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Review

Evidence Synthesis towards a Holistic Landscape Decision Framework: Insight from the Landscape Decisions Programme

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Abstract: The development of a decision framework for landscape governance and management has become one of the prioritised policy instruments for actualising policy objectives related to agri-food systems, biodiversity conservation, nature restoration, environmental management, climate change mitigation and adaptation, net-zero greenhouse gas emissions, and the transition to renewable energy supplies. However, the landscape lens in policy making is challenging because of the diverse landscape archetypes, environmental problems, and diverging policy targets that it must address. This highlights the importance of having a robust, evidence-based landscape decision framework. To address this issue, this study undertook a transdisciplinary synthesis of research outputs from the Landscape Decisions Programme (LDP). This study compiles and synthesises outputs from the LDP projects in the context of the relevant literature to develop an understanding of the relationships among the emerging evidence with respect to decision making for sustainable and multifunctional landscapes. The synthesis identified six themes that define the drivers of landscape decisions, and four themes that define the dominant methodological approaches used to generate evidence for landscape decisions. The emergent themes from the synthesis were distilled into five principles that can be used as a basis for the development of a holistic landscape decision framework.

Keywords: transdisciplinary synthesis; environmental policy; sustainable landscape; ecosystem services; landscape governance; land-use framework

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1. Introduction

Landscape management has become a major discourse in national and global policy processes on biodiversity, food security, land degradation, net-zero transition pathways, climate change, and ecosystem services [1,2]. Decisionmakers at all levels of governance and management are faced not only with a complex array of problems [3], but also with the complexity of incorporating existing land-use policies and planning constraints with an emergent scientific understanding of landscape multifunctionality and sustainability into the decision-making process [4]. Decision making on sustainable and multifunctional landscapes therefore requires simultaneously accommodating the production goals, environmental soundness, and social relevancy of landscapes [5]. This is further complicated by the synergies, trade-offs, and non-linear responses among the benefits delivered by landscapes, making it difficult to predict the combined effects of landscape management decisions [3]. Thus, the decision-making processes can be viewed as multi-criteria and multi-objective problems, requiring robust frameworks to analyse the multiple impacts of the decisions and possible trade-offs and synergies between different objectives [6].

Landscape decisions therefore require a systematic approach for evaluating and selecting the best option from a set of alternatives given the multiple interacting factors impacting multifunctional and sustainable landscape use and management [3,7]. A framework for landscape decisions is therefore a prerequisite, as this will enable decisionmakers to take a systematic and structured approach to evaluating and selecting the best option from a set of alternatives [7,8]. Evidence-based decision making is a rapidly developing discipline that aims to bring this multi-faceted understanding of the landscape into an integrated framework [9]. In this regard, decisions on landscape management require the integration of diverse disciplinary knowledge [10], including the integration of biophysical and social knowledge of how biodiversity, landscape benefits/disbenefits, and ecosystem services change over time, as well as an understanding of the society within which decisions are made [8]. However, the integration of knowledge based on different epistemic assumptions is challenging.

To this end, we must have a clear understanding of how decisions are linked to the functionality and sustainability of landscapes, and how they affect those landscapes' abilities to support their human and non-human occupants. A comprehensive decision-making framework for landscape governance has not yet been developed in the United Kingdom (UK). The Department for Environment, Food and Rural Affairs (DEFRA) is committed to publishing a land-use framework in 2023. The proposed land-use framework is a system-thinking approach that will deliver integrated, collaborative, and place-based decision making and optimise multifunctional benefits from landscape governance [11]. In the UK, land users, planners, and managers are guided by legislative and policy frameworks when making decisions on landscape management and governance [3,12,13]. Research on landscape decisions and decision-making processes on multifunctional landscapes have provided insights into sustainable landscape management and governance [14] and how this could be applied to policy. However, these insights are fragmented across a diversity of case studies that used a variety of methods.

To address this issue, this study undertakes a systematic review and synthesis of studies from the Landscape Decisions Programme (LDP) projects. The LDP is a large Strategic Priorities Fund (SPF) programme funded by the United Kingdom's Research and Innovation (UKRI), aimed at facilitating better evidence-based decisions within UK landscapes through research collaboration with policy, business, and land management partners to work towards a decision-making framework that will inform how land is used. The LDP is a programme of 70 wide-ranging, interrelated research projects over multiple disciplines, grouped into four work packages on new mathematics, new model solutions, new thinking and communities, and cross-cutting integration. The LDP projects cover various disciplinary aspects of landscape decisions, ranging from physical sciences and the modelling of ecosystem services and their interactions with land-use systems, to qualitative research and participatory decision making that engages various stakeholders in understanding how stakeholders' values and choices shape landscape management.

This study adopts a transdisciplinary approach to research synthesis, and it combines elements from the LDP project outputs into an overarching framework for landscape decision research. The study synthesises outputs from the LDP projects to develop an understanding of the relationships among the emerging evidence concerning decision making for sustainable and multifunctional landscapes. Additionally, attention is given to the methodological strengths and weaknesses (advantages and limitations of the methods/decision support tools used in the studies). Based on this synthesis, this study proposes a roadmap on how evidence from the LDP synthesis can support the development of an evidence-based landscape decision framework for the UK. Landscape framing, as used in this study, adopts a plurality view, and it defines landscape as the physical features of an area, including its terrain, natural resources, and the overall appearance of its natural and man-made elements. These include mountains, valleys, rivers, lakes, forests, farmland, and other natural features, as well as human-made elements, such as buildings, roads, and bridges. The analysis of landscapes in this study is focused on their aesthetic, ecological, cultural, and food-supply values. While there is a considerable body of literature on landscape decisions, there are still some notable gaps in the research that warrant further investigation. This study fills these gaps by investigating the role of interdisciplinary approaches in landscape decisions [15]. Many studies on landscape decisions focus on specific disciplines, such as landscape architecture, urban planning, or ecology. This study provides insight into landscape decisions from an interdisciplinary research perspective by synthesising insights from landscape decision research from various fields to provide a holistic understanding of landscape decision-making processes.

