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A PARTICIPATORY ANALYTIC HIERARCHY FRAMEWORK FOR EVALUATING URBAN AGRICULTURE IN COMPACT CITIES: IMPLICATIONS FOR SUSTAINABLE URBAN DEVELOPMENT AND SMART-CITY GOVERNANCE

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Urban agriculture is increasingly invoked in debates on sustainable and smart urban development, yet cities still lack a structured method for comparing the ecological, social, and economic implications of distinct urban agriculture models. This manuscript presents a participatory Analytic Hierarchy Process (AHP) framework for evaluating urban agriculture in a form directly relevant to strategic planning in compact cities. The study is based on a two-stage German case design. First, a European expert survey identified priority sub-criteria for sustainability assessment; 35 valid expert responses (29% response rate) were obtained from an expert pool of approximately 120 researchers. Second, a stakeholder survey in Germany weighted the selected criteria; 141 valid responses (28% overall response rate) were collected from urban administrations, non-governmental organisations, and practitioners or technical-scientific experts. The resulting AHP structure prioritises the environmental dimension (42%), followed by the social (34%) and economic (24%) dimensions, indicating a strong-sustainability orientation. At the sub-criterion level, biodiversity received the highest overall priority, while food quality and safety received the lowest. The framework identifies biodiversity, circular economy, local microclimate and hydrology regulation, community building and social justice, knowledge sharing and education, participation in food production, local value chains, affordability, and food quality and safety as the most relevant decision variables for urban agriculture assessment. Framed for a journal focused on urban development and smart cities, the article demonstrates that urban agriculture should be treated not as a generic green intervention, but as a governance-sensitive, multi-criteria planning decision requiring transparent prioritisation under conditions of land scarcity, competing urban functions, and diverse stakeholder values.

Index Terms — urban agriculture; analytic hierarchy process; sustainable urban development; smart cities; participatory planning; vertical farming; community-supported agriculture; multi-criteria decision analysis

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INTRODUCTION

Urban agriculture has become an increasingly important topic in contemporary urban development because it sits at the intersection of food security, biodiversity protection, climate adaptation, circular resource use, and neighbourhood-level social innovation [3, 4]. At the same time, urban agriculture is not a single intervention. It includes highly technological forms such as vertical farming and greenhouse-integrated production, as well as more socially embedded and nature-based forms such as community-supported agriculture, community gardens, and solidarity farming. These models differ markedly in their land-use implications, governance requirements, and sustainability effects. For urban planners operating under conditions of density, land scarcity, and competing development priorities, this diversity creates a practical decision problem rather than a merely conceptual one.

That problem is especially relevant to a journal focused on urban development and smart cities. Smart-city scholarship increasingly emphasises data-informed governance, transparent prioritisation, and cross-sector integration rather than technology alone. In that sense, urban agriculture is a smart-city issue when it is approached as part of a broader urban decision system: it shapes land allocation, environmental performance, civic participation, and local value creation. A framework that helps decision-makers evaluate different urban agriculture configurations is therefore directly relevant to smart-city governance, especially where cities must reconcile ecological goals with social inclusion and operational feasibility.

A major contribution in this area is the participatory framework introduced by John and Artmann [17], who developed an integrative evaluation structure for assessing the sustainability of different types of urban agriculture. Their study addressed a key gap in the literature: while many studies discuss the benefits of urban agriculture, systematic comparative evaluation of specific urban agriculture types in urban contexts has been rare. Using a multi-criteria analysis based on the Analytic Hierarchy Process (AHP), they proposed a hierarchy organised around three sustainability dimensions—environmental, social, and economic—and a set of weighted sub-criteria grounded in literature review, expert input, and stakeholder preferences.

The importance of that contribution lies not only in the criteria it identifies, but also in the normative ordering it reveals. The source study found that stakeholders placed the greatest weight on environmental sustainability, followed by social sustainability and, finally, economic sustainability [17, 30]. This result indicates a strong-sustainability interpretation of urban agriculture: ecological integrity is treated as the condition within which social and economic objectives must be pursued, rather than as one interchangeable pillar among others [20]. Such a finding has direct implications for urban development. It suggests that urban agriculture projects cannot be justified solely by innovation rhetoric, marketability, or short-term output; they must also be assessed in terms of biodiversity, local climate regulation, circularity, inclusion, and public participation.

