.

In Colombia, the selection of optimal sites for deploying new agricultural innovations must consider not only technical feasibility but also the economic dynamics of rural livelihoods, market connectivity, governance capabilities, and institutional readiness. Strategic deployment becomes even more crucial in value chains that involve underutilized crops such as cabuya, where innovation can unlock new market segments and socio-environmental benefits.

This study presents an expanded analysis using AHP for optimal site selection, complemented with a detailed discussion of its implications for agricultural economics and rural policy. Our results and proposed model aim to inform decision-makers, policymakers, and development practitioners interested in enhancing the impact of public investments in agricultural research and innovation. AHP was chosen for its ability to evaluate both quantitative and qualitative factors on a unified scale [9].

2. Materials and Methods

Selecting the site for the prototype fiber, juice, and bagasse extractor machine (PM) involves significant social, cultural, economic, and environmental implications. On one hand, the community stands to benefit from the delivery of the machine; however, this also necessitates training people in influential roles to operate and maintain it. A cultural shift will also be required since, in Colombia, giant cabuya producers traditionally transport fiber extraction machines to crop sites, leaving residues in the field. Centralizing operations would change this dynamic, enabling producers to monetize residues as raw materials for new products, a practice previously nonexistent. Consequently, production costs would also be affected due to the updated process. From an environmental perspective, these changes would generate positive externalities. The juice, which was previously leached into the soil, would no longer run off, and the cultural practice of cleaning fiber in water bodies would be discontinued, significantly reducing pollution.

The PM, the focus of this document, is a unique machine patented by two Colombian entities. Given the numerous potential locations for its deployment and the need to mitigate biases and political pressures, decision-making (DM) must adhere to rational principles. From an economic standpoint, rationality implies optimizing a system where all stakeholders benefit (a win-win approach), using a separable and additive function that is both increasing and concave [10]. This DM process also involves balancing trade-offs, loss aversion, and risk minimization, where profit functions are concave and loss functions are convex. As noted by Robinson & Johnson [11], decision-making occurs in a pandemic context characterized by profound uncertainties, and government performance is subject to heightened scrutiny, including actions taken to address human and economic costs.

The AHP model has been widely applied across multiple sectors. In healthcare, it was used for green public procurement in Australia [12]. In transportation, it evaluated optimal train portal locations [13] and logistics service center sites [14]. Other applications include selecting the most favorable solar photovoltaic plant sites [15], determining optimal water allocation scenarios to mitigate climate change impacts [2], and identifying biomass plant locations [16]. In agriculture, AHP has been instrumental in resource allocation for development projects, showcasing the versatility of Multi-Criteria Decision Analysis (MCDA) methods, especially the Analytical Hierarchy Process.

The AHP model, introduced by Saaty in the 1980s [17], is a powerful tool for addressing complex social and political decision-making problems [18,19]. It combines deductive and inductive reasoning, weighing multiple factors while making trade-offs to reach a synthesis or conclusion [17]. AHP relies on hierarchical decomposition (**Figure 1**) of evaluation criteria [14] and follows four steps: 1. Define the problem and identify the knowledge sought; 2. Structure the decision hierarchy, starting with the objective and moving through intermediate to detailed levels; 3. Construct paired comparison matrices where elements in higher levels are compared to those in the immediately lower levels; and 4. Aggregate priorities from these comparisons to obtain global rankings [20,21]. Other authors, such as Padma & Vaisakh [22], have extended AHP methodologies into eleven steps.

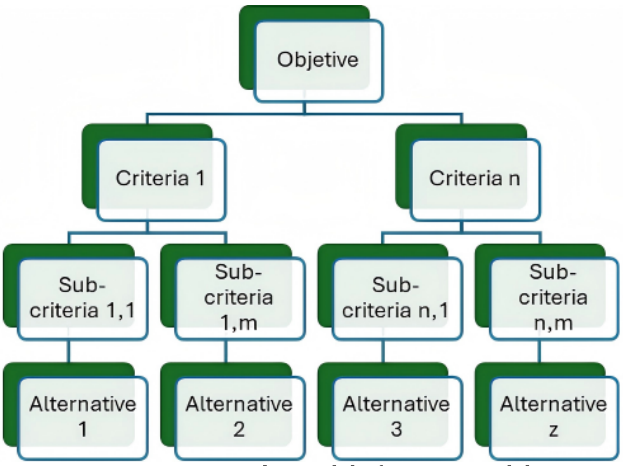

Figure 1. Hierarchy model of an AHP model.