The rest of the paper is structured as follows: Section 2 looks at how transdisciplinary synthesis is conceptualised and applied in this study, describing the theory behind the synthesis framework, and it introduces the research questions that guide the synthesis and structure of the paper. Section 3 presents the study findings. It focuses on the dominant themes that emerge from the synthesis to answer the study research questions, and it proposes a general landscape decision framework that can be used to guide evidenced-based decisions on sustainable and multifunctional landscapes. Section 4 concludes the study and presents five principles to aid the development of the landscape decision framework, which is capable of guiding decision-making processes related to landscape management and planning.

2. Materials and Methods

2.1. A Transdisciplinary Approach to Conceptual Synthesis for a Holistic Landscape Decision Framework

A landscape decision framework provides a way to facilitate and enhance decision making by providing conceptual structures and principles for integrating the economic, social, ecological, and legal/institutional goals into the decision making on landscape management and governance [2,4]. The LDP projects encompass economic, cultural, social, and environmental findings on landscape decisions, making them an interesting output for synthesis on landscape decisions. This makes a transdisciplinary approach to research synthesis the most suitable approach for this study because of its ability to deal with the complexity of the different types of disciplinary knowledge on landscape decisions by drawing on different disciplines and translating findings into more holistic and accessible forms [16,17]. Adopting a transdisciplinary synthesis approach enabled the identification of commonalities from different disciplinary knowledge on landscape decisions situated in the LDP work packages (WPs) [18–20]. Synthesising evidence from this different disciplinary knowledge is crucial for developing decision frameworks that are relevant to the British social, ecological, environmental, and political context [16,17].

A major barrier to the development of a landscape decision framework is the fragmentation of evidence [10,21,22]. Existing empirical evidence that informs decisions on the landscape often focuses on one problem or intervention at a time and ignores the complex interactions between them [23,24]. This makes it difficult to reconcile the fragmented evidence with the broad, holistic framing of policy questions on sustainable and multifunctional landscapes [3]. To begin the road mapping of the landscape decision framework through the transdisciplinary synthesis of evidence from the LDP projects, a general analysis of the dimensions in which land-use, human, and natural systems interface is necessary. We ask the overarching question: What evidence has been documented about the drivers of landscape decisions, the methodological approaches used to generate evidence to inform decisions, and the strengths and weaknesses of these methodological approaches? We disentangle this overarching question by posing the following three research questions:

1. What are the key issues that drive decisions on landscape governance and management?
2. What are the methods used to generate evidence to inform decisions on landscape management and governance, and what are the strengths and weaknesses of these methods?
3. How can knowledge of the drivers of decisions and methodological approaches to evidence sourcing contribute to the conceptual development of the landscape decision framework?

2.2. Transdisciplinary Synthesis

The synthesis process addresses the relationship among the findings in the LDP project output with respect to the study's research questions. Figure 1 graphically depicts the grouping of the LDP projects into the four thematic work packages, the disciplinary knowledge associated with the WPs, and the process involved in the transdisciplinary knowledge synthesis. The LDP projects based on their disciplinary knowledge contributions to landscape decisions can be grouped into two major themes: the conceptually driven projects with significant contributions to shaping the structure of the framework, and the technically driven projects through modelling with contributions to understanding the functioning of the framework. Adopting a transdisciplinary approach to research synthesis in this study enabled the synthesis of projects in each WP beyond the boundaries of the existing discipline's design concepts, thereby mitigating the complexity and increasing the understanding of the principles that will inform the development of a holistic landscape decision framework [25,26].

