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Prioritizing Strategies for Agri-Food Transformation in Meta, Colombia: A Hybrid ANP-DEMATEL-SBWM Model

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Abstract

Farmers' markets in Latin America continue to face structural challenges such as informality limited value addition, and weak institutional support. This article applies a hybrid multi-criteria model that integrates DEMATEL, ANP, and SBWM to prioritize agri-food transformation strategies in the department of Meta, Colombia. The methodology combined stakeholder mapping, Delphi-based validation of criteria, and the evaluation of strategic robustness under three prospective scenarios. The results show that the creation of working groups with public and private institutions (E.3) consistently emerged as the most robust strategy (weight = 0.0669 in SBWM), followed by infrastructure development (E.2. 0.0649) and participatory workshops on food sustainability (E.8. 0.0602). Sensitivity analysis confirmed the stability of the prioritization structure, with strategy E.3 remaining in the first position across all scenarios and only moderate variations in the positions of E.2 and E.8. The study contributes methodologically by demonstrating the integration of DEMATEL–ANP with SBWM to address interdependencies and uncertainty in participatory decision contexts. It also provides practical guidance for local governments and cooperatives to strengthen farmers' markets through institutional coordination, capacity building, and infrastructure investment, thereby supporting progress toward several Sustainable Development Goals (SDGs).



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Keywords: ANP-DEMATEL; SBWM; farmers' markets; rural-based strategies; agri-food sustainability; multi-criteria decision n-making methods; Meta (Colombia); prospective scenarios

1. Introduction

Agricultural transformation in Latin America has taken place in a context where some structural problems remain despite repeated efforts to address them. Issues such as productive informality, limited value added, and weak coordination between institutions are still present in many territories across the region [1]. In Colombia, these challenges are especially visible in the department of Meta, a region that has become important in the national agri-food system because of its diverse production structures and the coexistence of small family farms with large agro-industrial companies. The rapid expansion of Villavicencio, the main urban center, has added further pressure on local food systems and has made the relationship between rural production and urban demand more complex.

Within this setting, farmers' markets have gained relevance as spaces that bring producers and consumers into closer contact. By reducing the role of intermediaries, they support local food circuits and can improve income opportunities for rural households [2,3]. However, these markets are still far from consolidated. Many producers lack suitable

infrastructure for storage and basic processing; associative practices are often fragile and meeting the quality and safety standards required by formal markets remains a difficult task. These conditions restrict access to stable commercialization channels and slow progress toward key Sustainable Development Goals related to poverty reduction, food security and decent work (SDG 1, SDG 2 and SDG 8) [4].

Ensuring the sustainability of farmers' markets in Meta requires strategies that take into account not only economic performance but also social, cultural and environmental dimensions. Different actors participate in these markets with diverse interests, resources and levels of involvement. Although the literature recognizes their contribution to food security and local development, there are still relatively few methodological approaches that help prioritize strategies when multiple criteria and perspectives must be considered at the same time [5,6]. In such situations, methods that make it possible to organize information and clarify how different factors are related become particularly useful. Multi-Criteria Decision Analysis (MCDA) is one of these options because it incorporates expert judgment and helps reveal interdependencies that are not always evident.

Within this group of methods, DEMATEL supports the identification of cause–effect relationships among criteria, while the Analytic Network Process (ANP) allows the analysis of more complex interdependencies in decision systems with feedback [7–9]. Even so, most applications related to farmers' markets focus on current conditions and pay limited attention to how institutional or territorial changes over time may affect strategic priorities. The Stepwise Best–Worst Method (SBWM) adds a prospective dimension by examining how robust strategic alternatives remain under different possible future scenarios, including those characterized by stronger state support, the continuation of existing dynamics or pressures arising from urban transformation [10].

Taking these elements into account, this article examines how agri-food transformation strategies can be prioritized in the department of Meta in order to strengthen quality, associativity and sustainability in a context marked by uncertainty and actor diversity. The aim is to identify strategic priorities that reflect the complexity of the region and the multiple dimensions that shape its agri-food system. Three objectives guide the analysis: (i) to identify and validate decision criteria linked to the Sustainable Development Goals (SDGs) using the Delphi method; (ii) to examine causal and interdependent relationships among these criteria through DEMATEL and ANP; and (iii) to evaluate the robustness of strategic options under different prospective scenarios using SBWM. The intention is to contribute a methodological framework that can support territorial decision-making and provide practical elements to strengthen farmers' markets in Meta while advancing progress toward the SDGs.

2. Theoretical Framework

2.1. *Agricultural Transformation, Associativity, and the Cooperative Economy*

Agricultural transformation in rural contexts depends on overcoming structural barriers such as informality, market fragmentation, and low value addition. The social and solidarity economy framework emphasizes that cooperatives operate not only as economic units but also as social institutions that promote equity and sustainability [11]. In Colombia, peasant cooperatives have served as a fundamental mechanism for small-scale producers to access markets, strengthen their bargaining power, and build economic autonomy. This perspective is complemented by social capital theory [12], which highlights trust, reciprocity, and networks as key elements of collective efficacy, particularly in territories historically excluded from the formal economy.

Recent evidence confirms that cooperative models outperform conventional enterprises in efficiency and profitability, while also acting as agents of social innovation in the

agri-food sector [2]. However, studies in Latin America have warned that in the absence of strong democratic mechanisms, cooperatives may reproduce internal inequalities and limit the participation of women and youth [13]. These contrasts indicate that, although cooperatives are widely recognized as instruments of social cohesion, a methodological gap remains regarding how to prioritize their strengthening strategies under scenarios of uncertainty.

2.2. Participatory Governance and Rural Civil Society

Participatory governance theory argues that decision-making in rural contexts must acknowledge polycentrism, that is, the existence of multiple autonomous actors who share responsibilities in resource management and territorial planning [14]. Within this framework, rural civil society—particularly peasant organizations—plays a decisive role as a political actor capable of influencing public policies, demanding rights, and proposing alternative development models [15]. Evidence from Latin America shows that while farmers' markets enhance territorial self-management, they also face tensions derived from the exclusion of small producers in decision-making processes that are formally presented as participatory [16].

2.3. Farmers' Markets, Sustainability, and the SDGs

From a sustainability perspective, farmers' markets contribute directly to the achievement of several Sustainable Development Goals (SDGs), including SDG 1 (No Poverty), SDG 2 (Zero Hunger), SDG 8 (Decent Work and Economic Growth), SDG 12 (Responsible Consumption and Production), and SDG 15 (Life on Land). The sustainable food systems framework emphasizes that short supply chains reduce environmental impacts, support agricultural biodiversity, and promote healthier diets [17].

Beyond their economic function, farmers' markets have consolidated as spaces of social innovation and rural resilience [6,17]. In Germany, for example, they have been associated with reducing carbon footprints and promoting healthier local diets [5]. In Brazil and Uruguay, farmers' markets have strengthened rural agro-industrial chains and linked with public food supply policies [18,19]. In Colombia, however, their impacts remain limited due to informality and weak institutional coordination, creating a lag compared to international experiences. This contrast highlights the need for strategies adapted to the local context in order to maximize their social and environmental benefits.

2.4. Multi-Criteria Approaches

The prioritization of strategies in farmers' markets requires approaches capable of capturing their structural complexity. Multi-Criteria Decision Analysis (MCDA) methods, such as AHP and ANP, allow the structuring of hierarchies or interdependent networks and the participatory weighting of criteria [20]. The ANP, developed by Saaty [21], has been applied in regional planning and agri-food management, demonstrating advantages for modeling feedback in complex systems [22,23]. Meanwhile, DEMATEL is useful for identifying cause–effect relationships, particularly in dynamic contexts such as governance and circular agriculture [2,24,25].

The integration of ANP and DEMATEL has proven effective for identifying driving and dependent criteria, as recent applications in food policy and rural adaptation have shown [26]. However, most studies applied to farmers' markets lack prospective components that account for institutional and territorial variability across future scenarios. In this regard, the Stepwise Best–Worst Method (SBWM) offers an innovative approach. It was recently employed for sustainable technology selection under contrasting scenarios [10] but is still underexplored in rural agri-food systems.

2.5. State of Knowledge: Contributions and Gaps

International research on alternative markets and food governance has highlighted the benefits of short food supply chains in terms of environmental sustainability, social equity, and public health [16,26]. In Latin America, however, studies tend to focus on technical or organizational aspects in isolation, with limited integration of social and territorial dimensions [27].

