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Guiding sustainable land use planning in Ethiopia: A decision support framework using analytic hierarchy process

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ABSTRACT

Land use planning in countries like Ethiopia faces persistent challenges, including outdated technical standards, fragmented institutional coordination, and limited community participation. These issues are particularly pronounced in land use and watershed development initiatives. In the implementation of Forest Landscape Restoration (FLR), emphasis is often placed on restoring ecological functions, mitigating land degradation, reducing soil erosion, and enhancing carbon sequestration than local community well-being. Therefore, adopting a holistic approach is essential when approaching land use decisions, carefully considering various factors that influence land use decisions. This study seeks to develop a multi-stakeholder land use decision support framework that integrates environmental, social, and economic dimensions to inform land use planning decision-making processes in Ethiopia. To achieve this objective, the Analytical Hierarchy Process (AHP) model, a Multi Criteria Decision Making (MCDM) method, is applied. We organized four workshops with different stakeholders, including farmers and experts from woreda, zonal, and federal levels. In the workshops, land use decision factors at the indicator and sub-indicator levels were developed, and a ranking of these decision factors was applied using the AHP matrix. Results show that a higher degree of consistency is achieved in the matrix with a Consistency Ratio (CR) of 0.01, as determined by federal-level experts. A tolerable CR of 0.01 is also achieved with farmers' criteria ranking. Although respective stakeholders have varying priorities, in general, climatic, economic, and environmental factors are among the top three, showing high priority weights above 0.4. A sensitivity analysis of the priority weights is conducted, and sensitive factors are identified, which are then used to develop a decision support tree for land use factor prioritization. The decision tree highlights seven critical sub-factors that hold a priority weight above 0.4 and are sensitive at the threshold level of 0.01. Selecting well-defined and compelling indicators will help align stakeholder perspectives and foster consensus in decision-making.

1. Introduction

Land use planning is a decision-making process that is subject to economic, societal, and environmental considerations when allocating land for various uses (Chigbu et al., 2019; Hailu et al., 2023). Multiple factors must be considered, ranging from the physical attributes of the land and environmental issues to socioeconomic aspects (Morales Jr and de Vries, 2021). Ultimately, land use planning seeks to determine the optimal combination of land uses that meets stakeholders' needs while conserving the environment in the long term. However, these decisions are complex and the public requires more transparency; all must be supported with scientific information (Greene et al., 2010). The growing complexity of land use decisions, particularly in contexts where multiple stakeholders with divergent objectives must reach consensus has increased the need for structured decision support frameworks that integrate diverse perspectives with transparency and scientific rigor (Bousquet et al., 2023; Langemeyer et al., 2016).

Land use decision-making can be examined through multiple

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theoretical lenses that reflect the perspectives and constraints of different stakeholders. Expected utility theory suggests that decisions are shaped by risk tolerance and rational evaluation of outcomes (Briggs, 2014; Navarro-Martinez et al., 2018). Prospect theory emphasizes that perceived losses often weigh more heavily than equivalent gains, influencing how land use changes are evaluated (Barberis, 2013). Bounded rationality theory highlights that decisions are made under conditions of limited time, information, and resources, such as finance, time, and knowledge (Navarro-Martinez et al., 2018; Simon, 1997). By integrating these perspectives, a more comprehensive understanding of land use decision-making emerges one that accounts for values, constraints and uncertainty.

In rural landscapes, land use decisions are influenced not only by landholders but also by policymakers and researchers, development actors and extension agents. Global and national initiatives such as commitments to the Bonn Challenge (BC) are reflected in local projects where stakeholder priorities diverge. For the global actors, environmental protection and carbon storage potential are central goals, framed as climate change mitigation and adaptation strategies (Gichuki et al., 2019; Temperton et al., 2019). In contrast, smallholder farmers prioritize secure access to productive land with livelihood and food security as primary concerns (Eshetu et al., 2024; IFAD, 2013; Mulu et al., 2022). Because land use decisions made by private land managers and smallholders can have impacts beyond individual parcels, it is essential to incorporate their decision factors into participatory platforms to achieve consensus and coordinated action (Epanchin-Niell et al., 2022). Modern land use theory further emphasizes that multi-stakeholder engagement is critical to fostering decisions that are sustainable and successful over the long term (Mosadeghi et al., 2015).

This actors require reliable, scientifically grounded information that support their decisions that deliver economic, social and ecological benefits (Li et al., 2020). Furthermore, policy frameworks also play a critical role, as land use decisions involve diverse institutional actors whose interactions shape spatial and temporal dynamics (Holzhauer et al., 2019). This interplay between local decision-making and broader governance systems is particularly important in the context of FLR, where ambitious national restoration commitments under initiatives such as the African Forest Landscape Restoration Initiative (AFR100) and the BC increasingly depend on the everyday land management decisions of local landholders who operate under resource constraints and immediate livelihood imperatives.

In the implementation of AFR100 initiatives in East Africa region, restoration efforts are hindered by fragmented governance and limited stakeholder participation, resulting in FLR outcomes that often reflect top-down agendas rather than locally negotiated priorities (Elias et al., 2025; Löhr et al., 2024; Reed et al., 2020; Syampungani et al., 2021). Ethiopia offers a compelling case for developing transferable decision-support frameworks. The country pledged to restore 15 million hectares of degraded land as part of the BC commitment and AFR 100. This is in addition to a plan to manage 7 million ha of forests and woodlands as part of the Climate Resilient Green Economy Strategy (CRGE) (CRGE, 2011; Kassa et al., 2022). However, the implementation faces persistent governance barriers, including policy inconsistencies across administrative levels and weak coordination among federal, regional, and local institutions and limited stakeholder participation (Tesfaye et al., 2024). These challenges reflect broader systemic constraints observed across the Global South, where the participatory rhetoric of FLR policies frequently fails to translate into genuine local ownership and decision-making power (Chazdon et al., 2016; Mansourian and Parrotta, 2018; Reed et al., 2020).

Despite extensive research on land cover dynamics and restoration outcomes in Ethiopia (Betru et al., 2019; Demissie et al., 2017; Tolessa et al., 2017) studies that integrate the diverse interests of multiple stakeholders in land use planning remain scarce. Research has examined the drivers of land use chang (Alemu et al., 2015; Kindu et al., 2015) and smallholder decision-making, but most planning tools still rely on GIS-based suitability analysis (Rahman and Szabó, 2022). With the rise of social-ecological systems thinking, there is growing recognition of the need for inclusive and adaptive decision support models (Fischer et al., 2021). Land use planning in Ethiopia is further constrained by outdated technical standards, weak linkages between relevant institutions, and low levels of community participation (Gessesse et al., 2023). The expansion of agricultural land at the expense of forests and shrub lands, particularly on steep slopes unsuitable for cultivation, has led to severe soil erosion and sedimentation threatening ecosystems such as Lake Chamo. In response, multiple stakeholders including the Ethiopian government, international actors (like the German Gesellschaft für Internationale Zusammenarbeit (GIZ)), research institutes, universities (like Arbaminch University), and others are implementing FLR measures. Strategic land use decision frameworks are therefore essential to determine appropriate land allocations and mitigate land degradation.