Where:
n is the number of criteria included in the model
m is the number of sub- criteria,
z is the number of alternatives.

Regardless of the approach, the first step, defining the problem, must be straightforward and precise for decision-makers. Constructing a hierarchical model ensures that elements at each level are independent of siblings or descendants. The number of levels depends on the criteria and sub-criteria included, ensuring the hierarchy is complete, representative (capturing all relevant attributes), non-redundant, and minimalist (excluding irrelevant aspects).

The third step incorporates the preferences, tastes, and priorities of the stakeholders through judgments included in the paired comparison matrices, which must adhere to the fundamental scale established by Saaty [21] (**Table 1**).

Table 1. The fundamental scale of Saaty.

Intensity of Importance	Definition	Explanation
1	Equal Importance	Two activities contribute equally to the objective
2	Weak or slight	
3	Moderate importance	Experience and judgement slightly favour one activity over another
4	Moderate plus	
5	Strong importance	Experience and judgement strongly favour one activity over another
6	Strong plus	
7	Very strong or demonstrated importance	An activity is favoured very strongly over another; its dominance demonstrated in practice
8	Very, very strong	
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation

These assessments, conducted by experts [12,23], are facilitated through structured meetings aimed at thoroughly evaluating the problem to ensure rational decision-making that satisfies the defined objectives. The (f) is optimized across a set of alternatives (**A**). For the decision-making process to be effective and comply with the model's requirements, the evaluators' preferences must satisfy the transitivity assumption. This means they should be able to express their preferences explicitly (**P**), and their indifference (**I**) such that the decisions correlate logically with the problem objectives and the set of possible alternatives.

$$a_i \mathbf{P} a_n \Leftrightarrow f(a_i) > f(a_n)$$
$$a_i \mathbf{I} a_n \Leftrightarrow f(a_i) = f(a_n)$$

Where P and I are binary relations and are alternatives of **A**.

The comparison matrix is, then, a square matrix of the comparisons of the alternatives, criteria, or sub-criteria. Let **A** be a matrix of size nxm be such that:

$$\mathbf{A} = \begin{bmatrix} a_{ij} & \cdots & a_{im} \\ \vdots & \ddots & \vdots \\ a_{nj} & \cdots & a_{nm} \end{bmatrix}$$

Where **A** follows the **Axiom 1** of reciprocity, the judgment $a_{ij}=\mathbb{R}^+[1,9]$ satisfies the condition $a_{ji}=1/a_{ij}=\mathbb{R}^+[0,1]$. Additionally, the conditions of reflexivity, transitivity, and anti-symmetry must also be met.

Axiom 2 pertains to homogeneity, ensuring that the elements being compared are of the same order of magnitude or belong to the same hierarchical level.

Axiom 3 addresses the hierarchical structure condition, requiring that elements across two consecutive levels maintain a clear and logical relationship.

Axiom 4 establishes the rank order expectations, where the criteria and alternatives represented in the structure must derive from prior knowledge. While reflexivity is assumed, rationality is not, as individuals often exhibit irrational expectations.

The fourth step of the AHP model involves the normalization of matrix **A**, referred to as

$$\mathbf{A_n} = \begin{bmatrix} \overline{a}_{ij} & \cdots & \overline{a}_{im} \\ \vdots & \ddots & \vdots \\ \overline{a}_{nj} & \cdots & \overline{a}_{nm} \end{bmatrix}$$

Where, each $\overline{a}_{ij}$ from the matrix $\mathbf{A_n}$ is calculated as

$$\overline{a}_{ij} = a_{ij} / \sum\nolimits_{i=1}^{n} a_{ij} \quad (1)$$

Now, the column vector of the relative weights of the criteria and subcriteria $\mathbf{W_c}$ = 1,2,...,n, is constructed by calculating the mean of the entries in each row of $\mathbf{A_n}$, that is,

$$\mathbf{W_c} = \begin{bmatrix} w_i \\ \vdots \\ w_n \end{bmatrix}$$

$\mathbf{W_c}$ contains the weights of the alternatives w_i, and the number of criteria and subcriteria m, to obtain the average vector, where w_i is calculated using,

$$w_{i,\,j} = \sum\nolimits_{i=1}^{m} \overline{a}_{ij} / m \quad (2)$$

Where w_i is the weight corresponding to the *i*th row and w_i is the weight of the *j*th row.