Some works have applied multi-criteria methods to peasant organizations [25], but these remain limited to technical criteria and do not incorporate prospective sustainability scenarios. This reveals a methodological gap that this article seeks to address by integrating DEMATEL–ANP–SBWM, a hybrid model that captures interdependencies, feedback loops, and uncertainty scenarios. In doing so, it provides a participatory and context-specific tool for prioritizing strategies in farmers' markets, contributing both to academic debates and to territorial management in Colombia.

3. Materials and Methods

This article adopted a mixed and participatory approach, organized into four methodological phases aimed at prioritizing strategies for agri-food transformation in the department of Meta (see Figure 1).

Hybrid Decision-Making Process Using DEMATEL–ANP and SBWM

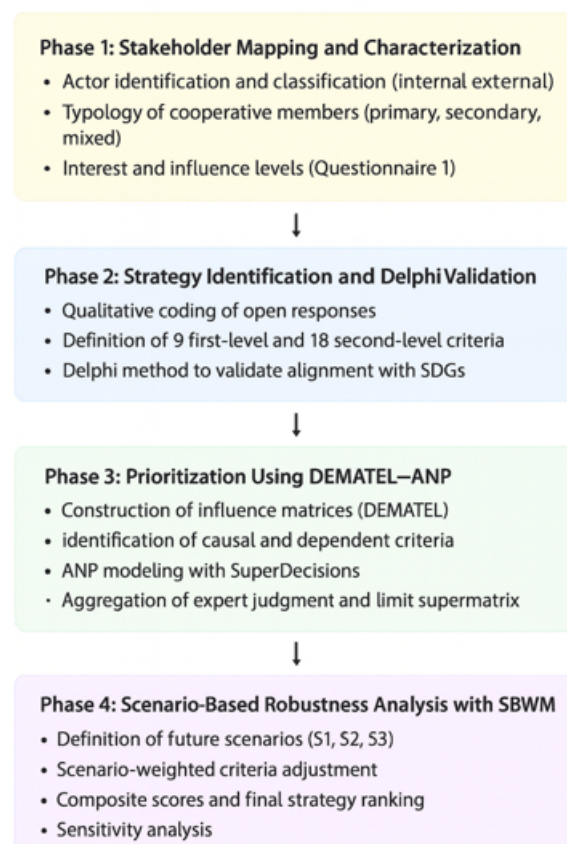


Figure 1. Decision-making process method.

Phase 1. Mapping and characterization of stakeholders linked to the cooperative

The first phase focused on identifying and characterizing internal and external stakeholders involved in strengthening farmers' markets. Information was gathered through a

literature review, semi-structured interviews and the administration of Questionnaire 1 (see Appendix A Table A1). The questionnaire was designed on the basis of stakeholder analysis methodologies and adapted to the specific context of the cooperative and its institutional environment. It collected information on levels of interest, influence and expectations regarding the development of the project, following a participatory approach to stakeholder management [28].

The sample included 26 active cooperative members, considered the strategic core of the research, and 15 external stakeholders: unaffiliated producers (40%), local market vendors (27%), public officials involved in rural development programs (20%) and regular consumers (13%). Incorporating these different perspectives increased the legitimacy of the process, broadened understanding of the local agri-food system and guided the identification of strategies from a participatory, multi-level governance perspective. The data were systematized to construct a stakeholder map, identify key relationships and define the strategic group that would take part in the subsequent phases, ensuring representation consistent with the dynamics of the local agri-food system [13,29].

During the first phase, it was also possible to identify a set of organizational, territorial, and functional characteristics of the internal members of the cooperative. Based on their productive activities, the members were grouped into three categories: primary producers (44 percent), secondary producers (44 percent), and mixed producers (11 percent). This classification made it possible to distinguish relevant differences related to geographic distribution, levels of commercial coordination, and forms of participation within the organization. In addition, information about their roles inside the cooperative showed that 59 percent of the members participated exclusively as regular associates, 15 percent sat on the Board of Directors, another 15 percent were inactive members, 7 percent were part of the Supervisory Board, and 4 percent held the position of Legal Representative. These findings provided a clearer view of the cooperative's internal structure and of the heterogeneity present among its members.

Phase 2 involved the identification and validation of transformation strategies. The work concentrated on systematizing the proposals gathered from the questionnaires completed by the various stakeholder groups. Open-ended responses were analyzed inductively through a direct reading of participants' narratives, without relying on predefined categories. Each response was reviewed manually, grouping expressions with similar meanings and forming categories that summarized recurrent patterns in the discourse. This process made it possible to organize the information into five strategic dimensions: associativity, marketing, institutional strengthening, quality production, and territorial development. Building on these dimensions, nine first-level criteria and eighteen second-level criteria were defined and subsequently arranged according to the overarching aim of strengthening associative and agro-industrial processes in rural territories, (see Table 1).

Table 1. Definition of first and second level criteria.

First Level Criterion	Second Level Criterion
C.1 Establishment of alliances with international and national farmers' markets to identify and replicate their best practices in MercaOrinoquia	C.1.1 Developing alliances with farmers' markets in other countries to identify their strengths and replicable processes
	C.1.2 Establishing of alliances with farmers' markets in other departments to identify their strengths and replicable processes
C.2 Creation of a pilot plant for the development of food production	C.2.1 Implementing of a collection center to improve post-harvest and storage activities for products sold at farmers' markets
	C.2.2 Executing the assembly of a pilot plant for the transformation of products sold in farmers' markets.

Table 1. *Cont.*

First Level Criterion	Second Level Criterion
C.3 Development of joint working groups between FAO and public entities (Ministry of Agriculture. Health. Trade and Culture)	C.3.1 Creating a national plan for standardization of processing and marketing of farmers' markets
	C.3.2 Developing work between agencies in order to achieve the strengthening of quality, productivity and competitiveness competencies of the members of MercaOrinoquia
C.4 Strengthening the local public procurement component in alliance with MercaOrinoquia (solidarity public procurement)	C.4.1 Preparing a standard document for compliance with quality and safety standards regarding how products should be delivered to participate in solidarity public procurement
	C.4.2 Developing a training and strengthening program in order to teach participants who wish to learn about the solidarity public procurement program
C.5 Design of quality and safety documents	C.5.1 Designing protocols together with public entities that integrate safety and quality standards
	C.5.2 Developing a quality and safety plan focused on agricultural food production
C.6 Promotion of the development of new products based on native and ancestral foods of the region	C.6.1 Producing of food and non-food products with raw materials from the region to increase its supply and implement marketing strategies for these new products
	C.6.2 Creating a booklet with ancestral foods and a communication strategy to periodically inform about their preparation, history and farmers' markets
C.7 Expanding the visibility and sales of MercaOrinoquia products	C.7.1 Developing an attractive online presence for the farmers' market, including the creation of an informative website, social media profiles, and targeted online advertising campaigns
	C.7.2 Promoting local participation through advertising in traditional media such as newspapers, radio, and brochures distributed in the community.
C.8 Promoting a participatory workshop titled "from seed to plate"	C.8.1 Promoting knowledge and application of sustainable practices in local agriculture, from seed selection to food preparation, to improve community nutrition and well-being
	C.8.2 Creating a collective diagnosis of the main challenges faced by farmers' markets from food production to sales in cities
C.9 Acquisition of external funds for the cooperative	C.9.1 Formulating a business plan
	C.9.2 Participating in financing programs

Based on the results of Questionnaire 1 (Appendix A), nine strategic alternatives were also defined that summarize the main proposals put forward by the social stakeholders consulted. These strategies emerged from a qualitative analysis of the open-ended responses, which expressed needs, expectations, and possible courses of action. The codification process allowed these proposals to be organized into strategic lines that encompass actions in infrastructure, partnerships, marketing, training, communication, and food sustainability. Table 2 presents these strategies:

Subsequently, in order to validate the formulated criteria and determine their correspondence with the Sustainable Development Goals (SDGs), an adapted Delphi technique was applied, following the methodological foundations proposed in [27]. A panel of nine experts evaluated the relationship between each criterion and the SDGs using a dichotomous matrix ("Related"/"Not related"). A consensus threshold of 75 percent was

established and achieved in the first round, which made additional rounds unnecessary. This procedure made it possible to consolidate a set of criteria aligned with territorial priorities and international sustainability frameworks.

Table 2. List of strategies.