The present manuscript is structured as a polished, standalone article grounded in the published evidence of the source study. It removes unsupported hypothetical alternative rankings and instead presents the original empirical framework in a journal-ready form centered on urban planning relevance. The paper has three aims: (1) to present the participatory AHP framework in a clear decision-support structure for urban development audiences; (2) to report the source paper's published empirical results on sub-criteria selection and weighting; and (3) to clarify why the framework is well suited to strategic planning and smart-city governance in compact urban regions.

CONCEPTUAL POSITIONING FOR URBAN DEVELOPMENT AND SMART CITIES

Urban development decisions increasingly require tools that can handle multi-dimensional trade-offs. In compact cities, every land-use intervention competes with housing, mobility infrastructure, public facilities, commercial development, and open-space provision. Urban agriculture therefore cannot be assessed adequately through a single metric such as productivity, technological novelty, or amenity value. Its contribution depends on how a given model performs across multiple planning goals.

From a smart-city perspective, this implies three requirements.

First, urban interventions should be assessed through transparent, structured decision architectures rather than ad hoc judgement. The AHP is well suited to this purpose because it translates complex value conflicts into an explicit hierarchy of criteria and pairwise comparisons [26, 27, 28].

Second, urban decision-making should be participatory. Urban agriculture depends not only on spatial suitability, but also on institutional support, civic capacity, and legitimacy. A framework that incorporates expert and stakeholder preferences is more useful for real-world planning than one based solely on technical criteria [7, 22].

Third, smart-city governance should integrate environmental intelligence with social and economic priorities. The source framework is especially valuable because it links the three-pillar sustainability model with ecosystem-service thinking, making it relevant both to urban sustainability assessment and to strategic planning for multifunctional urban landscapes [5, 3].

For these reasons, the framework analysed here is not only a contribution to urban agriculture studies; it is also a practical model for evidence-based and stakeholder-aware urban governance.

MATERIALS AND METHODS

Analytical Design

The study applies a multi-criteria analysis based on the Analytic Hierarchy Process (AHP) to assess the sustainability of different types of urban agriculture [17]. The framework combines a three-pillar sustainability structure—environmental, social, and economic—with the ecosystem service concept, which helps specify how urban agriculture contributes to urban development outcomes [5, 3].

The source study defined five AHP levels:

1. definition of the problem and goal;
2. definition of the hierarchy and its main criteria;
3. pairwise comparison and priority ranking of sub-criteria;
4. development of indicators;
5. evaluation of alternatives and sensitivity analysis.

The published article explicitly presented levels 1–3 only, focusing on the conceptual hierarchy, the selection of sub-criteria, and their weighting [17, 28]. This is an important methodological boundary: the study establishes a decision framework, but it does not yet report empirical scoring of specific alternatives such as vertical farms or community-supported agriculture systems.

Survey Stage 1: Selection of Sub-Criteria

The first stage identified the most important sub-criteria for evaluating sustainable urban agriculture. The authors prepared lists of 11 sub-criteria for each sustainability dimension (33 total), drawing on recent research on urban agriculture, sustainability assessment, and ecosystem services [12, 32, 15]. These lists were then evaluated through an online expert survey.

The expert survey targeted researchers in urban agriculture with a European focus. Experts were identified through project and publication screening; to qualify, a researcher needed at least four relevant publications since 2010. This process yielded an expert pool of approximately 120 persons [17]. The survey was conducted in English through SoSci Survey between 27 October and 3 December 2020. Experts first assessed the importance of the three main criteria and then rated the importance of each of the 11 sub-criteria per dimension using a five-point Likert scale ranging from 1 (unimportant) to 5 (very important). Means and standard deviations were calculated in IBM SPSS Statistics 25, and the top three sub-criteria per dimension were selected, with minor refinements based on open comments [17].

