Review

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

Chidiebere Ofoegbu *, Heiko Balzter, Martin Phillips

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

Chidiebere Ofoegbu[1,*], Heiko Balzter[1,2] and Martin Phillips[3]

[1] University of Leicester, Institute for Environmental Futures, School of Geography, Geology and the Environment, Space Park Leicester, 92 Corporation Road, Leicester, LE4 5SP, UK; hb91@le.ac.uk; bd167@le.ac.uk; ofoegbu.c@gmail.com

[2] National Centre for Earth Observation, University of Leicester, Space Park Leicester, 92 Corporation Road, Leicester, LE4 5SP, UK

[3]. University of Leicester, Institute for Environmental Futures, School of Geography, Geology and the Environment, University Road, Leicester, LE1 7RH, UK

*Correspondence: ofoegbu.c@gmail.com

Abstract: The development of a decision framework for landscape governance and management has become one of the prioritised policy instruments for actualising policy objectives relating to agri-food system, biodiversity conservation, nature restoration, environmental management, climate change mitigation and adaptation, net zero greenhouse gas emissions, and the transition to renewable energy supplies in the United Kingdom (UK). 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 decisions framework. To address this issue, this study undertakes a systematic review and transdisciplinary synthesis of research outputs from the Landscape Decisions Programme (LDP). This study compiles and synthesizes 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 more sustainable and multifunctional landscapes. The synthesis analyzed the drivers of landscape decisions, and methodological approaches used to generate evidence for decision-making. The emerging themes from the synthesis were distilled into five principles that can be used as a basis for a roadmap towards the development of a holistic landscape decisions framework.

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

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]. Decision-makers at all levels of governance and management are faced not only with a complex array of problems [3], but also complexity of incorporating existing land use policies and planning constraints with emergent scientific understanding of landscapes' multi-functionality and sustainability into the decision-making process[4]. Decision-making on sustainable and multifunctional landscapes, therefore, requires simultaneously accommodating production goals, environmental soundness, and social relevancy of landscapes[5]. This is further complicated by the synergies, trade-offs, and non-linear responses among 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 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 multi-functional and sustainable landscape use and management[3, 7]. A framework for landscape decisions is therefore a prerequisite as this will enable decision-makers 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' ability to support their human and non-human occupants. A comprehensive decision-making framework for landscape governance has yet not been developed in the 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 which 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 using 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 UKRI, aiming 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 covered various disciplinary aspects of landscape decisions ranging from physical sciences and modelling of ecosystem services and their interactions with land use systems, to qualitative research and participatory decision-making that engages various stakeholders to understand how stakeholders' values and choice shapes landscape management.

This study adopts a transdisciplinary approach to research synthesis and combines elements from the LDP project outputs into an overarching framework for landscape decisions 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 methodological strengths and weaknesses (advantages and limitations of the methods / decision support tools used in the studies). Based on this synthesis, the study proposes a roadmap on how evidence from the LDP synthesis can support the development of an evidence-based landscape decisions framework for the UK. Landscape framing as used in this study adopts a plurality view, and defines landscape as physical features of an area, including its terrain, natural resources, and the overall appearance of its natural and man-made elements. This includes 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 the study is focused on their aesthetic, ecological, cultural and food supply values.

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 introduces the research questions that guide the synthesis and structure of the paper. Section 3 presents the study findings. It focuses on the dominant theme that emerges from the synthesis to answer the study research questions, propose a general landscape decision framework that can be used to guide evidenced based decisions on the sustainable and multifunctional landscape, and finally. Section 4 concludes the study and presents five principles to aid the development of landscape decisions 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 the conceptual synthesis for a holistic landscape decisions framework

A landscape decisions 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 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

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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 [15, 16]. Adopting a transdisciplinary synthesis approach enabled the identification of commonalities from the different disciplinary knowledge on landscape decisions situated in the LDP Work packages[17-19]. 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 [15, 16].