Effective land use planning, particularly in the context of FLR, requires decision processes that harmonize both top-down policy priorities and bottom-up local knowledge. Such collaborative approaches ensure that diverse stakeholders are meaningfully engaged, their priorities are made explicit, and decisions are socially legitimate and context-responsive (Chigbu et al., 2019). Multi-Criteria Decision Analysis (MCDA) offers systematic support for land and natural resource management decisions involving multiple, often conflicting criteria (Diaz-Balteiro and Romero, 2008; Huang et al., 2011). However, existing MCDA applications often treat stakeholders as a homogeneous group, overlooking how different actors prioritize land use criteria. These limits, transparency and reduce the ability to negotiate trade-offs effectively. To address these limitations, this study develops a stakeholder-differentiated Analytical Hierarchy Process (AHP) based decision support framework for land use planning in FLR contexts. This approach integrates both qualitative and quantitative judgments and allows the assessment of the internal consistency of stakeholder preferences (Ishizaka and Labib, 2011; Saaty, 1980).Assigning relative weights to decision criteria is often challenging, and AHP simplifies this process while outperforming other weighting methods by handling inconsistent judgments and quantifying their reliability (Duc, 2006; Saaty, 1980; Saaty, 1990).

In the Ethiopian context, the success of FLR initiatives depends on linking national restoration commitments with local livelihood priorities and ecological realities. Yet institutional fragmentation and diverse stakeholder interests often hinder coordinated, landscape-level planning. This study responds to these challenges by applying a structured, participatory approach to make decision processes more transparent and aligned across actors. Using the AHP, we compare how different stakeholder groups prioritize land use decision criteria, illuminating where their values converge and where trade-offs emerge. By eliciting and weighting these criteria directly from actors engaged in land management, the framework supports more informed dialogue and negotiated decision-making. The general objective of this study is to develop a participatory land use decision-support tool that identifies and ranks the key factors influencing land use choices across stakeholder groups. Specifically, the study aims (i) to identify the criteria and sub-criteria considered most critical in land use decision-making, and (ii) to examine how these priorities vary among stakeholders in order to reveal the underlying drivers shaping land use dynamics within the landscape. In doing so, the framework aims to enhance transparency, facilitate negotiation around competing objectives, and contribute to more inclusive and context-appropriate land use planning in FLR landscapes.

2. Methodology

2.1. Selected case study

In this study, we focus on Ethiopia as a key FLR country, home to ambitious FLR goals and the interests of multiple stakeholders. Ethiopia is 1.1 million square kilometres (km^2), with 35 % of the land used for agricultural purposes AFR100 (Dave et al., 2017). Within this commitment, Ethiopia pledged to restore 15 million hectares of land by 2030 although the specifics of where restoration takes place and the available land size for restoration were not yet identified at the time of commitment. The country is guided by a national-level land proclamation that establishes different ownership levels and management strategies for rural land holdings. However, the responsibility to administer and manage land and natural resources is given to the regional states. The country lacks a national land use policy to provide a unified framework for guiding land use decisions across diverse social, ecological, and institutional contexts (Ariti et al., 2019; Tesfaye et al., 2024). The absence of a comprehensive land use planning framework has led to fragmented decision-making, increasing the risk of unsustainable land use practices.

To gain a more localized perspective on land use decision factors, we selected the Lake Chamo catchment as our area of study. As part of the country's ambitious global BC commitment, large-scale FLR projects are being implemented across various regions, including this catchment. A diverse range of stakeholders, including smallholder farmers, government agencies, and international organizations, are actively engaged in FLR initiatives within the landscape. These efforts encompass diverse plantation schemes and extensive tree-planting campaigns aimed at mitigating soil erosion, reducing sedimentation, and preserving both terrestrial and aquatic ecosystems.

Land use decisions, particularly in the context of FLR implementation, are influenced by a complex interplay of ecological, socioeconomic, and political factors, which vary based on stakeholder priorities. To capture these varying perspectives, we engaged a broad spectrum of stakeholders, including policymakers, land use practitioners, development workers, and farmers, to identify and prioritize key land use decision indicators for sustainable land use planning.

2.2. Sampling and stakeholder selection

Institutional stakeholders were selected using a purposive sampling approach. We identified key government and non-government organisations active in land use policy, practice, research, and education at federal, zonal and woreda levels and invited these organisations to nominate a representative. To ensure informed and contextually grounded contributions, institutions were asked to nominate experts who (i) have at least five years of professional experience in land use planning or management and (ii) are familiar with the local socio-ecological context. Nominated participants thus represented their organisation's perspective in the development and ranking of criteria.

Farmer participants were identified by the local administration according to explicit selection criteria provided by the research team to reduce selection bias and ensure diversity. Farmers were selected based on (i) ownership of diversified land use types, (ii) gender representation (balanced number of male and female participants), and (iii) spatial representation across the landscape (upper, middle, and lower catchment areas). The spatial representation criterion was included specifically to avoid over-representation of farmers who live close to administrative centres and to capture heterogeneous perspectives that reflect differences in biophysical conditions and land use decision contexts. These sampling procedures sought to balance feasibility with the need for knowledgeable, diverse input into indicator refinement and AHP ranking.

2.3. Data collection method

This study used a two-step approach to define and prioritise land use decision indicators: (i) literature-based indicator compilation and categorisation, and (ii) stakeholder workshops for verification, refinement, and ranking using the Analytic Hierarchy Process (AHP). From the literature review, we compiled candidate indicators and grouped them into broad factors (economic, environmental, social, institutional, biophysical, and climatic). These literature-derived indicators were presented to workshop participants as a starting point for discussion and refinement.