Survey Stage 2: Weighting of the Selected Sub-Criteria

The second stage weighted the selected sub-criteria through a stakeholder-based AHP survey in Germany. The study used ten German case-study cities selected through the Monitor of Settlement and Open Space Development of the Leibniz Institute of Ecological Urban and Regional Development. To capture urban contexts relevant for spatially constrained food production, cities had to have at least 50,000 inhabitants and more than 1,500 inhabitants per km^2. Five cities with the highest share of built-up settlement and transport area were selected (Herne, Munich, Oberhausen, Bochum, Gelsenkirchen), along with five cities with the lowest corresponding values (Freiburg im Breisgau, Konstanz, Aachen, Augsburg, Dresden) [17].

Three stakeholder groups were included:

- urban administrations,
- non-governmental organisations,
- practitioners or technical-scientific experts for community-supported agriculture or vertical farming.

A total of 500 invitations were compiled: 226 addresses for city administrations, 152 for non-governmental organisations, and 122 for practitioners or technical-scientific experts [17]. The survey was conducted in German through SoSci Survey between 14 February and 15 March 2022. Separate questionnaires were used for each stakeholder group, but all respondents performed pairwise AHP comparisons of the three main criteria and the three sub-criteria within each dimension.

To simplify the AHP process for non-specialist respondents, pairwise comparison began with a qualitative choice (which option is more important, or whether both are equal), followed by intensity scoring on the remaining points of the Saaty 9-point scale only when one option was preferred [27, 17].

AHP Processing and Consistency Rules

Weights were calculated in R using the `ahpsurvey` package [11]. After adapting survey exports for AHP processing, pairwise comparison matrices were constructed and individual preference weights were calculated through the dominant eigenvalue method. Individual judgements were then screened for consistency.

Only responses with a consistency ratio (CR) below 0.1 were retained for aggregate weighting, following standard AHP practice [26]. Aggregated criterion and sub-criterion weights were derived using normalized geometric means, and total sub-criterion weights were obtained by multiplying sub-criterion weights by the corresponding criterion weight [17]. The source study also deposited survey data and processing materials in an open repository [16, 19].

Table 1: Empirical design of the two-stage participatory framework

Stage	Purpose	Sample	Timing	Key output
Expert survey	Identify the most important sustainability sub-criteria across environmental, social, and economic dimensions	35 valid responses from an expert pool of about 120 (29%)	27 Oct–3 Dec 2020	Top three sub-criteria per sustainability dimension selected from 33 candidate sub-criteria
Stakeholder AHP survey	Weight the selected criteria and sub-criteria for a German urban case	141 valid responses from 500 invitations (28%); 55 urban administrations, 45 NGOs, 41 practitioners/technical-scientific experts	14 Feb–15 Mar 2022	Published dimension weights and sub-criterion weights based on consistent AHP responses

Consistent AHP observations retained for weighting: 90 for the three main criteria, 93 for environmental sub-criteria, 89 for social sub-criteria, and 85 for economic sub-criteria.

RESULTS

Priority Sub-Criteria Selected by Experts

The first survey yielded 35 valid datasets, corresponding to a 29% response rate [17]. Across the 33 candidate sub-criteria, experts selected three principal sub-criteria per sustainability dimension.

For the environmental dimension, the highest-rated sub-criteria were:

1. local microclimate and hydrology regulation,
2. species diversity,
3. circular economy.

For the social dimension, the highest-rated sub-criteria were:

1. practical knowledge gain, knowledge sharing, and education,

2. community building,
3. participation of residents/consumers in food production.

For the economic dimension, the highest-rated sub-criteria were:

1. food quality and safety,
2. local value chains/networks,
3. affordability for all social strata.

Following expert comments, two refinements were made before the second survey. First, species diversity was merged with genetic diversity and relabeled as *biodiversity*. Second, community building was sharpened conceptually and retitled as *community building and social justice*. These refinements improved conceptual clarity and reduced overlap between adjacent social criteria [17].

Table 2: Top-ranked sub-criteria selected in the first expert survey

Dimension	**Selected sub-criterion**	**Mean**	**SD**
Environmental	Local microclimate and hydrology regulation	4.11	0.90
Environmental	Species diversity[a]	4.09	0.87
Environmental	Circular economy	4.03	0.97
Social	Knowledge sharing and education	4.51	0.61
Social	Community building[b]	4.40	0.69
Social	Participation in food production	4.29	0.75
Economic	Food quality and safety	4.18	0.80
Economic	Local value chains/networks	4.00	0.94
Economic	Affordability for all social strata	3.91	1.07

[a] In the second survey, species diversity was merged with genetic diversity and relabeled as *biodiversity*.
[b] In the second survey, community building was refined and retitled as *community building and social justice*.