The calculation of the result matrix for each alternative and its respective criteria and subcriteria is obtained by multiplying the matrix of average vectors for each alternative per subcriterion by the average vector of the subcriteria for each criterion. At the end of this process, the results for each alternative are derived, with the highest value indicating the optimal option for each criterion.

Although not explicitly mentioned as a step, calculating the consistency index (CI) is essential to ensure coherence in the results and adherence to the axioms of the model, particularly transitivity. According to Saaty [17], the CI is calculated using the following equation:

$$CI = \frac{\lambda_{\text{max}} - n}{n - 1}$$

To ensure accurate assignment of preferences, the consistency ratio (CR) is calculated as the ratio between the consistency index (CI) and the random consistency index (RI) tabulated by Saaty [17,24]. However, alternative approaches can also be employed, such as constructing RI values or using simulations [25]. **Table 2** presents the RI values for different n, where the second row indicates the order of the matrix. The columns show values calculated by Saaty [17] based on a sample of 500 matrices and by Aguarón & Moreno-Jiménez [25] using a simulation of 100,000 matrices.

Table 2. Random consistency index.

	RI Index														
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Aguarón & Moreno	0.000	0.000	0.525	0.882	1.115	1.252	1.341	1.404	1.452	1.484	1.513	1.535	1.555	1.570	1.583
Saaty	0.000	0.000	0.580	0.900	1.120	1.240	1.320	1.410	1.450	1.490	1.510	1.480	1.560	1.570	1.590

The RI index should not exceed a value of 0.10; otherwise, it would indicate an error greater than 10%, necessitating that the experts re-evaluate their judgments and repeat the AHP mathematical process.

The methodology for obtaining the paired matrices involved workshops and interviews with representatives of giant cabuya producer associations, secretaries of agriculture, and experts from various Colombian municipalities involved in giant cabuya production. These stakeholders provided their assessments through a structured process. The first step was to explain the objective of the workshop and deliver **Table 1**, developed by Saaty [21]. Subsequently, experts were invited to provide their evaluations while the workshop leader compiled the data into a spreadsheet, enabling real-time review by the participants. Once the workshop results were consolidated, the calculations were performed using a spreadsheet prepared by the authors.

Data

This study utilizes data on giant cabuya (*Furcraea foetida*) production in Colombia to identify potential sites for deploying the prototype juice and bagasse shredding and separating machine. **Table 3** highlights five major producing areas in Colombia: Antioquia, Cauca, La Guajira, Nariño, and Santander.

Table 3. Giant cabuya production in tons by departments in Colombia 2010–2022.

Departament	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Antioquia	2356.0	2709.0	2434.0	2309.0	1745.0	1509.0	1168.0	1040.0	1123.0	492.0	2701.0	2799.0	2441.20
Boyacá	92.0	88.0	93.0	87.0	73.0	68.0	19.0	24.0	23.0	18.9	19.8	20.4	9.7
Caldas	204.0	390.0	315.0	245.0	286.0	151.0	37.0	1.0	1.0	0.0	14.0	2.0	2.0
Cauca	10,349.0	7774.0	7458.0	7338.0	5819.0	9549.0	5950.0	7528.0	7537.0	2122.0	6772.4	5128.4	3780.5
La Guajira	0.0	0.0	0.0	0.0	0.0	0.0	270.0	1040.0	1123.0	1115.0	1254.0	1269.0	1284.3
Nariño	7987.0	7676.0	7673.0	6706.0	5994.0	5621.0	6937.0	7454.0	7742.0	4321.0	9098.0	7465.7	8544.5
Norte de Santander	150.0	138.0	7.0	9.0	8.0	6.0	8.0	3.0	3.0	4.0	7.0	6.0	4.5
Risaralda	65.0	101.0	85.0	40.0	56.0	54.0	85.0	85.0	85.0	67.0	67.0	67.1	67.1
Santander	2756.0	3150.0	1682.0	1678.0	1825.0	2672.0	843.0	4337.0	1377.0	547.0	501.0	848.7	685.0
National	25,970	24,036	21,758	20,424	17,820	21,645	17,332	22,873	21,000	19,829	21,703	19,703	16,250

The matrix-vector for each criterion and subcriterion against the alternatives is constructed following the hierarchical structure established by the AHP (**Figure 2**). In this case, the objective function is defined by the central question: Where should the PM be located? This is evaluated under three main criteria: infrastructure, social capital, and economic perspective.