A total of four workshops (N = 56 participants) were convened to develop the AHP matrices and to elicit expert judgements. The first workshop was held at the federal level in Addis Ababa (16 participants) and focused on refining the indicator set and establishing the primary factor structure, drawing on participants' national-scale knowledge of land use systems. To capture sectoral perspectives, participants were organised into three working groups (agriculture, forestry, and land management/administration). Each group reviewed and supplemented the sub-indicators, presented consolidated lists, and together the plenary reformed and regrouped indicators where necessary. These indicators and sub-indicators were then used in pairwise comparisons and subsequent AHP ranking exercises. The second workshop (Southern Region) engaged 14 participants from regional and zonal institutions. The third workshops took place within the Lake Chamo catchment and comprised 12 participants, combining regional practitioners, NGOs working in the landscape and local experts. The fourth Workshop is conducted with the selected farmers. The first author facilitated each workshop and ensured structured sessions (approximately six to seven hours each), guiding indicator comparison from factor level down to sub-indicator level for the AHP matrices.

2.4. Defining criteria and sub-criteria with stakeholders

Stakeholders at the federal level play a key role in selecting and defining land use decision factors from a broad and diverse perspective. In this study, six primary factors influencing land use decisions were identified: economic, environmental, social, institutional, biophysical, and climatic. A comprehensive systematic survey on the application of AHP method by Russo and Camanho (2015) shows that the number of sub-indicators assigned to each main indicator does not significantly impact the final outcome. Therefore, the participating stakeholders were flexible in determining the number of sub-indicators that represent the six primary factors. To identify the sub-indicators, stakeholders were grouped based on their respective sectors: agriculture, forestry, and land administration. Each sector identified relevant sub-indicators that land use decision-makers must consider for sustainable land use planning. These sub-indicators were then reviewed collectively by all participant stakeholders, with overlapping or closely related indicators were consolidated. Stakeholders arrived with different numbers of sub-indicators and although the terms vary, the defining criteria highly overlap. Through this process, we developed 32 sub-indicators categorized under the six identified indicators. These are economic (8), Environmental (4), Social (5), institutional (5), biophysical (5) and climatic (5). Table 1 presents the final criteria and sub-criteria level factors identified by the stakeholders and that are used in AHP matrix ranking.

2.5. MCDA and determination of criteria weights with AHP

There are various methods within the broader MCDA framework, each employing distinct protocols for gathering input, structuring information, applying algorithms to synthesize data, then interpreting results for practical decision-making and advisory purposes (Huang et al., 2011). These approaches differ in how they prioritize criteria, model trade-offs, and translate complex evaluations into actionable insights**,** making them adaptable to diverse decision-making contexts. AHP is a MCDA tool that helps decision makers facing complex problems with multiple conflicting and subjective criteria (Ishizaka and Labib, 2011). One key advantage of AHP is its hierarchical structure, which enables users to systematically organize criteria and sub-criteria, allowing for a more focused approach to assigning weights (Ishizaka and Labib, 2011). Therefore, in this study, we employed the AHP tool as a MCDA method to identify priority indicators and sub-indicators among the list of indicators provided by stakeholders.

Table 1
Indicators and sub-indicators ranked using AHP.

Indicator	Sub-indicators	Definition
Economic	Access to production input and market	Availability and expenses for fertilizers, pesticides, seeds, and other inputs.
	Access to alternative livelihood	Availability and feasibility of alternative income-generating opportunities.
	Land value	Value of the land based on location, attributes, and market demand.
	Initial capital	The capital needed to establish and maintain a specific land use system.
	Cash income	A direct cash benefit from the land use practice
	Investment return period	The waiting time before harvesting or benefiting from the practice.
	Land size	The total land area (in hectares) owned or managed by a farmer that is available for land use decisions.
	Access to finance	Availability of financial support or credit for investment in land use.
Environmental	Ecosystem services	Provisional, regulating, cultural, and supporting ecosystem services such as climate and water regulations, provision of food, timber, nutrient cycling, and recreation.
	Climate change mitigation and adaptation	Actions to mitigate climate change impacts, such as carbon sequestration and the development of drought-resilient crops.
	Biodiversity conservation	Practice of diversified species to preserve species and minimize habitat destruction.
	Landscape protection and management	Protection of the landscape from degradation, halt soil erosion, and watershed management.
Social	Social cultural heritage value	Societal values related to the location, including cultural and historical sites in the landscape.
	Proximity to urban area	The distance from the urban centres influencing infrastructure, social cohesion and societal values.
	Labor availability	Availability of sufficient workforce to support the land use practice.
	Communal land purpose	Collective use and management for a shared purpose like grazing land and hosting social events.
	Skill and knowledge of land use practices	Traditional knowledge and skills used in land use management.
Institutional	Customary laws and traditional practices	Informal or traditional land governance systems recognized by the community.
	Access to information and technology	Availability of technical advice and support from development agents and provision of technology.
	Governance	Structure and decision-making process in land administration and land use practices.
	Regulation and binding conventions	Formal policies, laws, and regulations governing land use practices.
	Land tenure	Legal frameworks ensuring land ownership, access, and use rights.
Biophysical	Slope and aspect	The degree of steepness or incline of the land and the direction a slope faces which affects soil erosion, microclimate condition.
	Topography and landform	The physical features of the land, such as contour variation and terrain, such as valleys, hills and plains.
	Natural enemies and invasive species	Organisms such as predators that control pests and diseases and non-native plants that outcompete native asp and alter ecosystem function.
	Current land use land cover	The existing land cover and land use practices.
	Soil condition	The physical, chemical and biological properties of the soil.
Climatic	Vulnerability to anomalies	Susceptibility to extreme climate events such as drought and flooding.
	Humidity	The amount of moisture available for crop growth.
	Temperature	The average and extreme temperature ranges.
	Elevation	The height of the land above sea level.
	Rainfall	The amount and distribution of precipitation.

When setting up the AHP hierarchy, especially with a large number of elements, it is essential for the decision-maker to arrange these elements in clusters (Ishizaka and Labib, 2011; Saaty, 1991). This ensures that comparison remains meaningful and manageable, preventing extreme variations that could compromise the consistency and reliability of the analysis. AHP is often used to identify and prioritize alternatives, which is land use practice in this case. However, a comprehensive review study of AHP application shows that AHP is also widely used to identify and evaluate key indicators (Russo and Camanho, 2015), providing a structured approach to assess multiple criteria and support informed decisions. In this study, we focus on identifying the criteria and sub-criteria that stakeholders consider in land use planning in order to achieve the goal of a sustainable multi-functional landscape.

The AHP was originally developed by (1980) as a measurement technique using ratio scales. This method serves as a powerful tool for determining the relative importance of criteria and assessing various alternatives in complex decision scenarios. Here, we apply AHP to prioritize the relative importance of land use decision criteria. The method is based on a scale ranging from 1 to 9 to capture preferences through pairwise comparisons, enabling the evaluation of both criteria and alternatives relative to each criterion (Table 2). This scale quantifies the intensity of preference, providing a structural framework for prioritizing decision factors.