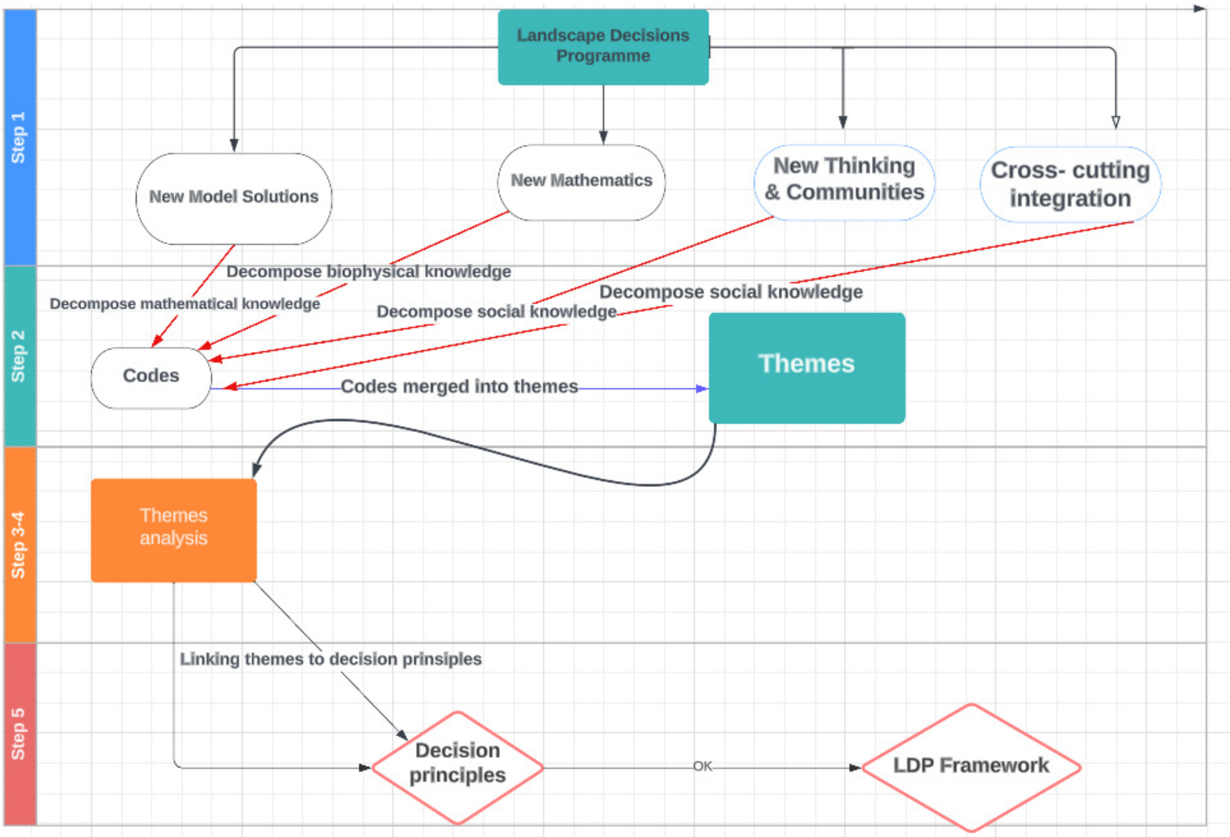

Figure 1. Transdisciplinary synthesis of evidence.

We explore how to combine emerging evidence from the four thematic LDP work packages to inform the development of a holistic landscape decision framework based on a systemic understanding of inherent complexity [10,25,27]. The synthesis tasks were carried out in five steps. Step 1 of the process began with an initial reading of all publications from the LDP projects, documenting the drivers of decisions, methodological approaches, and decision support tools used to facilitate evidence-based decision making on landscape management, noting the impact on sustainable and multifunctional landscape management (Table 1). This step encompassed the review and understanding of the discipline's fundamentals [25,26].

Table 1. List of LDP publications reviewed for this study (2019–2023).

Serial Number	Publication Type	Focus	Authors/ Publication Year
1	Peer review paper	Ecosystem service and landscape decisions	[28]/2023
2	Scientific report	Biodiversity assessment and landscape decisions	[29]/2021
3	Scientific report	Biodiversity assessment and landscape decisions	[30]/2022
4	Technical report	Net zero and landscape decisions	[8]/2022
5	Peer review paper	Regime shift and ecosystem services	[31]/2020
6	Peer review paper	Biodiversity assessment and landscape decisions	[32]/2021
7	Peer review paper	Peat and peaty soils and landscape decisions	[33]/2021.
8	Peer review paper	Social benefits of protected landscapes and landscape decisions	[34]/2021
9	Peer review paper	Ecosystem service and landscape decisions	[35]/2022
10	Peer review paper	Peat soils and landscape decisions	[36]/2021
11	Commentary	Freshwater ecosystem service and landscape decisions	[37]/2020
12	Peer review paper	Freshwater ecosystem service and landscape decisions	[38]/2020
13	Peer review paper	Bioenergy with carbon capture	[39]/2021
14	Peer review paper	Onshore wind energy and landscape decisions	[40]/2021
15	Peer review paper	Freshwater ecosystem service and landscape decisions	[41]/2020
16	Peer review paper	Freshwater ecosystem service and landscape decisions	[42]/2022
17	Peer review paper	Ecosystem service and landscape decisions	[43]/2019
18	Peer review paper	Ecosystem service and landscape decisions	[44]/2020
19	Peer review paper	Ecosystem service and landscape decisions	[45]/2021
20	Peer review paper	Ecosystem service and landscape decisions	[46]/2021
21	Peer review paper	Net zero, climate change mitigation, and landscape decisions	[47]/2021
23	Peer review paper	Ecosystem service function and landscape decisions	[48]/2021
24	Peer review paper	Peat soils and landscape decisions	[33]/2021
25	Peer review paper	Biodiversity assessment and landscape decisions	[49]/2020
26	Technical report	Ecosystem service and landscape decisions	[7]/2019
27	Peer review paper	Ecosystem service function and landscape decisions	[50]/2021
28	Peer review paper	Ecosystem service function and landscape decisions	[51]/2022
29	Peer review paper	Public engagement and landscape decisions	[52]/2022
30		Freshwater ecosystem service and landscape decisions	[53]/2020
31	Peer review paper	Ecosystem service and landscape decisions	[54]/2023

NB: Details on the LDP's 70 projects and the associated research outputs can be found at https://landscapedecisions.org/projects/, (accessed on 20 December 2022).