Strategies
E.1 Cultural exchange. Exchange of knowledge and experiences in production and commercial activities.
E.2 Infrastructure development. Assembly of a collection center and design of a pilot plant for product processing.
E.3 Work tables. Spaces to coordinate actions with public and private entities.
E.4 Public procurement. Government strategy that ensures that public and private entities promoting local policies, programs, and projects acquire goods and services in the same locality where they operate, whether in rural areas, municipalities, or regions.
E.5 Safety and quality documents. Design of protocols and plans for quality and safety.
E.6 Preparation of ancestral foods.
E.7 Marketing of products.
E.8 Participatory workshop entitled “from seed to plate”. It is a concept that encompasses the entire process of food production and consumption, from planting to serving.
E.9 Acquisition of external funds for the cooperative.

The selection of experts was based on their familiarity with the local context and their participation in processes aimed at strengthening the organizational, commercial, and territorial foundations of farmers’ markets. The panel ensured functional diversity, experience in associative processes, and proven participation in strategic planning environments, consistent with methodological recommendations for Delphi studies [28]. The group included cooperative members, technical personnel from public institutions, and representatives of allied organizations.

The choice of SDGs reflected the structural challenges and opportunities identified in the rural context of Meta, particularly in relation to strengthening farmers’ markets and associative dynamics. SDG 1 (No Poverty) was included because agricultural activity serves as a direct mechanism for improving income and reducing poverty in rural communities, especially when supported by cooperative structures. Evidence shows that participation in community agriculture and local markets contributes to reducing structural poverty through sustainable employment and income generation [30]. SDG 2 (Zero Hunger) was incorporated due to the importance of agroecological production and food sovereignty in enhancing local food security. Initiatives such as “from seed to plate” workshops facilitate dietary diversification, improve access to nutritious food, and encourage sustainable production practices [31,32]. In close connection, SDG 3 (Good Health and Well-being) was selected because of its relevance to food quality and safety, as well as the promotion of fresh and chemical-free products that improve nutrition and reduce health risks for producers and consumers [33,34].

SDG 8 (Decent Work and Economic Growth) relates to the development of productive infrastructure, the generation of local employment, and the strengthening of territorial economic networks through farmer associations. These actions promote more inclusive and sustained economic growth [35,36], while agricultural cooperatives contribute to reducing structural inequalities by creating decent work opportunities. In this regard, SDG 10 (Reduced Inequalities) was also considered, given the emphasis on incorporating tradi-

tionally marginalized groups—such as smallholders, women, and rural inhabitants—and fostering their participation in decision-making and collective economic processes [37]. SDG 9 (Industry, Innovation and Infrastructure) was included due to the relevance of establishing collection centers, pilot processing plants, and essential technical facilities, which are crucial for advancing agro-industrial development and adding value to agricultural products [38]. SDG 12 (Responsible Consumption and Production) aligns with the cooperative's emphasis on agroecological practices and short supply chains, which reduce waste, minimize intermediaries, and support more conscious consumption patterns [33]. Finally, SDG 17 (Partnerships for the Goals) was incorporated in recognition of the importance of coordinated action among public, private, and community actors to mobilize resources and knowledge necessary for the long-term viability of the proposed strategies, consistent with the 2030 Agenda's emphasis on collaborative governance [1].

Based on the Delphi validation and the correspondence matrix linking each sub-criterion to the selected SDGs (see Table 3), the eighteen second-level criteria defined in the previous phase were confirmed. All of them were incorporated into the ANP-DEMATEL prioritization model, as they met the established consensus thresholds and represented a coherent set of strategic elements aligned with both territorial needs and sustainability objectives.

Table 3. Correspondence matrix between second-level criteria and the Sustainable Development Goals (SDGs) validated using the Delphi technique.

	C.1.1	C.1.2	C.2.1	C.2.2	C.3.1	C.3.2	C.4.1	C.4.2	C.5.1	C.5.2	C.6.1	C.6.2	C.7.1	C.7.2	C.8.1	C.8.2	C.9.1	C.9.2
SDG 1	●	●	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
SDG 2	●	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
SDG 3	●	●	●	●	●	○	○	○	○	○	●	●	○	●	●	●	○	○
SDG 8	●	○	●	●	○	○	●	●	○	○	●	●	○	○	○	○	○	○
SDG 9	●	●	●	●	○	○	○	○	○	○	●	●	○	○	○	○	○	○
SDG 10	●	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
SDG 12	●	●	○	●	●	○	●	○	○	●	●	●	○	●	○	○	○	○
SDG 17	●	●	●	●	●	○	●	○	●	○	●	●	○	●	●	●	○	○

The circles show the Delphi consensus on the criterion–SDG relationship, evaluated through a dichotomous questionnaire (“Related”/“Not related”). The panel of nine experts applied a 75% consensus threshold. A green circle indicates consensus ($\geq 75\%$ “Related”), while a white circle indicates no consensus ($< 75\%$).

The selection of second-level criteria incorporated into the ANP-DEMATEL prioritization phase was guided by the number of relationships validated by consensus with the Sustainable Development Goals. Each agreement between a sub-criterion and an SDG was represented in the Delphi matrix, where green markers indicated consensus levels equal to or greater than 75 percent among the experts. Since all eighteen second-level criteria received at least one validated link to a priority SDG, their inclusion in the multicriteria model was considered methodologically appropriate. This ensured alignment between territorial priorities for strengthening farmers' markets and international sustainability frameworks, allowing the subsequent evaluation of strategies from a comprehensive and context-sensitive perspective.

Phase 3 involved the selection of strategies using an integrated ANP-DEMATEL approach. This phase examined both the causal relationships and the interdependencies among criteria. Questionnaire 2, presented in the Appendix A (Tables A1 and A2), served as the data collection instrument for this stage. Experts assessed the degree of influence among criteria and strategies using a scale ranging from 0 (no influence) to 5 (very high influence). The DEMATEL method was first applied to map the network of cause–effect relationships. Based on expert assessments, a direct-influence matrix was constructed and

subsequently normalized to obtain the total influence matrix. This process made it possible to identify driving factors (cause) and dependent factors (effect), establishing the structural basis for the next step.

Building on this structure, the Analytic Network Process (ANP) was applied to model the interdependencies among the elements. Pairwise comparison matrices were developed for each set of criteria and strategies and processed using SuperDecisions software version 3.2. The combined ANP-DEMATEL approach brought together the diagnostic capacity of DEMATEL with the interconnected network modeling capabilities of ANP, consistent with applications reported in previous studies [9,30,39].

As a result of this process, direct influence matrices were generated for each expert. Table 4 presents one of these matrices, illustrating the relationships between second-level criteria (C.1–C.9) and the strategies (E), and highlighting the elements exerting the greatest influence within the system.

Table 4. Expert influence matrix 1 for groups with DEMATEL.

	C.1	C.2	C.3	C.4	C.5	C.6	C.7	C.8	C.9	E
C.1	0	0	3	1	4	5	4	3	2	5
C.2	0	0	3	5	5	4	4	3	4	0
C.3	2	3	0	4	3	3	3	3	5	4
C.4	2	4	4	0	5	5	4	3	3	4
C.5	3	3	4	3	0	1	4	4	4	5
C.6	4	4	2	2	4	0	5	4	3	1
C.7	3	4	5	4	4	5	0	4	3	4
C.8	5	3	3	4	3	4	4	0	3	4
C.9	3	4	5	4	4	4	3	4	0	4
E	4	4	4	4	4	4	4	4	4	0

The full names and definitions of the criterion codes used in the table are presented in Table 1. The letter E represents the strategies found in Table 2.

In order to ensure comparability between experts, this matrix was normalized, obtaining proportional values between 0 and 1. In addition, the relationships between the second-level criteria (e.g., C.1.1., C.1.2) and the first-level criteria were structured using weights obtained from the ANP matrices. Table 5 shows a representative section of this weighting, focusing on criteria C.1 to C.5.

The weighted matrix was subsequently raised to successive powers, as established in the ANP methodology, until a stable or convergent supermatrix—referred to as the limit matrix—was obtained. In this final matrix, each element represents the cumulative influence that every second-level criterion exerts on the others within the network, capturing both direct and indirect effects. The iterative procedure, which in this case required eight iterations, progressively redistributed influence across all components of the system, ensuring that reciprocal dependencies and feedback loops were fully incorporated. Once convergence was reached, the limit matrix contained stable values that could be interpreted as the overall weights of each node—whether subcriteria or strategies—reflecting their structural relevance within the network. These weights served as the basis for establishing a robust ranking of strategies, grounded in the degree of influence each element exercises and receives within the overall decision system. The complete matrix is presented in the Appendix A (Table A3).