In the AHP analysis, the prioritization process is facilitated through a structured group discussion among stakeholders, moderated by a facilitator. The facilitator guides the participants by presenting pairwise comparisons of indicators, asking them to first identify which factor is more important between the two. Once the more important factor is selected, participants are then asked to rate the degree of importance on a predefined scale, typically ranging from equal importance to extreme importance (Table 2).

If there are variations in the ratings among stakeholders, they must discuss the reasoning behind the differing levels. The facilitator encourages open dialogue to explore the reasons behind the differing perspectives. The discussion allows participants to share their justifications and collectively reassess their judgments. The process continues until a consensus is reached, ensuring that the final weights assigned to

Table 2
AHP scale developed by Saaty (1980).

Scale	Definition	Explanation
1	Equal importance	Two factors contribute equally to the objective
3	Moderate importance of one over another	Experience and judgement moderately favour one factor over another
5	Essential or strong importance	Essential or strong importance
7	Very strong importance	A factor is strongly favoured, and its dominance is demonstrated
9	Extreme importance	The evidence favouring one factor over another is one of the highest possible orders of affirmation
2,4,6,8	Intermediate values between the two adjacent judgements	When a compromise is needed between the above scales

each indicator represent a shared understanding among the stakeholders.

To calculate the criteria weights, a pair of criteria (i, j) are compared using the AHP scale. If criterion i is preferred over j, the corresponding entry in the pairwise comparison matrix is assigned the value $a_{ij}=v_{AHP}$ from the scale. In contrast, the reverse comparison is expressed as $a_{ji}=1/v_{AHP}$. Additionally, all diagonal elements, a_{ii} are equal to 1, indicating that each criterion is equally preferred to itself.

The pairwise matrix was normalized, and the eigenvalues of the normalized matrix, which represent the parameter weights, were computed. The consistency of ratings provided was measured using an appropriate Consistency Index (CI), which quantifies the degree of deviation or consistency. When the number of comparisons made (n) is consistent, the CI value will be zero, signifying perfect agreement. Similarly, the Consistency Ratio (CR) will also be zero, ensuring that the initial preference ratings are logically coherent and internally consistent. The pairwise comparison is acceptable if CR is smaller than or equal to 0.1; otherwise, the pairwise comparison and computation is redone (Afshari et al., 2010; Chen, 2006). However, several authors have emphasized that the 0.10 cutoff point of CR should not be treated as absolute limit where CR up to 0.2 have been accepted in the application of AHP (Duleba and Szádoczki, 2022; Page, 2012; Schmidt et al., 2015).

$$\lambda = \sum_{i=1}^{n} CV_{ij} \tag{1}$$

$$CI = \frac{\lambda - n}{n - 1} \tag{2}$$

$$CR = \frac{CI}{RI} \tag{3}$$

Where CR = Consistency Ratio, CI = Consistency Index, RI = Random Index, n = number of comparisons/parameters. λ is calculated by averaging the value of the consistency vector, and it is obtained from the summation of products between each element of the Eigenvector and the normalized relative weight. Table 3 shows the value of random CI obtained from randomly generated pairwise comparisons for matrices ranging 1 to 10 developed by (Saaty, 1977).

2.6. Sensitivity analysis

In order to ensure the robustness of the AHP analysis, we applied sensitivity analysis following the methods developed by Saaty (1977). A sensitivity analysis determines the range within which a single comparison can fluctuate without changing the rank of the alternatives (Aguarón and Moreno-Jiménez, 2003). In this study, multi-stakeholders ranked the criteria factors for land use decisions that are susceptible to subjective judgements. Therefore, to verify the robustness of the factors ranking by different stakeholders, we conducted sensitivity analysis. In the process, we applied a threshold-based sensitivity analysis to adjust priority weights at the threshold levels (0.01, 0.02, and 0.03) to determine the stability of the criteria rankings. Given that the CR value should be less than 0.1 for the matrix to be considered consistent, our sensitivity analysis identified how the increment or decrease of the criteria weights by a small threshold level would change the value of the pairwise comparisons. Additionally, we analysed the impact of these variations across the stakeholders to identify which decision factors are the most sensitive to the weight adjustments. The AHP matrix is analysed using R software by utilizing specialized packages; “MCDA”, “ahp”, and “ahpsurvey”.

3. Results

3.1. Land use decision criteria selection and weights

The six land use decision-making criteria: economic, environmental, social, institutional, biophysical, and climatic were ranked by the stakeholders using the AHP matrix. The results of the AHP matrix indicate an overall acceptable CR below 0.1. Federal-level experts recorded the lowest CR, whereas the other three stakeholders, farmers, woreda, and zone-level experts, were registered to have almost similar levels of CR. The results show that land use decision criteria vary among stakeholders. The calculated priority weights, eigenvector value, and CR of the indicator-level factors are presented in supplementary material S2 in the annex. The result shows that climatic and biophysical factors are the most important factors in land use decisions, as ranked by different stakeholders, which are gaining high priority weights (Fig. 1). Climatic factors are the most prioritized factors for farmers and zone-level experts, while federal-level experts prioritize economic factors the most. Woreda-level experts distributed the priority weight to climatic, biophysical, and environmental factors, holding a medium priority. Overall, social indicators received the lowest priority weight, whereas institutional factors received a medium priority ranking by all stakeholders.

3.2. Land use decision sub-criteria weights

Acceptable CR is attained from the results of the AHP matrix analysis at the sub-indicator level. Federal-level experts for institutional sub-factors, demonstrating strong consistency in their judgments, record the lowest CR (0.01). In contrast, the highest CR (0.11) is observed among farmers for economic sub-factors. Given that economic sub-factors include eight different criteria, it is reasonable to expect some difficulty in recalling and ranking all of them accurately at the farmer level. Therefore, a slight deviation from the standard CR threshold of 0.1 is considered acceptable in this context. Notably, for all other sub-factors across stakeholders, the CR remains below 0.01, indicating a high level of consistency. The AHP matrix analysis, detailing the calculated Consistency Index (CI), CR, and eigenvector values, is provided in the supplementary file (S1).

Economic factors: Stakeholders assigned differing levels of importance to economic factors, with farmers and zone-level experts prioritizing climatic factors, while federal-level experts prioritize economic factors the most. Woreda-level experts distributed the priority weight to climatic, biophysical, and environmental factors, holding a medium priority. Land value emerged as the most influential sub-indicator, receiving the highest criteria weights and ranking as the top priority among zonal-level experts, followed closely by federal-level experts. The next most significant sub-indicator is access to production inputs and markets, followed by cash income and land size. However, different stakeholder groups assigned varying levels of importance to respective sub-indicators.