This was followed by step 2, in which qualitative data analysis software (NVIVO 12) was used to organise the data emanating from step 1 into codes. Given the diversity of the disciplinary knowledge and methodologies used in the reviewed studies, the organisation was performed by identifying useful knowledge that relates to the research questions and breaking it down into its constituent parts that provide a robust answer to the research questions. This enabled consistent coding, as well as the ability to code articles thematically. The codes that emerged in step 2 were further subjected to focussed coding in step 3. In step 4, we used abductive reasoning to analyse and organise the focused codes into themes. In an abductive-reasoning process, logical inferences are made by finding the simplest explanation for an observation or set of observations [55]. In step 5, the emergent dominant themes were defined, the relationship among them was examined, and deductions were made on the drivers of decisions, the dominant methodological approaches used to generate evidence for landscape decisions, and the strengths and weaknesses of the methodological approaches, and, finally, inferences were made on principles that can inform the development of the landscape decision framework. It is important to point out that the analysis of the strengths and weaknesses of the methodological approaches was not based on a mathematical validation of the models or decision support tools used in the studies, but rather on how they might improve landscape decision making. Assigning relationships and associations enabled the development of an understanding of how emerging evidence informs decisions for sustainable and multifunctional landscapes [26]. The thematic analysis process, grounded in the data, was used, as the analytic process moved inductively from the data toward an explanation of the data. We used conventional and summative qualitative analyses to identify emerging themes.

3. Results and Discussion

3.1. Emerging Evidence on Drivers of Decisions: Key Issues and Links to Landscape Decision Making

The thematic content analysis of the LDP outputs regarding research question 1 yielded six descriptive themes that we used to broadly categorise the drivers of decisions on sustainable and multifunctional landscape management. These themes are as follows: (1) recognising and preserving undervalued landscapes; (2) improving the efficiency of accounting for biodiversity and ecosystem service interaction; (3) innovation to improve landscape quantification; (4) transition to renewable-energy and net-zero pathways; (5) inclusion and participation; (6) awareness of human impacts on landscapes. The drivers and their applications in landscape decisions as shown in the reviewed documents are presented in Table 2.

Table 2. Key drivers of landscape decisions.

Key Decision Issues	Decision Focus	Reference
Recognising undervalued landscape services in landscape decisions	The decision is centred on ensuring that all landscape archetypes[1] and the services they provide are sustainably managed. Ref. [45] provide insight for integrating sanitation ecosystem services into the landscape decision framework. Ref. [41] provide insight for decisions on the management of temporal rivers.	[41,45,46]
Improving efficiency of accounting for biodiversity and landscape service interaction	Predicting complex species–environment interactions is crucial for guiding conservation and mitigation strategies in a dynamically changing world.The need to understand how landscape services respond to environmental change is crucial for decisions on landscape management.	[30,31,38,48]
Innovation to improve landscape service quantification	Landscape services need to be accurately assessed and mapped to be incorporated into policy-making and planning decisions.An accurate assessment of multiple landscape services, and the synergies and trade-offs among these services, in order to estimate the potential effects of land management and land-use change or other impacts is vital.	[18,35,36,43,44,54]
Transition to renewable-energy and net-zero pathways	Transition to renewable-energy, net-zero-emission pathways is key to mitigating the climate change impact. The dominant decision focus mainstreams fostering the coherence of the government's renewable energy plan/policy with other land-use policies.	[8,39,40]
Inclusion and participation	Inclusion and participation are the dominant themes on the drivers of landscape decisions. The dominant decision focus is the design of the participatory process in decision making with an increasing focus directed towards citizens. Equity in access to relevant information is an important aspect to facilitate this.	[8,54,56]
Awareness of human impact on ecosystem services	The need to promote the awareness of the environmental and ecological impact of human action on landscape services.	[34]

Recognising and preserving undervalued landscapes: While most categories of benefits and ecosystem services delivered by landscapes are well appreciated in the reviewed studies, there are, however, certain categories of benefits and ecosystem services that are less appreciated [41,45,46]. In this regard, one of the emerging dominant themes on the drivers of landscape decisions targets these undervalued landscape benefits and ecosystem services. The undervalued landscape benefits and ecosystem services that are driving research interests and landscape decisions include sanitation services [46], temporal headwater services [41], and cultural services [7,18,35]. In line with Goal 6 of the 2030 Agenda for Sustainable Development, which recognises the importance of ensuring the availability and sustainable management of sanitation, few of the reviewed project outputs target the management of landscape sanitation services [45]. Conventionally, engineered systems have been used to manage human waste; however, the approach of nature-based-solution sanitation services is receiving more policy attention. The authors of [46] have paved the way for future research to ensure that the sanitation services provided by landscapes are properly accounted for in decisions on landscape governance. Other undervalued landscape services that are driving attention in the research on landscape decisions are headwater streams that flow intermittently (that is, the Aqua Temporaria Incognita [37]) and cultural ecosystem services [57]. As pointed out in [57], the scientific discourse about landscape cultural services has lagged behind that on other provisioning and regulating services. Recognising undervalued landscape benefits and ecosystem services allows for a holistic understanding of the various functions and values provided by landscapes. It goes beyond simply considering economic factors and acknowledges the broader ecological, social, and cultural dimensions of landscapes. It therefore follows that any adopted landscape decision framework for the UK must, as a principle, ensure the inclusion of all categories of landscape services, including the undervalued services.