Table 5. Weighted matrix of expert 1.

		C.1		C.2		C.3		C.4		C.5	
		C.1.1	C.1.2	C.2.1	C.2.2	C.3.1	C.3.2	C.4.1	C.4.2	C.5.1	C.5.2
C.1	C.1.1	0.0000	0.0000	0.0000	0.0000	0.0505	0.0455	0.0184	0.0161	0.0556	0.0417
	C.1.2	0.0000	0.0000	0.0000	0.0000	0.0404	0.0455	0.0138	0.0161	0.0556	0.0694
C.2	C.2.1	0.0000	0.0000	0.0000	0.0000	0.0455	0.0404	0.0806	0.0605	0.0595	0.0694
	C.2.2	0.0000	0.0000	0.0000	0.0000	0.0455	0.0505	0.0806	0.1008	0.0794	0.0694
C.3	C.3.1	0.0427	0.0427	0.0647	0.0517	0.0000	0.0000	0.0645	0.0553	0.0417	0.0476
	C.3.2	0.0342	0.0342	0.0388	0.0517	0.0000	0.0000	0.0645	0.0737	0.0417	0.0357
C.4	C.4.1	0.0385	0.0385	0.0613	0.0613	0.0673	0.0673	0.0000	0.0000	0.0794	0.0694
	C.4.2	0.0385	0.0385	0.0766	0.0766	0.0539	0.0539	0.0000	0.0000	0.0595	0.0694
C.5	C.5.1	0.0513	0.0513	0.0460	0.0460	0.0673	0.0673	0.0538	0.0484	0.0000	0.0000
	C.5.2	0.0641	0.0641	0.0575	0.0575	0.0539	0.0539	0.0430	0.0484	0.0000	0.0000

For detailed descriptions of the criteria, see Table 1.

Phase 4 involved evaluating the robustness of the prioritized strategies under plausible future scenarios through the application of the Stratified Best–Worst Method (SBWM). After obtaining the hierarchy of strategies using the ANP-DEMATEL model, this phase introduced uncertainty by examining how changes in contextual conditions might alter strategic priorities. SBWM, an extension of the Best–Worst Method, allows the incorporation of future scenarios by assigning differentiated weights to the criteria according to the conditions defined in each context. For this phase, the same nine experts from Phase 3 participated, joined by two additional specialists.

The SBWM approach operates by comparing extreme criteria (the most and least important) while incorporating a stratified structure that reflects variations in contextual conditions. For this study, three plausible scenarios were defined, taking into account the operational challenges faced by a farmers’ market located in an urban environment. These scenarios (S1, S2, and S3) were developed through an inductive analysis grounded in empirical evidence and scholarly work on urban farmers’ markets in Latin America and Colombia, drawing on scenario planning and territorial analysis approaches [40,41] that emphasize the utility of constructing contrasting future situations.

- (S0) Base scenario–ANP–DEMATEL integration.
- (S1) Continuity without additional institutional support: the farmers’ market operates with logistical limitations and without formal state support, facing space restrictions, low visibility and conflicts over urban land use.
- (S2) Institutional support and favorable local regulation: the local government provides incentives and facilitates infrastructure for the establishment of the market, integrating it into urban food supply strategies and recognizing it as a fundamental actor in the solidarity economy.
- (S3) Pressure from urban reorganization and eviction: the market faces the threat of displacement or elimination due to urban renewal policies, real estate expansion, or regulations that restrict its presence in central public spaces.

In each scenario, the nine experts above, plus more two experts, identified the “best” and “worst” criteria and completed the corresponding comparison matrices. The generated weight vectors were then integrated by weighting according to the probability of occurrence of each scenario, which allowed estimating the potential impact of contextual change on

strategic priorities and building a robust and adaptive ranking of strategies, explicitly incorporating territorial uncertainty [4,42].

In each scenario, the experts identified the “best” (B) and “worst” (W) criteria and established the required comparisons. The SBWM model is formalized from the following formulation [43]:

1. Determine the set of criteria $C = \{C_1, C_2, \dots, C_N\}$.
2. Select the most important criterion C_B and the least important (worst) C_W .
3. Obtain the vector of comparisons of the best with the others: $A_B = [a_{B1}, a_{B2}, \dots, a_{Bn}]$.
4. Obtain the vector of comparisons of the others with the worst: $A_W = [a_{1W}, a_{2W}, \dots, a_{nw}]$.
5. Calculate the optimal weights $W_1, W_2, \dots, W_N$ that minimize the deviation function ξ under the following restrictions, where the difference between the weight of the “best” criterion and its comparison with the others must not exceed the allowed deviation ξ (Equation (1)). The difference between the weight of each criterion and its comparison with the “worst” must also be within the limit ξ (Equation (2)). The sum of all weights must be 1, and no weight can be negative (Equation (3)).

$$\min \xi$$

$$|w_B - a_{Bj} w_j| \leq \xi, \quad \forall j \quad (1)$$

$$|w_j - a_{jW} w_W| \leq \xi, \quad \forall j \quad (2)$$

$$\sum_{j=1}^n w_j = 1, \quad w_j \geq 0 \quad (3)$$

The evaluations provided by experts regarding the “best” and “worst” criteria in each scenario were recorded in the AB matrix (comparisons of the best criterion with the others) and the AW matrix (comparisons of the others with the worst). Both matrices were constructed using a relative importance scale from 1 to 9, where 1 indicates equal importance, 3 a slight preference, 5 a moderate preference, 7 a strong preference, and 9 an extreme preference. Intermediate values (2, 4, 6, and 8) were used to express intermediate judgments between two adjacent levels.

These values served as inputs for the minimization model of ξ , which was solved numerically to determine the optimal weights ($w_1^*, w_2^*, \dots, w_n^*$) under non-negativity and normalization constraints. This procedure allowed the generation of consistent and comparable weightings across scenarios, ensuring the internal coherence of expert judgments.

As an illustrative example, in one scenario the experts identified C.6.1 as the “best” and C.8.2 as the “worst” criterion. In the AB matrix, the best criterion (C.6.1) was considered six times more important than C.2.1 and five times more important than C.4.1. In the AW matrix, C.2.1 was evaluated as twice as important as the worst (C.8.2) and C.4.1 as three times more important than the same. These judgments can be represented by the following system of inequalities, following the general formulation presented in [10]:

$$|w_{C6.1} - 6w_{C2.1}| \leq \xi \quad (4)$$

$$|w_{C6.1} - 5w_{C4.1}| \leq \xi \quad (5)$$

$$|w_{C2.1} - 2w_{C8.2}| \leq \xi \quad (6)$$

$$|w_{C4.1} - 3w_{C8.2}| \leq \xi \quad (7)$$

$$\sum w_j = 1, \quad w_j \geq 0 \quad (8)$$

The optimization model seeks the set of weights ($w_1^*, w_2^*, \dots, w_n^*$) that minimizes the maximum deviation ξ , ensuring the internal coherence of the judgments and the

consistency of the comparisons among criteria within each scenario. For each scenario, the process is repeated in order to obtain its corresponding criteria–scenario matrix.

6. Consistency evaluation of comparisons: For each scenario, the consistency ratio (ES) was calculated, defined as the quotient between the minimum optimal deviation (ζ^*) obtained in the model and the tabulated consistency index (IC_n), corresponding to the magnitude of the comparison between the best and worst criteria and to the consistency index table (Equation (4)). An ES value < 0.2 indicates an acceptable level of consistency in comparisons, allowing the reliability of expert judgments to be validated [44].

$$ES = \frac{\zeta^*}{IC_n} \quad (9)$$

Weighted inter-scenario aggregation: once the consistency of the weight vectors $w(k)$ in each scenario was verified, a final aggregate vector w^* was calculated, weighting each scenario by its probability of occurrence p_k . This stratified aggregation allows prioritization to be consolidated considering contextual uncertainty (Equation (5)).

$$w^* = \sum_{k=1}^n p_k \cdot w^{(k)} \quad (10)$$

It is convenient to clarify that the weighted aggregation expression $w^* = \sum_k p_k \cdot w(k)$ must be complemented with a subsequent normalization in case the sum of the aggregated vectors is not 1.