For farmers, alternative livelihoods and land size were the most highly ranked sub-indicators under the economic factor. Federal-level experts prioritized land value, access to production inputs and markets, and access to finance as their top three sub-indicators. Similarly, woreda-level experts placed the highest emphasis on access to production inputs and markets, initial capital, and access to finance. Zonal-level experts identified land value, access to production inputs and markets,

Table 3
Confidence Interval (CI) values for factors ranging from 1 to 10.

Size of matrix	1	2	3	4	5	6	7	8	9	10
CI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

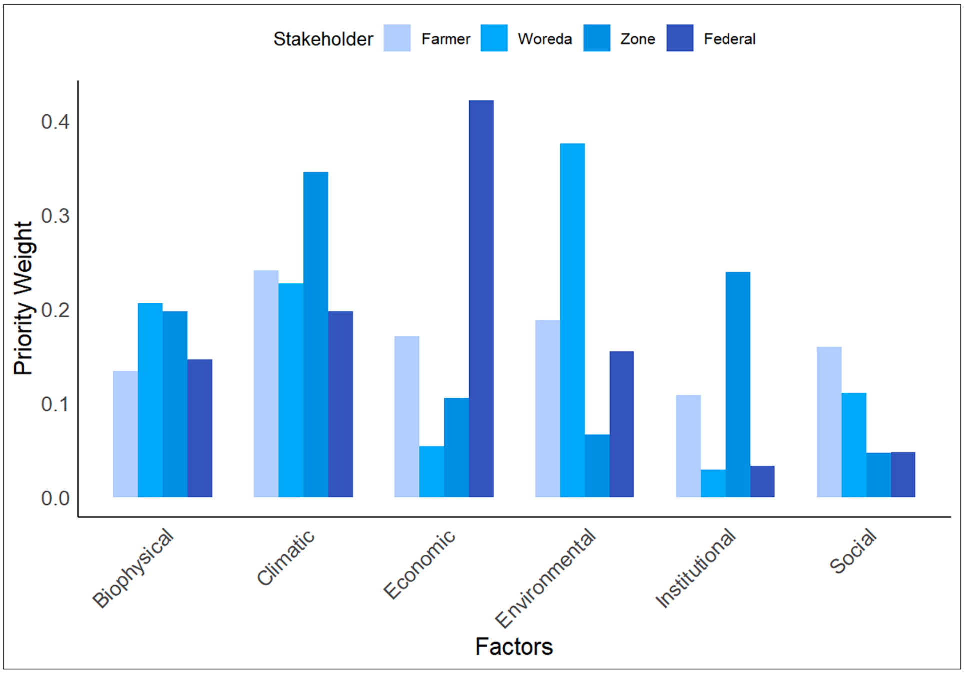

Fig. 1. Priority weights of the six main land use decision factors as ranked by different stakeholder groups.

and land size as their top priorities.

Environmental factors: The prioritization of sub-factors under the environmental indicator varied across different stakeholder groups. Overall, biodiversity conservation emerged as the most critical sub-factor, receiving the highest priority weight, particularly from farmers. Landscape protection and management followed closely, ranking highest among zonal-level experts. In contrast, federal-level experts placed the greatest emphasis on climate change mitigation and adaptation, while woreda-level experts prioritized ecosystem services. These differences highlight the diverse perspectives and priorities among stakeholders in addressing environmental goals in land use decision-making.

Social factors: Overall, social indicators received the lowest priority weight, whereas institutional factors received a medium priority ranking by zone-level experts. The other three stakeholders also give less priority to this factor. Woreda-level experts prioritise communal land use, while federal-level experts and farmers emphasize the importance of skills and knowledge in land use practices. In contrast, zone-level experts prioritize proximity to urban areas.

Institutional factors: Regarding institutional factors, farmers consider land tenure as the most critical aspect, whereas zone-level experts give more weight to regulations and binding conventions. Woreda-level experts focus on governance, while federal-level experts distribute their priorities across governance, land tenure, and regulatory frameworks.

Biophysical factor: In the case of biophysical factors, farmers prioritize soil condition while woreda-level experts emphasize current land use and land cover (LULC). Zone-level experts, on the other hand, give higher priority to natural enemies and invasive species.

Climatic factors: Farmers prioritize elevation as the most important climatic factor, while all stakeholders consistently rank rainfall as the second-highest priority. Woreda-level experts place greater emphasis on temperature, whereas federal-level experts assign higher priority to vulnerability to climatic anomalies and humidity compared to other groups (Fig. 2).

3.3. Sensitivity analysis

Strict sensitivity detection is conducted with three sensitivity thresholds: 0.01, 0.02, and 0.03. Sensitivity varies across stakeholders. The priority ranking by farmers, federal, zone, and woreda-level experts show 40.6 %, 59.3 %, 56.2 %, and 50 % sensitivity, respectively, at a threshold level of 0.01. At the 0.02 threshold level, farmers' and zone-level experts' priority ranking shows 18.7 % sensitivity, whereas federal-level and woreda-level experts' rankings show 12.5 % and 15.5 % sensitivity, respectively. The investment return period is the only sub-factor to be insensitive to any threshold level across all stakeholders, followed by access to alternative livelihood, which is sensitive to farmers at a threshold level of 0.01. Fig. 3 shows sensitivity analysis of the sub-factors across stakeholders at different sensitivity threshold levels.

3.4. Guiding framework for land use decision-makers

Based on the priority weights assigned at both the decision criteria and sub-criteria levels, as well as the sensitivity analysis, a decision tree was developed to guide land use decision-making among stakeholders. The decision tree highlights seven critical sub-factors that hold a priority weight above 0.4 and are sensitive at the threshold level of 0.01.