Improving the efficiency of accounting for biodiversity and ecosystem service interaction: The need to understand the impact of landscape management practices on biodiversity and landscape services (ecosystem services in particular) is one of the emerging dominant themes on the drivers of landscape decisions. Accurate assessment of the impacts of land management on landscape services is key to evidence-based decisions on landscape governance and management [18,35,43,54]. Nearly all the reviewed studies focused on or contained an element of this theme. There is a high level of complexity in how this theme is represented in the reviewed studies, and the complexity is also varied by landscape archetype. For instance, while the authors of [30] examined how single-species distribution is influenced by environmental factors (which are also influenced by landscape management decisions), those of [28] recognised that multidimensional approaches are, in practice, used to inform and evaluate land-use decisions. Ref. [3] examined how landscape services are impacted by land management practices. The general observable trend illustrates the diversity of interaction that exists among biodiversity and landscape services, which complicates the modality for adopting a decision framework to address this dominant driver. Incorporating insight from an improved understanding of the interaction between biodiversity and ecosystem services into decision-making processes will enable a more informed and balanced approach to landscape decisions. This will allow decisionmakers to consider the trade-offs and synergies between different land uses, weigh the costs and benefits, and make more sustainable choices that optimise the wellbeing of both ecosystems and communities. The question going forward is whether it is plausible to have a single framework or multiple decision frameworks guiding decisions on the complexity of interactions between biodiversity and landscape services in relation to decisions on landscape management and governance.

Innovation to improve landscape service quantification: Policy goals on biodiversity conservation, food security, net-zero emissions, and sustainable land and ecosystem service management are dominant themes that drive landscape decisions [1,2,16,58,59]. The rationale is that a sustainable and multifunctional landscape must be achieved within the context of actualising these policy goals [11,16,52,60]. However, decisions on landscape management that ensure the actualisation of these policy goals require an assessment of the synergies and trade-offs among them to estimate the potential effects of land management practices. To this end, several methodological approaches are being employed to assess landscape services. The common driver of decisions in this regard is the need to understand how landscape functions are linked to landscape services, and the benefits that landscape services give to human wellbeing, and indeed, the wellbeing of particular people [17,60]. The consensus is that, to make better decisions regarding trade-offs involved in landscape management and governance, a systematic account of the relationships between land management practices and landscape services is needed [13]. This is corroborated in [44], a work that linked the planning and implementation of a sustainable development approach in a region to an accurate knowledge of the landscape services in the region, and how they might respond to management choices [44]. As a principle, the landscape decision framework should encourage innovations and research on modalities for improving the efficiency and cost-effectiveness of methodological approaches used to quantify/assess the contribution of landscape services to wellbeing [7,61]. This helps ensure the sustainable use and conservation of landscapes, taking into account the long-term implications of land-use decisions on ecosystem health and human wellbeing.

Transition to renewable-energy and net-zero pathways: The landscape approach is assuming an important role in national policy discourse on climate change, the net-zero-emission pathway, the circular economy, and renewable energy. An important emerging theme on the drivers of landscape decisions is the need to understand how landscape can drive the transition to renewable-energy and net-zero pathways [8]. The reviewed studies assessed how landscape can support the UK renewable-energy and net-zero policy targets. Understanding and establishing basic principles on how landscape decisions can facilitate this transition is therefore an important target for any potential landscape decision framework [8,39,40]. In this regard, some studies have focused on how landscape decisions can facilitate the transition to renewable electricity production, the rationale being that the electricity generation industry is consistently the highest emitter of greenhouse gases across all regions in the United Kingdom [8,40]. While the work [39,40] developed insights into how evidenced-based landscape decisions can facilitate the upscaling of onshore wind technologies for the transition to renewable energy in Scotland, the question going forward is what fundamental decision principles are required to ensure that all landscape archetypes facilitate this transition, including how the upscaling process of renewable energy production to the UK is managed sustainably. Integrating renewable energy goals with landscape considerations is crucial for achieving sustainable and resilient energy systems. The transition to a renewable-energy and net-zero pathway can influence landscape decisions by affecting the siting of renewable-energy infrastructure, creating land-use conflicts and trade-offs, providing opportunities for landscape restoration, requiring local and community engagement, and promoting landscape-scale planning and ecosystem connectivity.

Inclusion and participation: Inclusion and participation are the emerging dominant themes on the drivers of landscape decisions. The key issue here is the design of a participatory process in decision making, with increasing focus directed toward citizens' roles in formal decision-making processes, and the elimination of barriers to support the participation of all stakeholders in the decision-making process [34,52]. Participatory approaches to decision making, including stakeholder engagement, are increasingly gaining policy traction for managing complex socioecological challenges with regard to sustainable and multifunctional landscapes [8,52]. In this regard, several issues have been addressed concerning the effective and efficient participatory framework for decision making. Ref. [52] investigated the potential of the participatory design method in Scotland. The study used insight from Dewey's pragmatist philosophy to demonstrate how Dewey's vision enables the rationalisation of past action and prospective future activity regarding landscape decision making. However, critical questions about social engagement in the landscape decision-making process remain. These include normative, political, and ethical questions around environmental justices, concerning who participates, who benefits and loses, what good can be accomplished, for what and whom, and by whom [28,62]. As a fundamental principle, a holistic landscape decision framework will have to facilitate inclusivity and wider participation to promote the ownership and participation of all stakeholders in the landscape decision-making process [54]. By involving diverse perspectives and local knowledge, decision making becomes more inclusive, leading to more effective and equitable landscape management outcomes.

Awareness of human impact on landscape services: Another dominant theme on the drivers of landscape decisions is the need to understand and improve the awareness of the impact of human actions (e.g., visitation to protected sites) on landscape services [8,34]. This driver is mostly associated with protected landscapes and endangered landscape services. For an example, the authors of [34] investigated the impact/awareness of the environmental and ecological impact of human visitation on nesting birds on Ilkley Moor. The study found that, during the bird breeding season, human visitation can have multiple impacts on nesting birds. These include nest failure, impaired nestling growth, reductions in the areas suitable for breeding, and the immunosuppression of fledglings, which all put pressure on individual birds and future recruitment into the local population. The goal here is that, by understanding how human visitation impacts the landscape, land management decisions can be aligned with the conservation priority within the site to reduce the negative impact on the landscape functionality [34]. This includes the consideration of empathy for non-human lifeforms and how experiences of the non-human biosphere are narrated and represented in the decision-making process.