The infrastructure criteria include the technical and environmental sub-criteria required for the PM's proper functioning and safety (**Table 4**). The social capital criteria encompass cultural and social aspects, while the economic perspective criteria focus on factors that facilitate the development of the new business model. These criteria and sub-criteria were agreed upon and validated by experts from the National Federation of Colombian Fique Growers, Artisans, and Processors (Fenalfique).

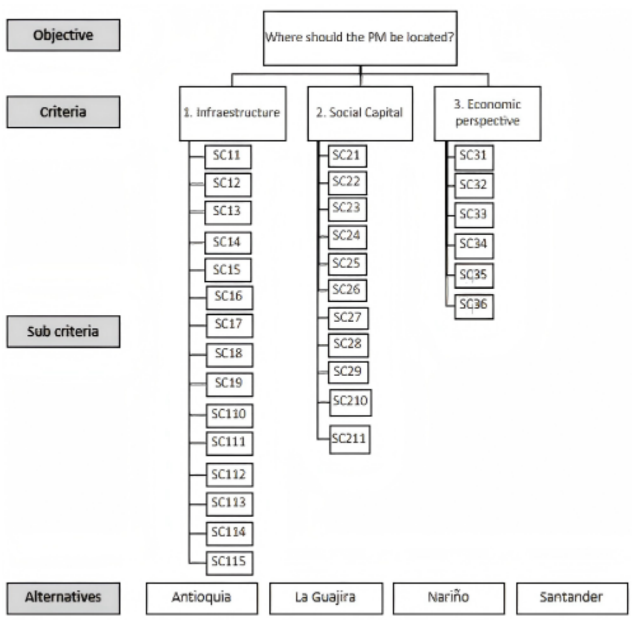

Figure 2. Structure of the AHP model for PM delivery.

Table 4. Criteria and sub-criteria used to make the decision to deliver the PM.

Infrastructure	Social Capital	Economic Outlook
SC11. Warehouse holding	SC21. Association existence	SC31. Obtaining resources
SC12. Profit center	SC22. Member in association	SC32. New model development expectation
SC13. Warehouse height	SC23. Association experience	SC33. Willingness to invest
SC14. Floor in cellar	SC24. Projection	SC34. Purchase-sale contracts
SC15. Electricity in cellar	SC25. Background in association projects	SC35. Bancarization
SC16. Water in cellar	SC26. Association-UMATA technical relations	SC36. Development of products and by-products
SC17. Sewerage in cellar	SC27. Association-Universities technical relations	
SC18. Internet in warehouse	SC28. Association-Government technical relations	
SC19. By-products area	SC29. Association-CAR technical relations	
SC110. Security in the warehouse	SC210. Intention to formalize relations Agrosavia-Utadeo	
SC111. Access to spare parts	SC211. Level of awareness to model change	
SC112. Hectares planted with giant cabuya near the benefit center		
SC113. Distance of crops to the winery		
SC114. Land surveying		
SC115. Sheet length		

This method ensures objective decision-making by minimizing biases and incorporating local stakeholders' perspectives, which enhances the transparency and inclusiveness of policy frameworks in rural regions.

3. Results

Following the steps outlined in the previous section, a set of paired comparison matrices was constructed for each criterion, sub-criterion, and model alternative. To gather the data required for these comparisons, fieldwork was conducted in four of the five areas with the highest production of giant cabuya in Colombia: Antioquia, La Guajira, Nariño, and Norte de Santander. This fieldwork included corroborating the technical aspects necessary for delivering the prototype machine (PM). Unfortunately, the area of Cauca could not be visited, nor were workshops with experts conducted there, due to public order challenges.

In total, 36 paired comparison matrices were created—one for each criterion relative to the objective, three for the sub-criteria, and others for the model alternatives. Notably, the sub-criterion under the economic perspective, as shown in **Table 5**, illustrates this process in detail.

Table 5. Paired comparison matrix for the sub-criteria for the economic perspective criterion.