From the environmental indicators, landscape protection and management and biodiversity emerged as the most critical sub-factors. Within the social indicators, land tenure and skills and knowledge of land use practices were identified as key determinants. Among the climatic factors, elevation and rainfall were found to be crucial, while from the biophysical indicators, soil condition stood out as a top priority. These findings underscore the essential factors that must be prioritized to enhance effective and sustainable land use decision-making. In addition, the analysis identified five sub-factors with priority weights above 0.4 that, while important, are less sensitive to change. These sub-factors remain stable in land use decision-making and provide a consistent foundation for policy and planning. From the social indicators, **c**ommunal land purpose emerged as a key but less sensitive determinant**.** Within the institutional indicators, governance, regulations, and binding conventions, and among the biophysical indicators, current LULC and natural enemies/invasive species were recognized as significant yet stable factors in land use decision-making. Although these stable sub-factors are less influenced by variability, they remain essential considerations in land use decision-making, ensuring long-term resilience and effective management strategies. Fig. 4 illustrates the detailed decision tree of the sub-factors category based on their priority

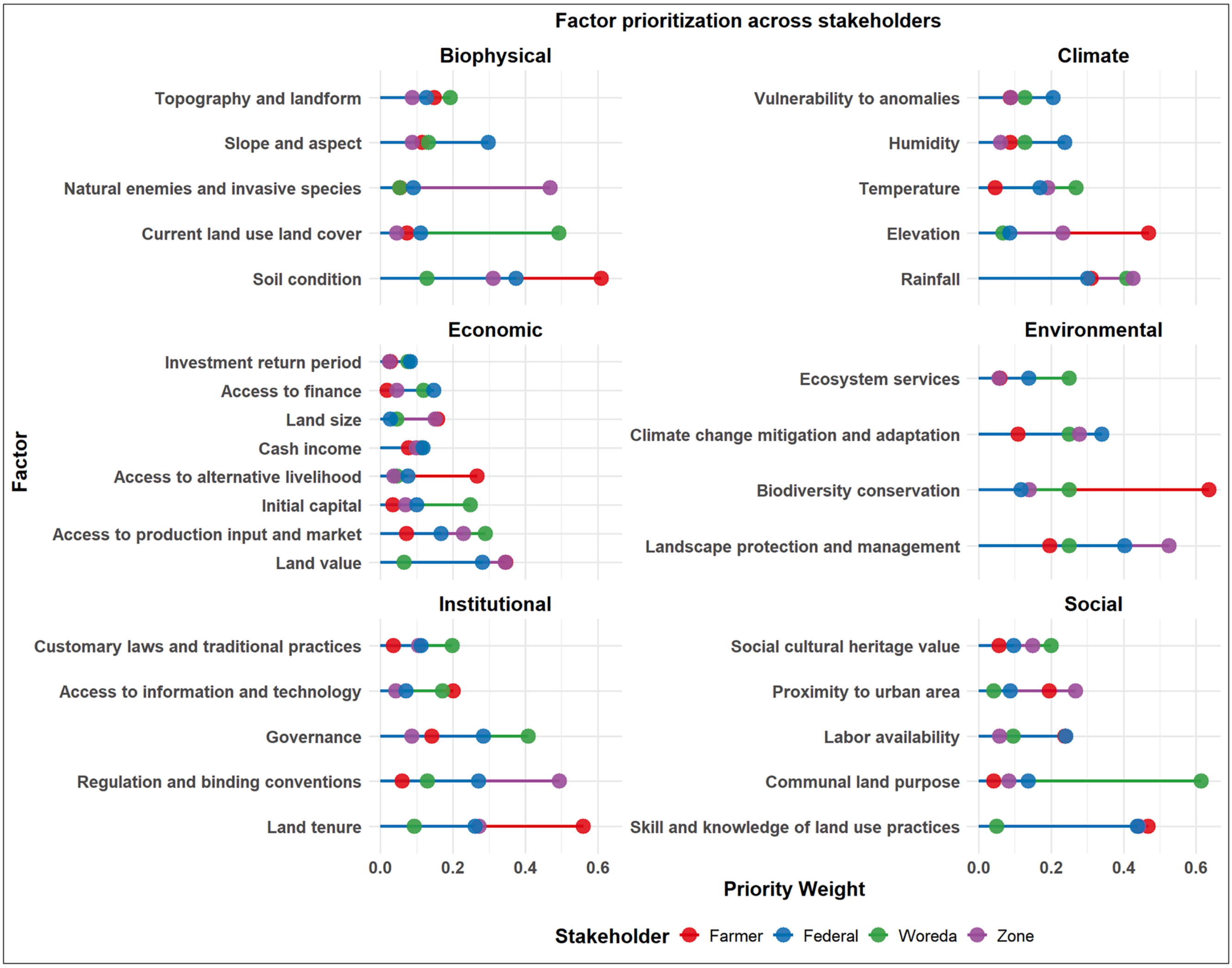

Fig. 2. Priority weight of identified sub-indicators across stakeholders.

level and sensitivity.

The decision tree serves as a structured framework that guides land use planners in organizing and prioritizing choices throughout the implementation process. By integrating key sub-factors such as soil quality, rainfall patterns, biodiversity, land tenure, and indigenous knowledge, it anchors decision-making in both ecological realities and socio-cultural contexts. The framework also distinguishes between determinants that are highly dynamic and require continuous monitoring and those that remain relatively stable, which can act as reference points for long-term strategic planning. In practice, this enables planners to systematically compare alternative land use options such as agroforestry, woodlot establishment, watershed protection, and mixed-farming based not only on their short-term feasibility but also on their long-term resilience to climatic, institutional, and ecological shifts.

During implementation, the decision tree facilitates adaptive management by signalling when critical indicators, such as rainfall variability, soil degradation, or the spread of invasive species, begin to change, thereby prompting timely interventions. Ultimately, the decision tree functions as both an initial guide for land use allocation and a dynamic monitoring tool that sustains effectiveness and resilience over time. By translating complex multi-criteria analysis into a practical decision-support instrument, the framework empowers local planners to make transparent, evidence-based, and participatory land use decisions. This approach ensures that interventions are not only ecologically viable but also socially legitimate and institutionally embedded, thereby enhancing the long-term sustainability and adaptability of land use planning in Ethiopia.

4. Discussion

The results of the AHP analysis for all stakeholders, and sub indicators level shows high consistency except for the farmer's matrix of Economic sub-indicators with eight factors. The highest CR (0.11) was observed among farmers evaluating economic sub-factors, which involved eight distinct criteria. Given the cognitive complexity of comparing multiple interrelated economic considerations such as market access, input cost, profitability, and credit availability slight inconsistencies in judgments are expected. Numerous studies acknowledge that perfect consistency is rarely attainable in applied decision-making, especially when non-expert participants are involved or when the number of criteria increases (Canco et al., 2021; Salomon and Gomes, 2024). Similar observations have been made in participatory or stakeholder-based AHP applications, where respondents balance numerous factors under real-world uncertainty and accepted CR of 0.2 (Duleba and Szádoczki, 2022; Frish et al., 2025; Page, 2012). In this study, our sensitivity analysis confirmed that small adjustments to the pairwise judgments did not alter the ranking order of the economic sub-factors, indicating that the derived priority structure is robust to minor inconsistency. This further aligns with recommendations in the AHP literature that accept borderline CR values when stability of results

Fig. 3. Sensitivity analysis of decision sub-factors at different threshold levels.

can be demonstrated (Frish et al., 2025; Salomon and Gomes, 2024).