Stakeholder-Derived Weights

The second survey yielded 141 valid responses: 55 from urban administrations, 45 from non-governmental organisations, and 41 from practitioners or technical-scientific experts [17]. After consistency screening, approximately two-thirds of the observations were retained for aggregate weighting.

The main finding is clear: stakeholders gave the greatest weight to the environmental dimension (42%), followed by the social dimension (34%), and then the economic dimension (24%). This establishes an explicit hierarchy of priorities for urban agriculture assessment.

Within the environmental dimension, biodiversity received the highest internal weight (37%), followed by circular economy (32%) and local microclimate and hydrology regulation (31%). Within the social dimension, community building and social justice ranked first (37%), followed by knowledge sharing and education (35%) and participation in food production (28%). Within the economic dimension, local value chains and networks ranked highest (41%), followed by affordability (32%) and food quality and safety (26%).

When these internal weights were combined with the three main criterion weights, biodiversity received the highest reported total priority, while food quality and safety received the lowest [17]. This ordering makes the environmental logic of the framework especially visible.

Table 3: Published AHP weights for the sustainability framework

Dimension	Sub-criterion	Dimension weight	Within-dimension weight	Reported total weight
Environmental	Biodiversity	42%	37%	16%
Environmental	Circular economy	42%	32%	13%
Environmental	Local microclimate and hydrology regulation	42%	31%	13%
Social	Community building and social justice	34%	37%	13%
Social	Knowledge sharing and education	34%	35%	12%
Social	Participation in food production	34%	28%	9%
Economic	Local value chains/networks	24%	41%	10%
Economic	Affordability for all social strata	24%	32%	8%
Economic	Food quality and safety	24%	26%	6%

Reported total weights correspond to the published overall priorities shown in the source paper's weight diagram and are presented here in rounded percentage form.

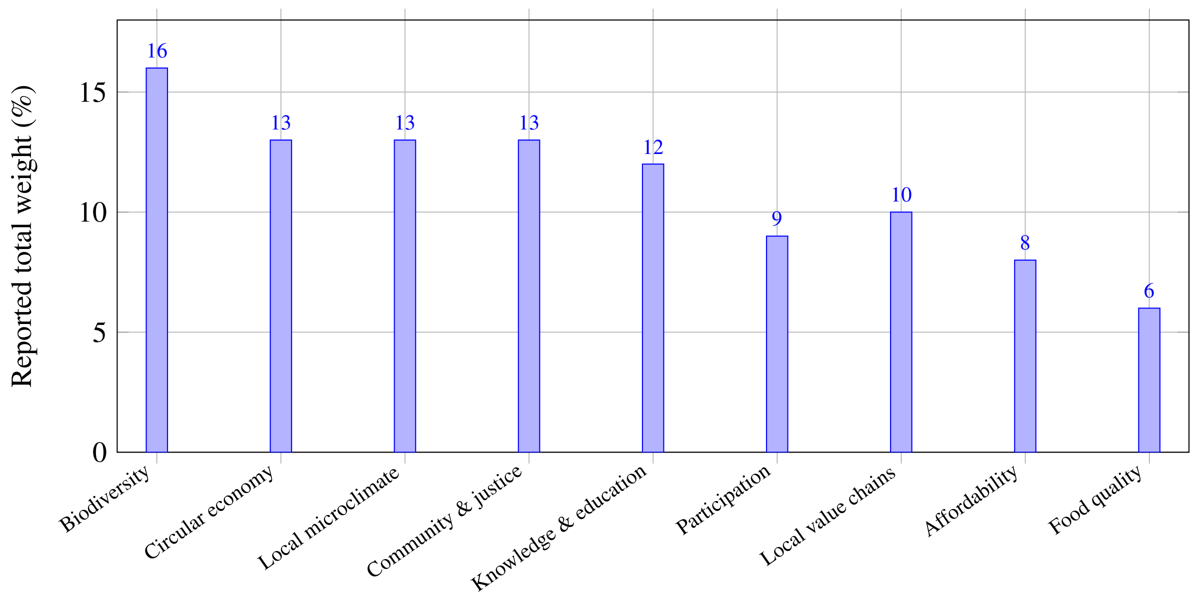

Figure 1: Reported total weights of the nine selected sub-criteria.