	Obtaining Resources	Obtaining Resources	Obtaining Resources	Obtaining Resources	Obtaining Resources	Obtaining Resources
Obtaining resources	1	5	1	2	5	1/2
New model development expectation	1/5	1	1/4	1/2	5	1
willingness to invest	1	4	1	2	4	1
Purchase-sale contracts	1/2	2	1/2	1	3	1/3
Bancarization	1/5	1/5	1/4	1/3	1	1/4
Development of products and by-products	2	1	1	3	4	1

On the other hand, 32 paired matrices were obtained for the 4 alternatives for the second level sub-criteria. We only show one of those 32 matrices comparing the alternatives for warehouse ownership in **Table 6.**

Table 6. Paired comparison matrix for the alternatives for the sub-criteria of warehouse ownership, normalization, and average vector by giant cabuya-producing area.

	Santander	Guajira	Antioquía	Nariño	Standardization				Average Vector
Santander	1	1/8	1/8	1/2	0.052631	0.0545454	0.0545454	0.0370370	0.04968988
Guajira	8	1	1	6	0.421052	0.4363636	0.4363636	0.4444444	0.43455609
Antioquía	8	1	1	6	0.421052	0.4363636	0.4363636	0.4444444	0.43455609
Nariño	2	1/6	1/6	1	0.105263	0.0727272	0.0727272	0.0740740	0.08119794

The matrices described above were normalized, and the average vectors were calculated to determine the global priority of the model and the respective consistency indices, ensuring compliance with a maximum error of 10%.

Figure 3 presents the results obtained by the model, showing that the La Guajira area, despite having younger crops and production data starting in 2016, achieved the highest score, followed by Antioquia. The results highlight that mathematically based decision-making can differ significantly from decisions made through other approaches.

Table 7 displays the model's results, illustrating that the normalized priorities sum to 1. These values can be expressed ideally by dividing each priority by the highest value, which is 0.3981 for the department of La Guajira. This indicates, for instance, that Antioquia is approximately 70% as suitable as La Guajira.

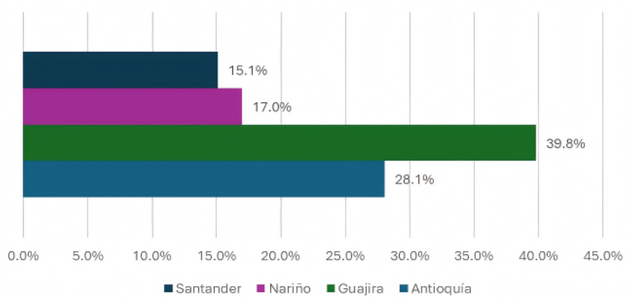

Figure 3. Results of the AHP model for the selection of the area to deliver the PM.

Table 7. Results matrix of the AHP model.

	Normal Priorities	Ideals Priorities
Antioquia	0.28073	0.70501
Guajira	0.39819	1
Nariño	0.17002	0.42699
Santander	0.15103	0.37929

Furthermore, the consistency indices in **Table 8** confirm that the value judgments provided by the experts comply with all the model's axioms, ensuring the reliability of the decision-making process.

Table 8. Consistency index.

Infrastructure	Consistency Index	Social Capital	Consistency Index	Economic Outlook	Consistency Index
SC11	0.00388	SC21	0.00000	SC31	0.00772
SC12	0.00388	SC22	0.00000	SC32	0.00000
SC13	0.00000	SC23	0.00000	SC33	0.00772
SC14	0.02660	SC24	0.00000	SC34	0.08783
SC15	0.00772	SC25	0.00000	SC35	0.00000
SC16	0.00156	SC26	0.00000	SC36	0.00000
SC17	0.00000	SC27	0.00000		
SC18	0.04348	SC28	0.00772		
SC19	0.01865	SC29	0.00772		
SC110	0.01865	SC210	0.01783		
SC111	0.00156	SC211	0.00000		
SC112	0.00000				
SC113	0.00772				
SC114	0.00000				
SC115	0.00000				

The observed variation in rankings across the evaluated criteria reveals the critical need for a comprehensive and balanced approach to public policy formulation. While economic performance remains a key driver of decision-making, these results emphasize that policies exclusively focused on short-term economic gains may overlook essential dimensions such as social capital and infrastructure development. A multidimensional perspective is therefore necessary to ensure that policy interventions foster inclusive and sustainable rural development, aligning with long-term territorial and community resilience goals.