In summary, a holistic understanding of the drivers of decisions promotes sustainable and multifunctional landscape governance, improves decision-making processes, enhances resilience and adaptation, fosters stakeholder engagement, and highlights the economic benefits of maintaining healthy ecosystems. These hold valuable insights for the development of a comprehensive landscape decision framework.

3.2. Linking Methodological Approaches to Landscape Decision Making: Strengths, Weaknesses, and Limitations

This section discusses the results of the thematic grouping on the methodological approaches used to generate evidence for landscape decision making. The analysis focused on the study research methods and techniques. The analysis yielded four dominant thematic groupings (Table 3). We use the thematic groupings to provide clarification at the conceptual level about the techniques and methodological approaches used to inform landscape decisions. The benefits, strengths, and weaknesses of the methods are then discussed, making explicit the relationships between the methodologies, landscape decisions, and landscape sustainability/multifunctionality outcomes. The aim is to provide insights that might improve methodological approaches to decision making about landscape management.

Table 3. Summary of the strengths and weaknesses of methodological approaches used to generate evidence for landscape decisions.

Method/Description	Strength	Weakness	Link to Decisions	Landscape Services	References
Model prediction—remote sensing in landscape decisions	Faster means of making decisions on spatial variations in landscapes. Slope and elevation (sensor data) are used as parameters for explaining spatial variations in organic-horizon depth.	The method only considered basic topographic variables (elevation, slope, aspect). Additional topographic derivatives (e.g., topographic position, topographic roughness, heat-load index, and topographic moisture index) may also be beneficial in the estimation of the organic-horizon depth.	The approach used in the study contributes to improvements in the measurement and reporting of the depth of the organic content of landscapes, particularly where decisions are made at a catchment scale.	Estimating organic-surface-horizon depth for peat and peaty soils.	[33,36]
Model prediction—ensemble	Ensembles had, at minimum, a 2–17% higher accuracy than a randomly selected individual model, and, in general, ensembles weighted for among model consensus provided better predictions than unweighted ensembles.	Increases the complexity of ecological models, which also increases the amount of data and expertise required for implementation and interpretation, with unclear consequences for the results. It is unclear whether an investment in increasing model complexity leads to more accurate information for policy and decision making on local and regional scales.		Reduces error in projections for landscape service change with respect to land management strategies.	[18,35,43,54]
Model prediction—eDNA for rapid biodiversity assessment	As eDNA surveys have become increasingly used as monitoring tools; they have the potential to replace traditional survey methods that rely on the direct observation of species, especially for difficult-to-detect species.	The levels of replication needed at different stages of the workflow have not been standardised across eDNA studies, with some undertaking replication at both the sample-collection and analysis stages, while others replicate only at the analysis stage.	Enhances the process of decision making about landscape service conservation. Makes data collection easy but data interpretation difficult.	eDNA can provide metrics for decisions on biodiversity conservation.	[29,30,32,63]
Participatory landscape planning and management: The study uses various participatory approaches to enhance bottom-up approaches to decision making on landscape management and governance.	Facilitates the incorporation of a diversity of values and interests in landscape decisions.	Key concerns around framing of stakeholder participation. Who is invited? When? How is the participation run? And do all participants have access to the required information?	Enhances bottom-up approaches to landscape governance.	Integration of stakeholders' values in a landscape decision framework could provide a starting point for conversations across disciplines.	[34,52,54]

Modelling–remote-sensing technique in landscape decisions: Modelling using remote-sensing techniques is one of the emerging thematic groupings of methodological approaches used in landscape decisions. The method is used for a variety of purposes for rapid and enhanced evidenced-based decision making on landscape management. In some studies, remote-sensing techniques were used to analyse relationships between the slope, elevation, and organic-layer depth to guide decisions on peat landscape thickness to aid a land management strategy [12,32,33,63,64]. For example, Ref. [33] used information from digital elevation models to analyse the organic-layer depth of a peat landscape. Some projects have used it for assessing soil ecosystem services in order to improve decisions on how land use might improve their diversity and functionality [36]. Ref. [36] applied the linear mixed-models technique to the remote-sensing technique to analyse the spatial variation in soil properties by analysing the relationship among relevant covariates, such as radiometric data, satellite imagery, or elevation. The conventional approach to soil measurement is generally costly and time-consuming and often requires samples of soil to be collected and taken to a laboratory for preparation and analyses. Also, many such samples are required for the broad-scale prediction of the variation in soil properties, such as the concentrations of soil nutrients and contaminants, or the depth of the soil. Remote sensing offers an alternative approach to monitoring soils, particularly over large landscapes, in an efficient and cost-effective manner [33]. While it is clear from the synthesis that modelling using the remote-sensing technique is gaining momentum in landscape decisions, it is still not clear how lessons and experiences from this technique application can inform the decision principle to guide the development of the landscape decision framework.