7. Final prioritization of strategies: Based on the aggregated vector w^* , a final ranking of strategies was established. This ranking reflects the robustness of each alternative in different future scenarios. To do this, the optimal weights for each criterion are multiplied by the corresponding values in the normalized decision matrix, which allows for obtaining the aggregate scores for each strategy and ranking them based on their overall performance.
8. Sensitivity analysis: A sensitivity analysis is performed to assess the stability of the strategy ranking derived from the SBWM model in the face of variations in critical system parameters, i.e., specific thresholds in parameter variation beyond which a significant change in the ranking of prioritized strategies occurs.

4. Results

Drawing on the information collected through the questionnaires and the structured matrices described in the Methods section, the DEMATEL–ANP–SBWM model was applied to analyze the system of criteria and prioritize the proposed strategies. The following section presents the main results of this hybrid approach, including the influence relationships among criteria, the relative weights obtained within the network, the consistency assessment and the final prioritization outcomes.

The experts participating in the study first constructed their individual decision models, expressing the influence of each criterion on the others through separate matrices. These matrices were later combined using the Aggregation of Individual Judgments (AIJ) technique, which calculates the geometric mean of the normalized priorities [45]. This approach ensured that individual perspectives were incorporated into a single, representative group judgment.

The DEMATEL results allowed the identification of causal and dependent relationships among the first-level criteria. The analysis showed that criteria associated with productive transformation and associativity functioned as driving factors within the sys-

tem, while environmental and cultural dimensions tended to be more dependent. This configuration suggests that strengthening farmers' markets requires, as an initial step, the consolidation of economic and organizational foundations, which subsequently supports environmental and cultural improvements. The detailed matrices can be found in the Appendix A (Tables A4 and A5), while the main findings are summarized here.

The ANP analysis provided the relative weights for each criterion and strategy. Within the interdependent network, criterion C6.1 (productive transformation) obtained the highest weight, followed by criteria related to infrastructure and associativity. By contrast, cultural and gender-related criteria appeared with lower weights. These results align with the literature on the social and solidarity economy, which highlights the relevance of infrastructure and associativity as enabling conditions for the sustainability of farmers' markets [11,12]. Intermediate matrices and all numerical values are reported in the Appendix A.

The consistency analysis performed with SBWM confirmed the stability of the experts' judgments across the four scenarios (S0, S1, S2, S3). As shown in Table 6, the consistency values (ξ) remained below the acceptability threshold ($ES < 0.2$), indicating that the weight vectors are robust and the prioritization is valid.

Table 6. Selection of extreme criteria and assessment of consistency by scenario under the SBWM.

Scenario	Best Criterion	Worst Criterion	ξ	ES
S0	C.6.1	C.8.2	NA	NA
S1	C.6.1	C.8.2	0.0658	0.0126
S2	C.1.2	C.5.1	0.1143	0.0219
S3	C.9.1	C.3.2	0.5605	0.1072

NA (Not applicable).

The procedure followed to obtain the results in Table 6 was the following. First, for each scenario (S1–S3), the expert panel identified the extreme criteria—"best" (the criterion perceived as most influential) and "worst" (the least influential). This identification was reached through structured discussions during the participatory workshops: each expert presented their individual assessment, and consensus was achieved through majority agreement supported by a brief justification. This participatory step follows recognized practices in scenario planning and expert elicitation [10,30,40].

Second, within each scenario, experts provided the Best-to-Others (AB) and Others-to-Worst (AW) comparisons required by the SBWM for the full set of second-level criteria. The individual judgments were aggregated using the geometric mean to obtain the AB and AW vectors. These vectors were used to solve the SBWM optimization model, producing the optimal weights and the minimum deviation ξ for each scenario [10,39,40].

Third, internal consistency was evaluated using the consistency ratio (ES), computed as $ES = \xi^*/IC_n$, where ξ^* is the optimal deviation and IC_n is the index tabulated for n criteria [40]. A value of $ES < 0.2$ indicates acceptable consistency among the judgments [44]. The row corresponding to Scenario S0 represents the initial, non-stratified baseline, used only to record the identification of extreme criteria. Because no optimization is performed at this stage, ξ and ES are not applicable.

To illustrate the computation, consider Scenario S1. Experts selected C6.1 as the most influential ("best") and C8.2 as the least influential ("worst") criterion. Based on the pairwise judgments provided, the respective matrices were constructed using the 1–9 importance scale, which served as the input for the SBWM optimization process.

Expert judgments (Scenario S1):

Best-to-others (AB): aB, C6.1 = 1; aB, C1.1 = 3; aB, C5.1 = 5; aB, C8.2 = 9.

Interpretation: C6.1 is three times more important than C1.1, five times more than C5.1, and nine times more than C8.2.

Others-to-worst (AW): aC6.1, W = 9; aC1.1, W = 6; aC5.1, W = 4; aC8.2, W = 1.

Interpretation: C6.1 is nine times more important than C8.2, C1.1 six times more, and C5.1 four times more.

Linear optimization model:

$$\text{Min } \xi$$

subject to

$$|w_{6.1} - 3w_{1.1}| \leq \xi \quad (11)$$

$$|w_{6.1} - 5w_{5.1}| \leq \xi \quad (12)$$

$$|w_{6.1} - 9w_{8.2}| \leq \xi \quad (13)$$

$$|w_{1.1} - 6w_{8.2}| \leq \xi \quad (14)$$

$$|w_{5.1} - 4w_{8.2}| \leq \xi \quad (15)$$

$$w_{6.1} + w_{1.1} + w_{5.1} + w_{8.2} = 1, \text{ with } w \geq 0 \quad (16)$$

Solving this system gives:

$w_{6.1} = 0.420$, $w_{1.1} = 0.260$, $w_{5.1} = 0.190$, $w_{8.2} = 0.130$, and the minimal deviation $\xi = 0.0658$.

Consistency evaluation: The consistency index for aBW = 9 is CI = 5.23 [42]

$$ES = \frac{\xi}{CI(a_{BW})} = \frac{0.0658}{5.23} = 0.0126 \quad (17)$$

Since $ES < 0.20$, the expert judgments are considered consistent.

A similar procedure was followed for Scenarios S2 and S3, resulting in the following summary:

Each scenario (S1–S8) represents a distinct prospective context evaluated through the Stepwise Best–Worst Method (SBWM). The best and worst criteria were selected for each case, and the linear optimization model was solved to minimize the maximum deviation ξ under non-negativity and normalization constraints ($\sum w_j = 1$). The ES value indicates the consistency ratio of each scenario, obtained as the optimal ξ^* .

Once the consistency of the weight vectors $w(k)$ was verified in each of the scenarios, a final aggregate vector w^* was calculated. Future scenarios were weighted based on expert judgments. At this stage, participants were asked about the probability of each of the proposed scenarios occurring. The experts assigned relative values of occurrence: 0.3% for S1 (Continuity without institutional support), 0.4% for S2 (Institutional support) and 0.3% for S3 (Pressure for urban reorganization). The assignment of probabilities to future scenarios was based on expert judgment, following the principles of subjective Bayesian theory and strategic foresight. In contexts characterized by uncertainty and limited empirical information, scenario likelihoods are commonly derived from the informed beliefs of domain experts rather than from statistical frequencies. This approach aligns with the principles of scenario planning and multi-criteria decision analysis under uncertainty, where experts' collective assessments are used to reflect the perceived plausibility of each scenario. As emphasized in the literature [42,43], the estimation of scenario probabilities through expert consultation enhances the robustness of foresight models by integrating experiential and contextual knowledge. Similarly, in the field of decision sciences, other studies [45,46] support the use of expert-derived probabilities as a valid mechanism to weight outcomes

in multi-criteria models when objective data are unavailable. The weighted aggregation of the vectors of each scenario was performed, and w^* was normalized (Table 7).

Table 7. Criteria weights based on SBWM by scenario (S0–S3).