4. Discussion

Making decisions in the field of agricultural technology delivery involves balancing multiple factors that directly impact the success of a project, including its scope effectiveness, economic viability, and social implications. For this reason, the AHP was employed in this study as a valuable tool to structure and prioritize factors systematically, enabling well-informed decisions about the deployment of the prototype in Colombia's cabuya-producing regions.

One of the primary advantages of AHP in decision-making lies in its ability to decompose complex problems into simpler hierarchical components. This hierarchical structure captures the relationships between various criteria and alternatives, allowing decision-makers to analyze the problem from multiple dimensions while considering all relevant interactions.

Employing mathematical methods like AHP ensures the quality of decisions and reduces potential disputes. Unlike decisions based solely on human judgment, often influenced by bureaucratic or non-technical criteria, AHP applies rigorous calculations to rank alternatives, thereby minimizing uncertainty in the selection process.

Deploying a prototype agricultural machine in rural territories such as those producing giant cabuya in Colombia entails a series of technical, economic, and institutional decisions with long-term implications for local development. The use of the AHP in this study allowed decision-makers to overcome subjectivity and integrate complex variables into a systematic framework that evaluates infrastructure, social capital, and economic outlook in a balanced way. The results demonstrate how public policy can benefit from multi-criteria models, particularly in contexts where resources are limited. Such models help eliminate selection biases, enabling a more equitable and objective decision-making process.

From the perspective of agricultural economics, the implications are profound. First, technological innovations like the PM generate upstream and downstream economic activities. Upstream, they demand local inputs, skilled labor, and institutional coordination. Downstream, they open opportunities for new value chains—fiber, juice, and bagasse can feed into markets for textiles, bioplastics, fertilizers, and bioenergy. By identifying regions with greater capacity and motivation to adopt such technologies, public policies can strategically concentrate investments where economic multipliers are likely to be higher.

Moreover, the AHP model facilitates the identification of territories where technological deployment may yield higher social returns. In rural areas, returns on investment are not limited to productivity gains but include job creation, community empowerment, and the development of associative business models. For example, regions with strong associations and willingness to co-invest—as measured in the "social capital" and "economic outlook" criteria—are more likely to ensure the sustainability of innovation efforts.

Economic rationality also plays a key role. When models prioritize areas like La Guajira, which might not be the top producer historically but demonstrate stronger institutional arrangements and local infrastructure readiness, it reflects the capacity of mathematical models to move beyond linear logics of volume-based investment. Instead, it emphasizes strategic deployment that maximizes impact per unit of investment.

In addition, the AHP results encourage public-private partnerships by providing a roadmap for coordinated investment. Local governments, associations, and research institutions are empowered to co-design regional innovation systems. As suggested by the findings, having technical ties between associations and universities or government agencies significantly increases a region's readiness to host agricultural innovations.

A closer analysis of the results reveals how outcomes can vary significantly depending on the criteria considered. For instance, if only infrastructure were evaluated, Antioquia would emerge as the top choice, followed by a tie between La Guajira and Nariño, as illustrated in **Figure 4**. Conversely, if the economic perspective were prioritized, La Guajira would lead, followed by Santander.

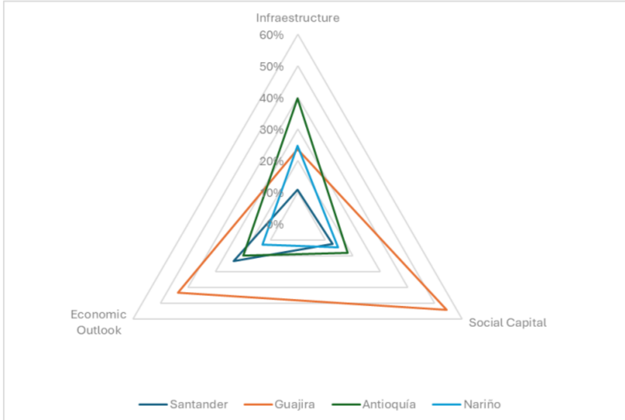

Figure 4. Results by individual criterion.

These findings underscore the importance of incorporating multiple criteria to achieve a comprehensive and balanced evaluation.