Model prediction—ensemble: Decisions on landscape management are often made with the aid of modelled projections to ensure that complex problems are addressed in a comprehensive manner [18,35,38,39]. Although single models were the most commonly used approach for predicting the impact pathways of landscape management decisions in the reviewed studies [31], there is a growing realisation that decision making based on single models is not robust for large regions (e.g., national scale), as high variation between model estimates means that using a different model or incorporating an additional model into the decision-making process is highly likely to result in a different decision [18,24,54]. The authors of [44], for example, demonstrated that, for a large region (e.g., sub-Saharan Africa), decisions based on a single model are not robust. Ensemble-model use in landscape decisions is seen as a solution to the uncertainty from single-model use [18,54]. Ref [44] demonstrated that ensembles of models increased robustness and can provide improved accuracy over individual models. However, most of the available models for landscape decisions are very specific with regard to the landscape archetype and socioecological challenge being addressed [43,44]. There is therefore a knowledge gap in terms of how to make ensemble modelling standard practice for evidence-based decisions on landscape governance and management [22,44,54]. Adapting and integrating sectoral and relevant land-use models to uptake ensemble-model use in landscape decisions will require not only the development, adaptation, and validation of new approaches, but also cross-disciplinary collaboration at an unprecedented level [37]. Such integration may not only encourage better "evidence-based decisions", but it may also help move us closer to a robust decision framework for landscapes.

Model prediction—eDNA for rapid biodiversity assessment: Conventionally, field surveys have been used to evaluate the impact of land management decisions on landscape services and multifunctionality. The studies have contributed to improved decision making on the effect of environmental change on populations/landscape functioning. However, the efficiency of using the conventional approach to generate evidence for decision making is often constrained by data availability and the long processes of field surveys [32,63]. eDNA is one of the emergent thematic groupings of the methodological approaches used in landscape decisions. eDNA-based surveys are increasingly being adopted for biodiversity monitoring and landscape decision making [63]. This is because, firstly, using observations from thousands of sites permits reliable and large-scale estimates of species distributions, and secondly, it provides opportunities to explore how species distribution and detection rates are influenced by land management practices [30,42]. The method is suitable for rapid biodiversity (e.g., species distributions) assessment. eDNA provides opportunities for data exploration that are not possible using conventional methods. However, like any scientific method, eDNA has some drawbacks and limitations:

1. Detection limitations: The sensitivity of eDNA detection can vary depending on various factors, such as DNA degradation, environmental conditions, and the concentrations of target organisms. It may be challenging to detect low-abundance or rare species accurately, especially if their DNA is present in very low quantities or is quickly degraded in the environment;
2. Species identification: eDNA analysis typically provides information about the presence or absence of a particular species, but it may not provide detailed taxonomic information or allow for species differentiation. This limitation arises because eDNA often targets specific regions of the genome that are shared among related species, making it difficult to distinguish between closely related organisms.

Despite these limitations, the eDNA method offers significant advantages in many ecological applications, such as monitoring rare or elusive species, detecting invasive species, and studying ecosystem dynamics. Ongoing research and advancements in methodology are continuously addressing some of these drawbacks and improving the effectiveness and reliability of eDNA analysis [28,29,62].

Participatory approach to landscape decisions: Stakeholder participation is viewed as a means of incorporating a diversity of values and interests in landscape decisions in order to achieve responsive and democratic governance [56]. This is because basing landscape decisions on evidence generated through research in silos without input from stakeholders has been shown to be insufficient to drive multifunctional and sustainable landscape management [52]. Also, sustaining a productive interaction between landscape users/practitioners and decisionmakers via government intervention alone is not possible without well-planned stakeholder engagement [56,65]. The integration of stakeholders' values into a landscape decision framework could provide a starting point for conversations across disciplines. This will be crucial for accounting for the multifunctional nature of landscapes in management and governance decisions [16]. In addition, pathways towards sustainable and multifunctional landscape governance are largely driven by stakeholders' decisions and actions, underpinned by multiple types of motivations and values. Therefore, understanding how stakeholders' values underpin their landscape management decisions represents a key aspect of landscape-decision-framework development [66]. However, stakeholder participation is a complex process, and its effective implementation remains a challenge. This is a topic of considerable ongoing research and discussion [31,55].

3.3. Framing Evidence to Inform Landscape Decisions: A Roadmap to a Holistic Landscape Decision Framework

The previous sections explored the drivers of landscape decisions and the methodological approaches used to generate evidence to inform landscape decisions. However, these alone are not sufficient to foster governance for a sustainable and multifunctional landscape. An important prerequisite required to support landscape decisions that currently does not exist is a robust decision framework. As noted by The Royal Society (2023), a national landscape framework would foster greater coherency between sectoral policies that have large-scale landscape impacts, such as those related to agriculture, energy, the environment, development, and infrastructure, that impact landscape governance to facilitate decisions on multifunctional and sustainable landscapes in a way that promotes synergies, avoids trade-offs, and improves productivity. It is therefore important to support landscape decisionmakers with frameworks to systematically account for the consequences of their decisions [28].

The development of a landscape decision framework in the UK has become a priority policy instrument for actualising policy objectives on biodiversity, the environment, climate change mitigation and adaptation, net-zero commitments, and the transition to a renewable-energy pathway [8]. There have been a series of dialogues and research projects in the UK on the development of a decision framework for sustainable and multifunctional landscape governance [7,67]. The landscape lens in policymaking is challenging because of the diverse landscape archetypes, socioecological challenges, and diverging and temporally shifting policy targets that they address [3,68]. Decisionmakers have to deal with an explicit demand for landscape services from a broad range of stakeholders [8]. This makes it challenging to have a single landscape decision framework that meets national policy needs at the level of the Devolved Administrations of Scotland, Wales and Northern Ireland, as well as for England and at the UK scale. With this in mind, the emerging themes from the synthesis were distilled into five landscape decision principles that can be used as a basis for a roadmap towards the development of a holistic landscape decision framework.