Criteria	S0	S1	S2	S3
C.1.1	0.0517	0.2537	0.2587	0.2638
C.1.2	0.0485	0.0490	0.0500	0.0509
C.2.1	0.0610	0.0441	0.0450	0.0458
C.2.2	0.0583	0.0226	0.0230	0.0233
C.3.1	0.0539	0.0295	0.0300	0.0305
C.3.2	0.0572	0.0432	0.0440	0.0447
C.4.1	0.0594	0.0304	0.0310	0.0315
C.4.2	0.0557	0.0363	0.0370	0.0376
C.5.1	0.0532	0.0206	0.0210	0.0213
C.5.2	0.0506	0.0296	0.0290	0.0283
C.6.1	0.0616	0.1101	0.1079	0.1056
C.6.2	0.0597	0.0877	0.0859	0.0841
C.7.1	0.0548	0.0459	0.0450	0.0440
C.7.2	0.0580	0.0551	0.0539	0.0528
C.8.1	0.0503	0.0337	0.0330	0.0322
C.8.2	0.0483	0.0378	0.0370	0.0361
C.9.1	0.0602	0.0388	0.0380	0.0371
C.9.2	0.0575	0.0317	0.0310	0.0303
ES	N.A.	0.0176	0.0381	0.1868

N.A. (Not applicable): The ES value is not computed for scenario S0 because the baseline scenario does not include the SBWM consistency evaluation.

The probabilities of occurrence for the three future scenarios were determined through an expert elicitation process following the methodological approach of Moreno-Solaz et al. [10] and the scenario planning framework proposed by Godet [40]. During the participatory workshops, experts were asked to assess the relative likelihood of each scenario (S1, S2, and S3) based on their experience and the contextual trends observed in recent years in the operation of farmers' markets in urban areas. Individual assessments were expressed as proportional values whose sum equaled one and were then aggregated using the geometric mean to obtain the final probability vector. The resulting probabilities—0.3 for S1 (continuity without institutional support), 0.4 for S2 (institutional support and favorable regulation), and 0.3 for S3 (pressure from urban reorganization)—reflect a balanced distribution of uncertainty consistent with the principles of scenario planning and probabilistic expert judgment [10,36].

The probability vector was normalized to satisfy the condition of completeness, ensuring that the sum of all probabilities equals one and each element lies within the $[0, 1]$ interval:

$$\sum_{k=1}^3 p_k = 1 \quad \text{and} \quad 0 \leq p_k \leq 1 \quad (18)$$

The final normalized vector was:

$$p = [p_1, p_2, p_3] = [0.3, 0.4, 0.3] \quad (19)$$

This probability distribution was later used in the stratified aggregation of weights across scenarios, according to the following expression:

$$w^* = \sum (k=1)^3 p_k \cdot w^{(k)} \quad (20)$$

Criterion C.1.1 received the highest weight, reflecting the importance attributed by experts to international alliances as a mechanism for knowledge transfer, market access, and the long-term sustainability of farmers' markets in Meta.

To prioritize the strategies, another questionnaire was then administered to the experts, asking them to identify the best and worst strategies for each criterion evaluated. Subsequently, the BWM technique was implemented again for each scenario considered.

The final prioritization of strategies was obtained by aggregating the normalized performance values of each alternative across all evaluation criteria. Each value in the normalized decision matrix represents the relative performance of a strategy with respect to a specific criterion, while the optimal weight W^* indicates the relative importance of that criterion within the overall decision model. Therefore, multiplying each criterion value by its optimal weight reflects the weighted contribution of that criterion to the overall performance of the strategy. The global score of each strategy was then calculated as the sum of these weighted contributions, as shown in Equation (21):

$$S_i = \sum_j W_j^* \times V_{ij} \quad (21)$$

where S_i is the aggregated score of strategy i , W_j^* is the final weight of criterion j , and V_{ij} is the normalized performance of strategy i with respect to criterion j .

The resulting matrix (Appendix A Table A6) was multiplied by the optimal weight matrix of the criteria (Table 8), in order to obtain the aggregate score for each strategy.

Table 8. Optimal weights of the criteria.

Criteria	C.1.1	C.1.2	C.2.1	C.2.2	C.3.1	C.3.2	C.4.1	C.4.2	C.5.1	C.5.2	C.6.1	C.6.2	C.7.1	C.7.2	C.8.1	C.8.2	C.9.1	C.9.2
Normalized W^*	0.259	0.050	0.045	0.023	0.030	0.044	0.031	0.037	0.021	0.029	0.108	0.086	0.045	0.054	0.033	0.037	0.038	0.031

The full names and definitions of the criterion codes used are presented in Table 1.

The prioritization results are presented in Table 9, which contrasts the values obtained with the ANP–DEMATEL and SBWM models.

Table 9. Prioritized strategies with ANP–DEMATEL and SBWM.

ANP-DEMATEL		SWBM	
Strategies	Weights	Strategies	Weights
E.2	0.1299	E2	0.0652
E.6	0.1278	E4	0.0611
E.3	0.1237	E3	0.0594
E.4	0.1228	E8	0.0578
E.5	0.1180	E6	0.0506
E.1	0.1041	E1	0.0504
E.9	0.0966	E7	0.0500
E.8	0.0957	E5	0.0494
E.7	0.0815	E9	0.0483

The full names and definitions of the Strategies codes used are presented in Table 2.

In the ANP-DEMATEL model, the highest-rated strategies were E.2 (infrastructure development) with a weight of 0.1299, followed by E.6 (preparation of ancestral foods) with 0.1278, and E3 (working groups) with 0.1237. In turn, in the SBWM model, which incorporates prospective weighting by scenarios, E2 also ranked first (0.0652), followed by E4 (public procurement) with 0.0611 and E3 (working groups) with 0.0594. The predominance of strategies related to institutional coordination and capacity building reflects the facilitating role of associativity and infrastructure in consolidating farmers' markets as sustainable territorial systems. This finding supports the arguments of the social and solidarity economy, in which collective action and investment in basic infrastructure are identified as prerequisites for long-term sustainability [2,46]. Similar evidence has been reported in the Brazilian context, where public procurement policies and cooperative networks significantly improved small farmers' access to markets [18], and in Uruguay, where infrastructure and organizational support were decisive in consolidating local food circuits [19].

Conversely, strategies focused exclusively on commercialization, such as E.7 (product marketing), showed limited effectiveness when not supported by prior associativity processes. This observation aligns with evidence from alternative food networks in Latin America, where studies in Mexico, Chile, and Bolivia have demonstrated that the sustainability of farmers' markets depends not only on access to marketing channels but also on collective organization and institutional support [16].

A sensitivity analysis was performed to evaluate the robustness of the SBWM model under variations in the most influential criterion. The weight of criterion C.1.1 was progressively increased from 0.1 to 1.0, while the remaining criteria were proportionally adjusted to maintain normalization. For each parameter value, the composite scores of the nine strategies were recalculated, and their evolution was plotted (Figure 2). The results reveal that the model exhibits moderate sensitivity, with several rank reversals observed among intermediate strategies. Crossings occur between E2–E8 ($c \approx 0.15$), E2–E3 ($c \approx 0.25$), E4–E8 ($c \approx 0.29$), E4–E3 ($c \approx 0.41$), and E6–E7/E1 ($c \approx 0.30$ – 0.40). These inversions indicate that small changes in the importance of C.1.1 can alter the relative position of second- and third-tier strategies, although the overall structure remains coherent.

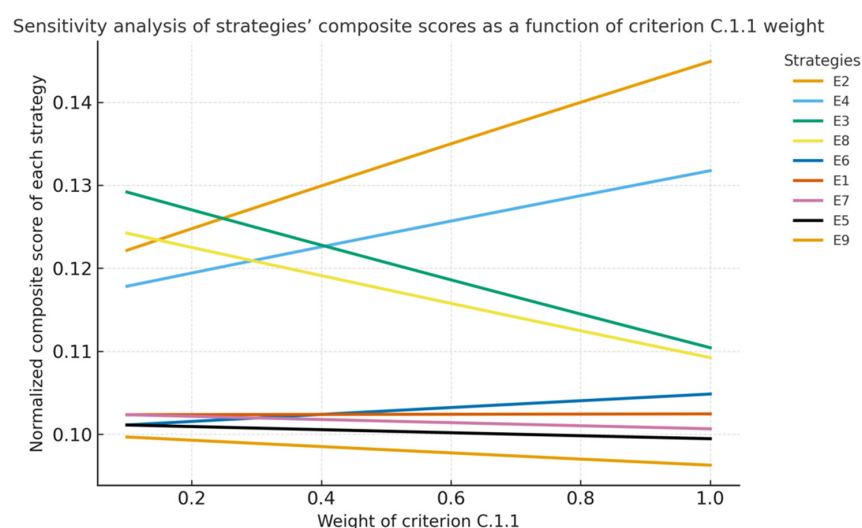


Figure 2. Sensitivity of the strategies to the weight of criterion C.1.1.