Stakeholders exhibit diverse priority weight assignments when evaluating economic and environmental factors. Federal-level experts place greater emphasis on economic considerations, whereas woreda-level experts prioritize environmental factors. Farmers, meanwhile, rank both factors highly, assigning them the second-highest priority in their decision-making. This variation reflects differences in perspectives, with higher-level policymakers focusing on the economic contributions of land uses, while local-level experts and farmers emphasize the critical role of environmental factors, such as landscape protection and management, as well as climate change mitigation and adaptation factors. Similarly, IFAD (2013) highlights that, despite the economic benefits, smallholder farmers tend to prioritize sustainable land management practices that enhance long-term productivity. Ecosystem services were the least ranked sub-indicator under the category of environmental factors. However, studies suggest that integrating ecosystem services into decision factors in addition to socioeconomic objectives is important in land use decision-making (Felipe-Lucia et al., 2018; Knoke et al., 2020). Land use decision processes should capitalize on those indicators with strong overlap in the priority lists by stakeholders, as these reflect shared concerns and provide a solid foundation for consensus-driven planning.

Among the economic sub-factors, land value received the highest priority weight (0.38), underscoring its significant influence on land use decisions. Land value is shaped by its location and biophysical characteristics, with stakeholders agreeing that land situated near urban areas holds a different economic worth compared to land in remote regions. The study also highlights the importance of production inputs and

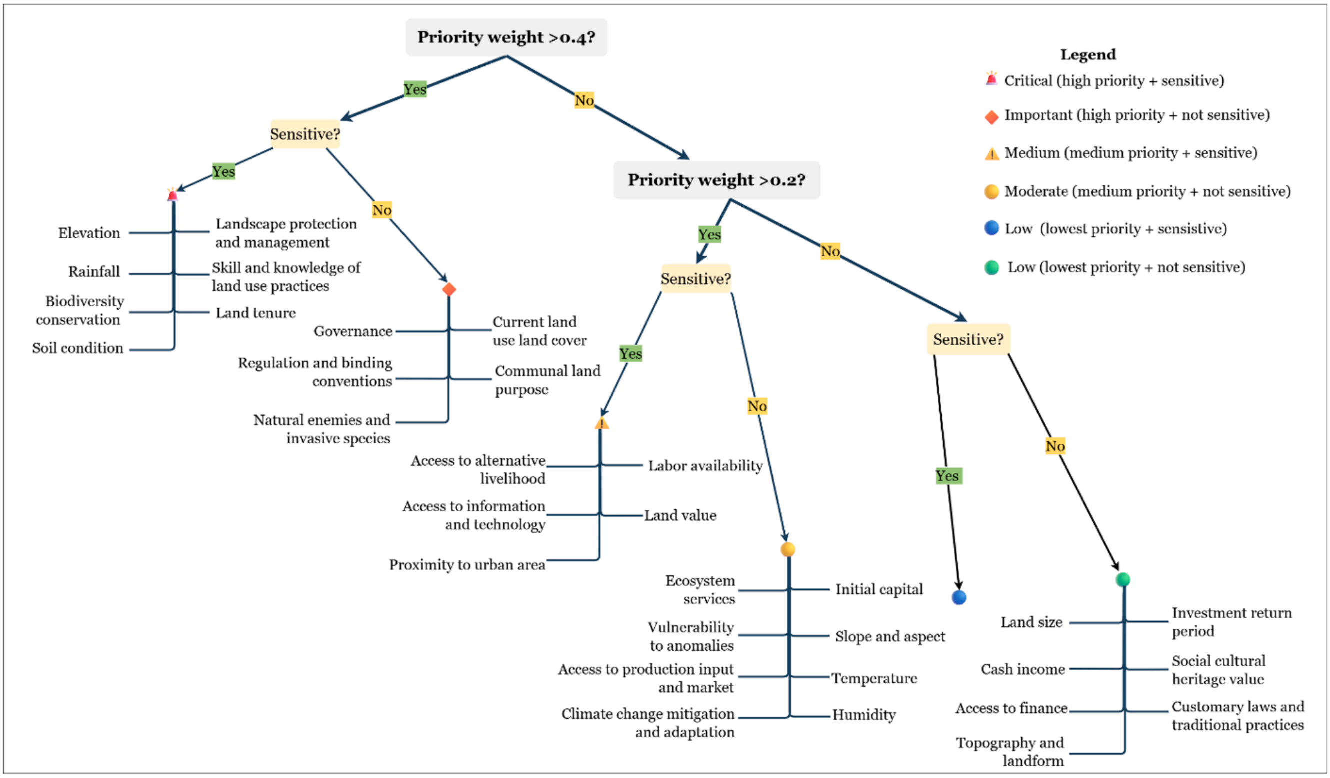

Fig. 4. Decision tree based on factor importance and sensitivity.

markets by giving the second highest priority ranking to this factor, which is related to the land value in terms of location. This distinction highlights the crucial role land value plays in determining appropriate land use allocations, as it directly impacts economic feasibility, investment potential, and long-term sustainability. (Monbiot et al., 2019) state that land is increasingly valued as a financial asset as compared to its productive value. Therefore, land value in terms of location and infrastructure plays a crucial role in land use decisions.

Studies highlight that land tenure has a greater influence on land use decisions as it is both a social and legal matter (Chigbu et al., 2019). This factor is among the critical top priorities in this study's decision tree, showing a priority weight above 0.4 and sensitive to all stakeholders at a threshold level of 0.01. Tripathi et al. (2024) highlight that farmers possess substantial knowledge about biodiversity, a conclusion that aligns with our findings. Biodiversity conservation emerged as the top priority factor among stakeholders, with farmers placing particular emphasis on its importance. During the priority ranking discussions, farmers highlighted that biodiversity conservation is linked to farm diversification, which enhances their income by providing a variety of marketable products. They also highlight that biodiversity plays a key role in mitigating climate-related risks and vulnerabilities. By adopting diverse farming practices, they can buffer against crop failures caused by climatic anomalies, ensuring greater resilience and sustainability in their agricultural systems. That is why they ranked vulnerability to climate anomalies and climate change mitigation and adaptation factors with the lowest priority.