The following principles were deduced that could underpin the landscape decision framework:

1. *Drivers of decisions must be supported by appropriate methodologies and techniques*: To be most effective, the drivers of decisions in landscape frameworks should be guided by appropriate methodologies and techniques, which are analysed and presented in a way that ensures that decisions are informed by appropriate evidence. The methods and techniques used to generate evidence to inform decisions and policy play critical roles in landscape decisions;
2. *System thinking*: The LDF emphasises understanding landscapes as complex systems with interconnected ecological, social, and economic components. It recognises that decisions in one part of the landscape can have cascading effects on other parts, and it aims to consider the broader landscape context;
3. *Multidisciplinary approach*: Different disciplinary research techniques underpinning landscape decisions must be integrated for better landscape decisions. The multidisciplinary-approach principle encourages the integration of knowledge and expertise from various disciplines, such as ecology, economics, sociology, and planning. It recognises the need for interdisciplinary collaboration to address the complex challenges and trade-offs associated with landscape management. Individual disciplinary methods used to generate evidence to inform landscape decisions can be improved via better data analysis. However, there are challenges associated with achieving the necessary levels of integrated methodological research methods required for sustainable and multifunctional landscapes. A transdisciplinary approach to data analysis is needed to tackle this complex challenge;
4. *Trade-off analysis*: The trade-off-analysis principle acknowledges that landscape management often involves trade-offs between different goals and objectives. It promotes the evaluation of alternative management scenarios and the consideration of multiple criteria, such as ecological integrity, social equity, economic viability, and cultural values, to inform decision making;
5. *Stakeholder engagement*: This principle promotes the involvement of diverse stakeholders, including local communities, landowners, experts, and government agencies, in decision-making processes. It recognises the importance of incorporating different perspectives, knowledge, and values to achieve more inclusive and effective landscape management.

These principles provide a framework for guiding decision-making processes that balances ecological conservation, socioeconomic development, and stakeholder interests in landscape management. The specific application of the principles may vary depending on the context and objectives of a particular landscape, but the overarching aim is to promote integrated and sustainable approaches to landscape decision making. By adopting the proposed principles as a guide in the construction of a decision framework, landscape decisions will become more robust, responsive, and effective in addressing the complex challenges and opportunities of landscape management. The proposed principles will ensure that the landscape decision framework embodies sustainability, inclusivity, and accountability while promoting the long-term health and wellbeing of landscapes and communities. This assertion is supported by the findings in [15] on sustainable and multifunctional landscapes. Nevertheless, we face a formidable challenge when identifying landscape decision principles at a regional or national scale that could be used to provide a scientific rationale and support the specific types of drivers of decisions per landscape archetype [8,22,58,69].

4. Conclusions

Landscape decisions require robust research methods and techniques for the assessment of the likely consequences of the decision drivers, balancing conflicting policy objectives and the diversity of stakeholders' preferences and values. This requires grounded decision principles for the improved integration of evidence informing landscape decisions so that landscape governance results in a sustainable and multifunctional landscape in an inclusive and socially acceptable manner. Not surprisingly, modelling was the most common methodological approach used to generate evidence for informing landscape decisions in the reviewed studies. Models are suitable tools for addressing the complex challenge of landscape decisions. Nevertheless, modelling techniques used in the generation of evidence to inform landscape decisions vary in their analytical strengths and weaknesses. Interrogating the lessons from the analysis of methodological approaches to evidence sourcing to inform landscape decisions activates a fundamental link between landscape decisions and the research technique used to generate evidence informing decisions. Integrating research methods and techniques to robustly generate evidence to inform decisions may help decisionmakers to determine optimal pathways to a sustainable and multifunctional landscape, but doing so may mask some of the important complexity and trade-offs present in the way policy interactions influence the drivers of decisions. This reinforces the needs for decision principles that could underpin the functioning of the landscape decision framework.

By analysing the methodological techniques used in evidence synthesis with respect to the landscape decision process, this study provokes reflective thinking regarding the functioning of a landscape decision framework. When generating evidence to inform landscape decisions, it is imperative to understand the limitations of the methodological approach used. Failure to fully consider the strengths and weaknesses of the research technique can lead to erroneous decisions. Using an appropriate methodological approach to generate evidence to inform landscape decisions towards governance for a multifunctional and sustainable landscape is not solely an issue of using data to underpin decisions, but also of placing these in the social framing of landscape decisions. Insights from the emergent thematic group on participatory landscape planning and management have demonstrated the importance of the interaction between decisionmakers and stakeholders in integrating stakeholders' preferences and values into the landscape decision process, and its influence in achieving a sustainable and multifunctional landscape.

Landscape decision frameworks are particularly important in operationalising the concept of multifunctionality in landscape decisions. This study provides important insights on decision principles that are capable of guiding the development of the landscape decision framework. The results identify decision principles that can be applied to all landscape archetypes towards actualising the goal of sustainable and multifunctional landscapes. Nevertheless, there remains the need for further research in order to develop a national-scale landscape decision framework for landscape planning, management, and governance. There exists a knowledge gap in terms of the space for transdisciplinary research in the functioning of a landscape decision framework. Hence, the goal for further studies will be to identify specific options for the application of a transdisciplinary evidence synthesis/research technique for handling the large volumes of complex interconnected data required to inform the functioning of a landscape decision framework.

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Note

[1] A landscape archetype refers to a recurring or fundamental pattern or theme that is often found in various natural landscapes. Landscape archetypes can be identified based on their physical features, such as landforms, vegetation, water bodies, and climate characteristics. An archetype serves as a general representations of landscape types and provide a framework for understanding and categorizing different natural environments.

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