Despite these fluctuations, strategy E2 (infrastructure development) consistently maintains the highest composite score across the entire range, confirming its dominant and stable priority. In contrast, strategies E3 (working tables) and E8 (participatory workshops) show decreasing trajectories as the weight of C.1.1 increases, suggesting that their relative

importance diminishes when external and institutional cooperation becomes more relevant. It is worth noting that while criterion C.6.1 (development of new products based on regional raw materials) was identified as the most influential factor in the structural ANP–DEMATEL model, criterion C.1.1 (international alliances) emerged as the most dominant in the aggregated SBWM vector. This shift reflects how the introduction of prospective weighting modifies the decision context, emphasizing institutional and governance aspects over productive capacities.

Overall, the model demonstrates a balanced robustness: while the leading strategy (E2) remains unaffected, the middle-ranked strategies exhibit sensitivity to institutional-criteria variations. This behavior reflects the adaptive nature of the SBWM approach, in which prospective weighting highlights how governance and external partnerships can reshape local priorities under uncertain conditions.

5. Discussion

The results obtained through the ANP–DEMATEL and SBWM models reveal meaningful differences in the prioritization of strategies for strengthening farmers' markets in the department of Meta. In the structural model based on ANP and DEMATEL, strategies linked to physical investment and cultural preservation—such as infrastructure development (E.2) and the preparation of ancestral foods (E.6)—were positioned as priorities. This outcome reflects an emphasis on transforming the productive base and aligns with experiences reported in Brazil and Uruguay, where the consolidation of rural agro-industries has improved value addition and regional food security through public policies that support modular infrastructure and appropriate technologies [47,48]. In contrast, the prospective analysis performed through SBWM, which incorporates expert assessments under alternative scenarios, assigns greater relevance to strategies focused on institutional coordination (E.3: working groups) and participatory training (E.8: from seed to plate). This redistribution suggests that, under conditions of uncertainty or institutional variability, strategies that reinforce organizational capacities and facilitate collaborative networks gain greater strategic value. Evidence from Mexico, where sustainable agriculture and public procurement programs are supported by local governance processes, demonstrates similar trends [49,50].

Feedback from community stakeholders provided relevant insights into the practical significance of the prioritized strategies. During the dissemination sessions, participants expressed agreement with the relevance of infrastructure development (E.2), working groups (E.3), participatory workshops (E.8) and the promotion of ancestral foods (E.6). However, several participants mentioned difficulties in understanding how qualitative assessments were transformed into quantitative rankings. This observation highlights the need to reinforce explanatory mechanisms in future applications. It should be noted that stakeholders were not explicitly asked to reflect on the divergences between the ANP–DEMATEL and SBWM rankings, which constitutes a limitation of the study. Future applications could incorporate a dedicated feedback space to present both rankings side by side, accompanied by plain-language explanations and short protocols that combine Likert items with open-ended prompts to collect agreement levels, disagreements and underlying reasoning. Such an addition would strengthen transparency and further legitimize the prioritization process.

The findings also show clear connections with several Sustainable Development Goals (SDGs), particularly SDG 2 (Zero Hunger), SDG 8 (Decent Work), SDG 9 (Industry, Innovation and Infrastructure), SDG 12 (Responsible Consumption and Production) and SDG 17 (Partnerships for Development) [3,4]. Prioritized strategies such as working groups, infrastructure investment and participatory workshops contribute to stakeholder

coordination, foster local value addition and build community capacities, all of which are central to the achievement of the 2030 Agenda.

From a methodological standpoint, the integration of DEMATEL, ANP and SBWM offers complementary strengths for multi-criteria decision-making. DEMATEL helps identify causal structures, ANP models hierarchical interdependence, and SBWM introduces a scenario-based robustness component. Recent studies have demonstrated the usefulness of hybrid models in sustainable agri-food planning [51], although applications explicitly targeting farmers' markets remain limited, which underscores the originality of this article. Limitations of the study include the small number of expert participants, the reliance on qualitative judgments in constructing comparison matrices and the lack of ex-post empirical validation of the selected strategies. Nonetheless, the hybrid model is particularly suitable for contexts with incomplete or limited statistical information, as it relies on structured expert judgment and prospective scenarios to produce robust prioritization outcomes. Future research could incorporate dynamic variables such as input prices, access to credit or climate variability into the hybrid approach.

The results also encourage reflection on the potential contributions of this research to the agri-food industry more broadly. The prioritization of infrastructure development (E.2) and participatory training (E.8) points toward the modernization of farmers' markets and the strengthening of regional competitiveness. These outcomes are consistent with studies showing that the reconfiguration of agri-food chains in Latin America, especially under crisis conditions, has depended on resilience-oriented strategies [52]. Additional evidence suggests that innovation in agro-industrial processes, such as those in the citrus chain, depends on collective management capacities and clearly defined priorities, which resonates with the results of this research [53].

Beyond these convergences, the integrated model proposed here provides advantages that surpass the contributions of the individual methods. By combining DEMATEL and ANP, the analysis captures both causal dynamics and interdependencies in a coherent network, avoiding fragmented interpretations of farmers' markets. The inclusion of SBWM complements this structure by testing the robustness of priorities under alternative futures and by reducing the cognitive load on experts due to fewer and simpler comparisons. This feature is particularly valuable in participatory rural settings, where many actors are unfamiliar with complex modeling techniques. These attributes highlight the originality and applicability of the hybrid model for agri-food planning in Latin America.

Finally, continuous engagement with community stakeholders through workshops and cooperative assemblies remains essential. This interaction ensures that prioritization outcomes are not isolated analytical products but rather inputs that inform collective decision-making and support the long-term sustainability of farmers' markets.

6. Conclusions

This article applied a hybrid DEMATEL–ANP–SBWM model to prioritize agri-food transformation strategies in the department of Meta, Colombia, incorporating criteria of quality, associativity, and ancestral knowledge. The results show that priorities vary depending on the methodological approach: while the structural model (ANP–DEMATEL) emphasized investment in infrastructure and cultural valorization, the prospective model (SBWM) gave greater relevance to institutional coordination and participatory training. The consistency of strategy E2 (infrastructure development) across models and scenarios confirms its central role in strengthening farmers' markets.

From a theoretical perspective, this research demonstrates that the integration of three complementary multi-criteria techniques can simultaneously address interdependencies, causal relationships, and uncertainty scenarios, thereby broadening methodological appli-

cations in rural agri-food systems. In practical terms, the findings provide guidance for cooperatives, local governments, and social organizations on the importance of prioritizing institutional coordination, basic infrastructure, and participatory training as enabling conditions for the sustainability of farmers' markets.

The sensitivity analysis confirmed the robustness of the prioritization model. The persistence of infrastructure development (E.2) as the leading strategy across all parameter variations supports the reliability of the SBWM framework. Although some middle-ranked strategies showed moderate sensitivity to institutional criteria, the overall ranking remained coherent, indicating that the model provides stable results for decision-making under uncertainty.

This article is subject to certain limitations, including the relatively small number of experts consulted and the reliance on qualitative judgments in the construction of comparison matrices. In addition, the impacts of the prioritized strategies were not empirically validated after implementation, which opens avenues for further applied research. Another limitation concerns the scalability of the DEMATEL–ANP–SBWM model. Although the discussion highlights advantages such as adaptability and reduced cognitive burden, its practical application requires advanced methodological knowledge and specialized technical resources. This discrepancy implies that, despite its potential to facilitate stakeholder participation, the complexity of data processing and validation may hinder replication in contexts with limited institutional capacities.

Future studies should extend the application of this hybrid model to other regions and incorporate dynamic variables such as access to credit, climate variability, fluctuations in input and production costs, consumer demand trends, and regulatory changes. The inclusion of these variables would enhance the robustness and relevance of the model as a decision-support tool, contributing to Sustainable Development Goals related to responsible production, institutional partnerships, food security, and social inclusion.

This article contributes to the literature by integrating three complementary MCDM techniques (DEMATEL–ANP–SBWM) into a unified participatory and scenario-based framework. This hybridization provides a novel approach to model interdependencies and uncertainty in rural decision-making, particularly in farmers' markets of Latin America, where such integration had not been previously applied. Methodologically, it expands the analytical capacity of participatory MCDA; empirically, it introduces evidence from a real cooperative context in Meta, Colombia; and practically, it offers a reproducible tool for policy design and resource allocation in agri-food systems under uncertainty.