Among the biophysical factors, soil condition received the highest priority weight, particularly from farmers, making it one of the most critical decision factors identified in this study's decision tree analysis. This aligns with other findings, which confirm that soil condition is a key determinant alongside economic benefits in driving land use transformation among smallholder farmers (Eshetu et al., 2024; Obidike-Ugwu et al., 2025). Most of the biophysical indicators are related to land capability and suitability based on the slope, landform, and soil condition, which plays a significant role in decision-making process of land allocation. According to Briassoulis (2009), land use is influenced by the characteristics of the local biophysical environment that determine, to a considerable extent, land suitability for a range of uses. In the case of contemplated or planned changes of use, suitability acts as a constraint on the range of choices considered by landowners and determine the final decision.

Social and institutional factors received lower overall priority weights compared to economic and environmental considerations. Similarly, Christensen and Van Eetvelde (2024) emphasize that existing conceptual frameworks of human behaviour in land systems and landscape research frequently neglect the integration of social and cultural dimensions in decision-making processes. They underscore the urgent need to adopt more comprehensive human decision-making models that explicitly incorporate these components. Their work advocates for a more integrated approach that views society not merely as external influencers but integral parts of complex socio-ecological land systems. However, our study results indicate that woreda-level experts assigned higher importance to aspects related to governance, communal land management, social and cultural heritage values, and traditional and customary laws. This heightened emphasis stems from their role in managing communal lands, ensuring compliance with customary laws, and preventing land use decisions that might undermine cultural and heritage values. Their perspective reflects the critical role of local governance in maintaining social cohesion and preserving traditional land management practices.

For farmers, the criteria level ranking provides the top three priorities for climatic, environmental, and economic indicators, whereas the least ranking was given to institutional factors. Among the climatic factors, elevation was given higher attention, followed by rainfall. This is because altitudinal differences in the area are quite visible, often determining the crops and land use types that the farmers should practice. In the lower altitudes, farmers benefit from practising perennial crop production, mainly bananas, thus they benefit from land use practices they can or are able to implement. Mid-altitude farmers practice annual crops such as teff, maize, and mung bean. Meanwhile, high-altitude farmers practice agroforestry, with coffee and *Ensete ventricosum* (enset) as major components of the agroforestry system (Ahimbisibwe et al., 2024; Eshetu et al., 2024). Farmers tend to notice what is more feasible on the ground, which limits them in choosing land use. Thereby, for the climatic factor, elevation received the higher priority weight.

Beyond assessing internal consistency using the CR, we undertook additional steps to validate the relevance and contextual robustness of the framework. The indicator prioritization results were presented and discussed in a multi-level expert workshop involving practitioners engaged in Forest Landscape Restoration. These discussions helped confirm that the prioritization reflects on-the-ground realities and aligns with current restoration planning challenges reported in the literature, where decision-making often requires balancing livelihood concerns with ecological sustainability. Further validation was conducted through engagement with the GIZ participatory land use planning project working within the study landscape. The project would test the feasibility of integrating the prioritized indicators into ongoing planning processes, demonstrating the framework's potential to support actionable and context-specific land use decisions rather than remaining a purely analytical exercise.

Importantly, this study makes a distinct methodological contribution by integrating sensitivity analysis into a participatory AHP-based decision framework. This integration not only allows the identification and ranking of priority indicators but also enables a systematic examination of how shifts in stakeholder preferences may influence decision outcomes. This aspect is rarely addressed in conventional MCDA applications for land use planning. In contrast to many existing decision support tools that focus predominantly on biophysical or economic optimization, our framework places stakeholder-derived priorities at the centre and tests the robustness of these priorities across governance levels. This combined approach increases transparency around trade-offs and highlights areas where stakeholder perspectives converge or diverge information that is critical for negotiation and consensus building in a contested landscape.

5. Conclusion and recommendation

This study shows that while stakeholder groups differ in the emphasis they place on specific land use decision criteria, they share a broader common goal of sustaining landscape functionality. Federal-level experts tend to prioritise economic considerations, whereas farmers emphasise livelihood security; yet both perspectives ultimately converge around the need to maintain productive and resilient landscapes. Climatic and biophysical factors received the strongest consensus, providing a shared foundation for negotiating trade-offs in landscape planning. In contrast, institutional factors consistently ranked lower across all stakeholder groups, indicating a persistent gap between governance arrangements and on-the-ground needs an area requiring targeted policy reform to improve coordination, support, and accountability.

The stability analysis further highlights landscape protection and management as the most consistently prioritised and least sensitive indicator across stakeholder groups. Its robustness reflects widespread recognition of its central role in sustaining ecosystem functioning, climate resilience, and livelihood security. Policymakers should therefore move beyond framing FLR primarily as a carbon-sequestration strategy and adopt a holistic approach that integrates ecological integrity, social well-being, and climate objectives in a balanced manner. Furthermore, the decision tree derived from the weighting and sensitivity analysis identified key leverage factors. Landscape protection and management, biodiversity conservation, land tenure security, knowledge and skills in land use practices, and biophysical determinants such as rainfall, elevation, and soil condition. These factors represent critical entry points for designing effective and context-responsive FLR interventions.

Although the empirical work was conducted in the Lake Chamo catchment of Ethiopia, the framework is intentionally modular and adaptable, making it suitable for application beyond the study area in contexts where multiple value systems and multi-level governance influence land use decisions. By offering a structured, transferable process for aligning ecological, social, and economic considerations, the framework enhances both the practical relevance and scalability of participatory land use decision support. At the same time, several limitations must be acknowledged. The framework relies on subjective stakeholder judgments, which are inherently shaped by individual experience, institutional affiliation, and value orientations. Although involving diverse stakeholders helped to reduce individual bias, selection bias remains possible, as workshop participation and expert nominations may have favoured actors already familiar with restoration planning processes. Therefore, future applications would benefit from expanding stakeholder representation, particularly among marginalised groups whose land use perspectives are often underrepresented. Additionally, while initial field-level validation supports the framework's practical utility, full-scale implementation and evaluation over time would be necessary to verify its long-term effectiveness in decision-making contexts. Future research should expand the application of this framework to a broader and more diverse group of land users to further examine how socio-economic variation influences prioritisation patterns. Such work would strengthen generalisability and help refine the framework's applicability across diverse socio-ecological contexts.

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CRediT authorship contribution statement

Shibire Bekele Eshetu: Writing – review & editing, Writing – original draft, Visualization, Methodology, Formal analysis, Data curation, Conceptualization. **Katharina Löhr:** Writing – review & editing, Validation, Supervision, Resources, Methodology, Investigation, Funding acquisition. **Mahlet Degefu Awoke:** Writing – review & editing, Validation, Methodology. **Marcos Lana:** Writing – review & editing, Validation, Supervision, Investigation. **Stefan Sieber:** Writing – review & editing, Validation, Supervision, Investigation, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.tfp.2025.101106.

Data availability

Data will be made available on request.

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