DISCUSSION

Strong Sustainability as the Core Planning Logic

The weight structure reported by the study indicates that urban agriculture is not treated by stakeholders as a primarily economic innovation. Rather, it is understood as a sustainability intervention in which ecological outcomes have first priority, social outcomes have second priority, and economic outcomes, while still relevant, are subordinated to both [17]. This is a strong-sustainability pattern [20]. It challenges weaker formulations of urban sustainability that assume ecological impacts can simply be offset through social or market gains.

For urban planning, this finding is consequential. It means that projects framed as efficient, marketable, or technologically advanced are not automatically favoured if they do not perform convincingly on biodiversity, circularity, and local climate-related functions. In urban development terms, the framework places nature-based performance and ecological systems thinking at the center of evaluation. This makes it especially relevant for cities attempting to align land-use decisions with climate resilience, ecosystem restoration, and sustainable resource management.

Why the Specific Sub-Criteria Matter

The environmental priorities are notable because they emphasise biodiversity, circular economy, and local microclimate and hydrology regulation rather than only productivity or space efficiency. This broadens the meaning of urban agriculture from food production alone to multifunctional urban infrastructure. Biodiversity-related outcomes matter because urban agriculture can contribute to habitat provision, diversification, and pollination support when appropriately designed [24, 25]. Circular economy matters because urban food production may improve local water, nutrient, and energy metabolisms, especially when compared with longer and more resource-intensive supply chains [21]. Local microclimate and hydrology regulation matter because urban growing systems may contribute to heat mitigation, evapotranspiration, and runoff management in dense urban settings [3].

The social priorities are equally important for urban development. Community building and social justice, knowledge sharing and education, and participation in food production collectively position urban agriculture as civic infrastructure rather than solely production infrastructure. This is precisely the kind of multifunctionality relevant to smart cities that seek to combine environmental intelligence with public engagement and place-based inclusion.

The economic priorities are also revealing. Local value chains rank above affordability and food quality. This suggests that stakeholders see the local economic embedding of urban agriculture—through local direct marketing, shorter chains, and neighbourhood-based networks—as more central to sustainability than purely market-oriented indicators. In planning terms, this supports forms of urban agriculture that strengthen territorial economies rather than operating only as isolated commercial ventures.

Relevance to Smart-City Governance

This framework fits the concerns of smart-city governance in at least four ways.

First, it provides a formal decision structure. The AHP offers a transparent way to compare options in settings where multiple values and trade-offs must be weighed. That is directly useful for planning departments, municipal innovation units, and urban sustainability offices.

Second, it is participatory by design. The framework does not rely on expert opinion alone; it incorporates a wider stakeholder field that includes administrative, civic, and practice-based actors. This improves democratic legitimacy and practical usability [10, 23].

Third, it supports integrated planning. Because the framework links ecological, social, and economic criteria, it helps city governments avoid siloed thinking in which food, climate, social cohesion, and local economic development are treated separately.

Fourth, it is adaptable. The published study presents levels 1–3 of the AHP, thereby establishing a robust platform for future indicator development and application to concrete alternatives. This modular quality is highly valuable for urban governance, where local authorities may need to adapt a framework to specific neighbourhood conditions, regulatory constraints, or planning objectives.

What the Framework Does Not Yet Claim

A crucial scholarly point is that the framework should not be over-interpreted. The source article does not yet empirically rank vertical farming against community-supported agriculture or any other concrete alternative. It presents the conceptual hierarchy and the weighting architecture, but not alternative-level scoring. Any claims that one specific urban agriculture model outperforms another would therefore go beyond the reported evidence. The present manuscript preserves that boundary.