These findings reinforce the connection between local decision-making and the Sustainable Development Goals, emphasizing that stable and evidence-based prioritization mechanisms are essential for advancing inclusive governance, sustainable food systems, and territorial resilience in rural–urban interfaces.

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Institutional Review Board Statement: This non-interventional study adhered to the ethical principles of the Declaration of Helsinki (1975, revised in 2013) and was approved by the Bioethics Committee of Universidad de los Llanos (Acta 006, filing number 3110.02.0380) on 24 November 2022.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data that support the findings of this study are available from the corresponding author upon request. These data include ANP–DEMATEL matrices, SBWM prioritization vectors, and aggregated survey results collected from strategic stakeholders in the regional agri-food system. Due to ethical and confidentiality considerations, the data are not publicly available, as their disclosure could compromise participant anonymity and institutional sensitivities.

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Abbreviations

The following abbreviations are used in this manuscript:

ANP	Analytic Network Process
DEMATEL	Decision-Making Trial and Evaluation Laboratory
SBWM	Stratified Best–Worst Method
MCDA	Multi-Criteria Decision Analysis
SDG(s)	Sustainable Development Goal(s)
FAO	Food and Agriculture Organization of the United Nations
AIJ	Aggregation of Individual Judgments
CCS	Short Supply Chains
IC _n	Consistency Index (used in SBWM consistency calculation)
ξ	Deviation (in SBWM optimization equations)

Appendix A. Questionnaire 1–Identification of Stakeholders, Strategies and Criteria

1. General information: participant’s name, occupation, type of producer (primary, secondary or mixed) and municipality of residence.
2. Level of interest in participating in the research process, rated on a scale of 1 (no interest) to 5 (very high interest).
3. Farmers’ market needs: Participants were asked to identify up to three priority needs that they perceive as relevant.
4. Strategic actions: identification of concrete proposals that could be implemented in the short and medium term to strengthen farmers’ markets.
5. Types of support needed: Selection of support types, including infrastructure, equipment, technical training, promotion and sales, financing, and others—with optional justification.

Table A1. Questionnaire 2–Evaluation of strategies for farmers’ markets. The questionnaire served as an input for the application of DEMATEL (Decision-Making Trial and Evaluation Laboratory), which aims to prioritize the implementation of strategies based on the impact that one has on the others. The following table presents the assigned influence values of each criterion or alternative over the rest.

	Amount	Description
None	0	No influence of one criterion or alternative on another criterion or alternative
Very Low	1	Very little influence of one criterion or alternative on another criterion or alternative

Table A1. Cont.

	Amount	Description
Low	2	Little influence of one criterion or alternative on another criterion or alternative
Medium	3	Average level of influence of one criterion or alternative on another criterion or alternative
High	4	Significant influence of one criterion or alternative on another criterion or alternative
Very High	5	Too much influence of one criterion or alternative on another criterion or alternative

Table A2. Example of structured influence matrix from Questionnaire 2.

First-Level Criteria and Strategies										
	C.1	C.2	C.3	C.4	C.5	C.6	C.7	C.8	C.9	E
C.1										
C.2										
E										

For space reasons, only C.1, C.2, and E are shown in the column. The complete matrix includes all first-level criteria from C.1 to C.9 and the strategy E. The full names and definitions of the criterion codes used in the table are presented in Table 1. The letter E identifies the strategies.

Table A3. Limit matrix.

[illegible]

Table A4. Overall weights of the second-level criteria aggregated using the Individual Judgment Aggregation (IJA) method.

Criteria	C.6.1	C.2.1	C.9.1	C.6.2	C.4.1	C.2.2	C.7.2	C.9.2	C.3.2	C.4.2	C.7.1	C.3.1	C.5.1	C.1.1	C.5.2	C.8.1	C.1.2	C.8.2
weights	6.16%	6.10%	6.02%	5.97%	5.94%	5.83%	5.80%	5.75%	5.72%	5.57%	5.48%	5.39%	5.32%	5.17%	5.06%	5.03%	4.85%	4.83%

The full names and definitions of the criterion codes used are presented in Table 1.

Table A5. Results of the SBWM optimization model for scenario S1.

Criterion	AB (Best vs. C_j)	AW (vs. Worst C_j)	Weight $w^{(k)}$	Restr. Best $ w_B - a_{Bj}^* w^{(k)} $	Restr. Worse $ w_j - a_{jW}^* w^{(k)} $	Maximum $\frac{ w_B - a_{Bj}^* w_j }{ w_j - a_{jW}^* w^{(k)} }$
C.1.1	5	6	0.0464	0.0328	0.0425	0.0425
C.1.2	4	6	0.0649	0.0606	0.0239	0.0606
C.2.1	5	7	0.0526	0.0639	0.0511	0.0639
C.2.2	6	6	0.0433	0.0605	0.0456	0.0605
C.3.1	6	6	0.0433	0.0605	0.0456	0.0605
C.3.2	6	5	0.0433	0.0605	0.0308	0.0605
C.4.1	7	7	0.0378	0.0658	0.0658	0.0658
C.4.2	6	6	0.0433	0.0605	0.0456	0.0605
C.5.1	5	6	0.0526	0.0639	0.0362	0.0639
C.5.2	4	5	0.0649	0.0606	0.0091	0.0606
C.6.1	1	9	0.1990	0.0000	0.0658	0.0658
C.6.2	3	8	0.0528	0.0405	0.0656	0.0656
C.7.1	4	5	0.0649	0.0606	0.0091	0.0606
C.7.2	5	6	0.0530	0.0657	0.0359	0.0657
C.8.1	7	4	0.0204	0.0566	0.0389	0.0566
C.8.2	9	1	0.0148	0.0658	0.0000	0.0658
C.9.1	5	5	0.0526	0.0638	0.0214	0.0638
C.9.2	5	4	0.0503	0.0524	0.0089	0.0524
Addition			1.000		ζ (must be minimized)	0.0658

The full names and definitions of the criterion codes used are presented in Table 1.

Table A6. Normalized decision matrix of alternatives.

Criterion	E1	E2	E3	E4	E5	E6	E7	E8	E9
C.1.1	0.0525	0.1089	0.0836	0.0710	0.0186	0.0203	0.0070	0.0850	0.0621
C.1.2	0.0992	0.0024	0.1108	0.0987	0.0253	0.0237	0.0220	0.0298	0.0542
C.2.1	0.0605	0.0334	0.0699	0.0165	0.0348	0.0478	0.0546	0.0770	0.0206
C.2.2	0.0720	0.0679	0.0053	0.0720	0.0203	0.0085	0.1136	0.0947	0.0835
C.3.1	0.0427	0.0112	0.0782	0.0522	0.0145	0.0646	0.0041	0.0892	0.0267
C.3.2	0.0928	0.0357	0.0594	0.0648	0.0220	0.1265	0.0928	0.0921	0.0924
C.4.1	0.0838	0.1056	0.0101	0.0232	0.0054	0.0424	0.0465	0.0266	0.0856
C.4.2	0.0500	0.0322	0.0620	0.0167	0.0956	0.0097	0.1182	0.0757	0.0205
C.5.1	0.0008	0.0934	0.0807	0.0864	0.0919	0.0097	0.0429	0.0114	0.0891
C.5.2	0.0873	0.0379	0.0073	0.0369	0.0388	0.0952	0.0763	0.0870	0.0488

Table A6. Cont.

Criterion	E1	E2	E3	E4	E5	E6	E7	E8	E9
C.6.1	0.0168	0.0817	0.0869	0.0665	0.0919	0.0644	0.0626	0.0419	0.0026
C.6.2	0.0151	0.0036	0.0727	0.0373	0.0606	0.1184	0.0299	0.0402	0.0780
C.7.1	0.0321	0.0088	0.0331	0.0191	0.1108	0.1054	0.0758	0.0855	0.0830
C.7.2	0.0261	0.1022	0.0616	0.0957	0.1068	0.0415	0.0132	0.0224	0.0441
C.8.1	0.1146	0.0986	0.0008	0.0605	0.0498	0.0290	0.0144	0.0331	0.0974
C.8.2	0.0453	0.0594	0.0803	0.0431	0.1158	0.1255	0.0301	0.0488	0.0311
C.9.1	0.0399	0.0042	0.0696	0.0596	0.0061	0.0363	0.1088	0.0235	0.0150
C.9.2	0.0686	0.1129	0.0277	0.0797	0.0908	0.0310	0.0872	0.0361	0.0653

The full names and definitions of the criterion codes used are presented in Table 1.

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