Importantly, this case also demonstrates how mathematical modeling in policy contexts enables adaptive governance. In contrast to rigid or politically motivated allocations, models like AHP provide transparent and participatory tools that adapt to local conditions and stakeholder input. In this project, the inclusion of workshops and structured expert judgment sessions reflects a participatory model of knowledge generation, which is essential for building legitimacy and ownership.

Finally, applying models such as AHP contributes to a broader agenda of inclusive rural transformation. By supporting equitable distribution of technological assets based on empirical criteria, rather than historical power dynamics or political lobbying, it becomes possible to reconfigure rural economies toward sustainability, resilience, and innovation. The model's transparency and replicability make it a valuable tool not just for one project, but for institutionalizing better decision-making processes across agricultural development programs. Likewise, for policymakers, these results underscore the importance of aligning technological innovation with local conditions, fostering both economic growth and social welfare in rural areas.

5. Conclusions

This study highlights the effectiveness of the Analytical Hierarchy Process (AHP) as an objective and multidimensional framework for site selection in agricultural innovation. By integrating social, economic, and environmental criteria, AHP facilitates informed and equitable decision-making aligned with the Sustainable Development Goals (SDGs). The case of the cabuya prototype machine in Colombia illustrates how AHP can guide policymakers in identifying optimal locations by evaluating not only technical feasibility but also the broader socio-environmental impacts on local communities.

As rural regions increasingly confront complex challenges in promoting technological innovation, incorporating AHP into policy frameworks emerges as a powerful strategy to enhance rural development and support the long-term success of agricultural advancements. The participatory nature of our methodology further ensured the integration of local knowledge, strengthening community buy-in and facilitating smoother implementation [20].

For agricultural policymakers, the use of multi-criteria decision-making tools such as AHP can significantly improve the allocation of public resources. Our findings echo concerns within Colombia's technology transfer policy framework, where a lack of prioritization mechanisms has led to delays and regional disparities [3]. By objectively identifying the region with the highest overall potential—La Guajira, in our case—decision-makers can direct investments where they are most likely to generate impact, advancing national innovation system objectives. More broadly, this approach mitigates the risk of decisions being driven by political expediency or single-variable reasoning, ensuring that new interventions contribute meaningfully to sustainable rural development.

From a public policy perspective, the adoption of AHP enhances both the efficiency and equity of agricultural investments. These models enable the identification of optimal investment zones not solely based on productivity, but also on critical social, institutional, and environmental variables that underpin the sustainability of innovation. This is particularly relevant in rural areas, where multiple vulnerabilities intersect and where technological adoption must be context-sensitive and socially embedded.

Based on our findings, the following policy recommendations are proposed:

1. Institutionalize mathematical decision-making tools within rural development planning. Government agencies should formally adopt methods like AHP to guide territorial investment strategies, especially in the agricultural sector.
2. Strengthen local institutional capacity by supporting producer associations, expanding technical education, and reinforcing local governance structures. These elements are essential for the effective absorption and sustainability of agricultural innovations.
3. Promote integrated rural innovation systems that connect research institutions, producer organizations, universities, and public agencies. Such collaborations enhance the relevance, adoption, and scalability of new technologies.
4. Extend the use of AHP and other Multi-Criteria Decision Analysis (MCDA) tools to broader agricultural planning contexts, including the siting of agro-processing facilities, irrigation infrastructure, and climate adaptation technologies, thereby fostering data-driven and participatory development.
5. Ensure active participation of rural communities at all stages of decision-making. Incorporating local knowledge and cultural values through structured participatory processes increases the legitimacy, ownership, and long-term success of public interventions.

The AHP-based evaluation conducted in this study successfully identified the most suitable region for deploying the cabuya fiber extraction prototype, replacing what might have been a politically influenced decision with one based on empirical evidence. La Guajira's selection was grounded in a comprehensive assessment of multiple dimensions—an outcome that would not have been attainable using a single-criterion approach. This reinforces the value of integrating multi-criteria tools into agricultural policymaking to improve transparency, accountability, and effectiveness.

Author Contributions

All authors contributed substantially to the conception, design, analysis, and writing of this manuscript. All authors have read and approved the final version of the paper.

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Not applicable.

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Not applicable.

Data Availability Statement

The matrices used in this study will be made available in the journal's repository to facilitate replication and further research.

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Conflicts of Interest

The authors declare no conflict of interest.

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