At the same time, the source article clearly identifies where future research should go: toward indicator development, assessment of alternatives, and sensitivity analysis. It also explicitly notes the possibility of exploring a hybrid form that combines the spatial logic of vertical farming with the social organization of community-supported agriculture. The discussion references the Dresden-based initiative Wolkenfarm as an example of such a direction, suggesting that future research should examine whether community-based vertical farming can combine higher spatial efficiency with stronger civic participation and better food-behaviour outcomes [17, 34, 13]. This is best understood as a next-step research agenda, not as a finding already demonstrated by the present evidence.

IMPLICATIONS FOR URBAN DEVELOPMENT AND SMART-CITY PRACTICE

For urban development and smart-city decision-making, the framework yields several practical implications.

First, urban agriculture should be assessed as infrastructure. The strong emphasis on biodiversity, circularity, and microclimate functions indicates that urban agriculture belongs in conversations about climate adaptation, blue-green infrastructure, and ecosystem services—not only in food policy.

Second, urban agriculture is a governance question, not just a design question. Because community building, education, and participation rank so highly, the organisational form of an urban agriculture project is central to its planning value.

Third, municipal decision-making needs explicit prioritisation tools. Dense cities cannot treat all green interventions as equally beneficial. A structured AHP-based framework offers a way to compare proposals and justify planning decisions under conditions of contested land use.

Fourth, technology alone is insufficient. Vertical farming may offer clear advantages in controlled environments and spatial intensity [1, 18, 2], but the framework shows that evaluation must extend beyond technical efficiency to include ecological and social performance.

Fifth, future smart-city applications should move toward indicator integration. Because the source study establishes the weighted hierarchy but not yet the operational indicator layer, the next practical step for cities is to translate the selected sub-criteria into measurable indicators that can be used in project appraisal, funding calls, pilot selection, and neighbourhood planning.

LIMITATIONS AND FUTURE RESEARCH

The framework is methodologically robust, but several limitations should be made explicit.

First, the published study presents the conceptual and weighting stages of the AHP only. It does not yet include indicator development, alternative evaluation, or sensitivity testing. This means the framework is decision-ready in structure, but not yet fully operationalised for empirical benchmarking of specific projects

[17, 28].

Second, the weighting results are grounded in a German case. Although the framework is transferable conceptually, the precise weights may change in other institutional and cultural contexts.

Third, while the participatory approach is a major strength, multi-criteria decision-making remains sensitive to stakeholder composition. The selection of actors shapes the resulting priority structure.

Fourth, the three-pillar model, while analytically clear, may not exhaust all relevant urban sustainability dimensions. The source study itself discusses the possibility of adding health and well-being, including a broader planetary-health perspective, in future work [17, 34].

Future research should therefore proceed in three directions: (1) develop measurable indicators linked to the selected sub-criteria [8, 6]; (2) apply the completed framework to concrete urban agriculture alternatives; and (3) test how the framework performs across different urban scales, governance contexts, and smart-city strategies.

CONCLUSION

Urban agriculture is often discussed in broad and optimistic terms, but strategic urban development requires a more disciplined approach. The participatory AHP framework presented here provides that structure. By combining a three-pillar sustainability model with ecosystem-service reasoning and stakeholder-based weighting, the study establishes a transparent basis for evaluating urban agriculture in cities.

The central empirical finding is that stakeholders prioritise environmental sustainability over social sustainability, and social sustainability over economic sustainability. Within this hierarchy, biodiversity emerges as the most important overall sub-criterion, while food quality and safety receives the lowest overall priority. This pattern indicates that sustainable urban agriculture is best understood through a strong-sustainability lens that places ecological integrity at the center of decision-making.

For a journal focused on urban development and smart cities, the significance of this contribution is clear. The framework is not merely about food production; it is a model for participatory, multi-criteria, and governance-aware urban decision support. It offers a rigorous basis for integrating urban agriculture into land-use planning, resilience strategies, and smart-city governance in compact urban regions. Its immediate value lies in clarifying what should matter when cities assess urban agriculture. Its longer-term value lies in providing the foundation for indicator-based, context-sensitive, and operational future applications.

DECLARATIONS

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Data availability. The source study reports that survey materials, anonymised data, and AHP processing resources were deposited in an open repository.

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