A major barrier to the development of a landscape decision framework is the fragmentation of evidence [10, 20, 21]. 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 [22, 23]. 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 decisions 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 drivers of decisions and methodological approaches to evidence sourcing contribute to the conceptual development of the landscape decision framework?

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 project through modelling with contributions to understanding the functioning of the framework. Adopting a transdisciplinary approach to research synthesis in the study enabled the synthesis of projects in each WP beyond the boundaries of the existing discipline's design concepts, thereby mitigating complexity and increasing understanding of principles that will inform the development of a holistic landscape decisions framework [24, 25].

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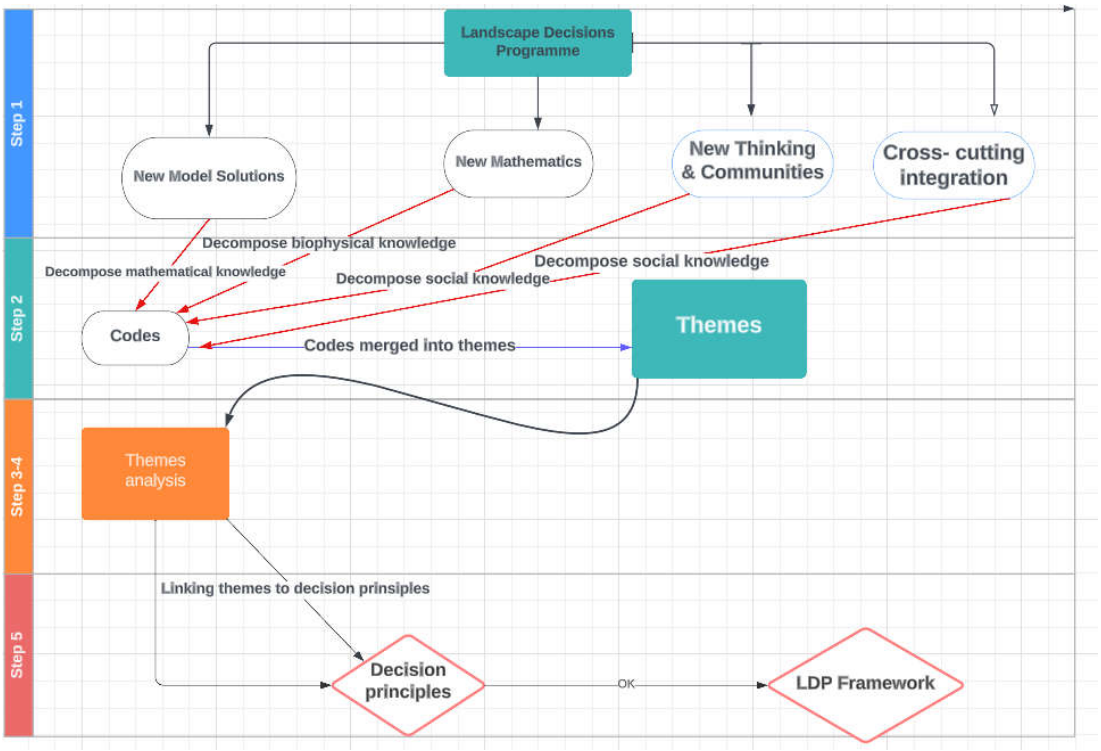

Figure1: Transdisciplinary synthesis of evidence

We explore how to combine emerging evidence from the four thematic LDP work packages to inform the development of a holistic landscape decisions framework based on a systemic understanding of inherent complexity [10, 24, 26]. The synthesis tasks were carried out in five steps. Step 1 of the process begins with an initial reading of all publications from the LDP projects, documenting the drivers of decisions, the 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 encompasses the review and understanding of the discipline's fundamentals [24, 25].

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	[27]/ 2023
2	Scientific report	Biodiversity assessment and landscape decisions	[28]/ 2021
3	Scientific report	Biodiversity assessment and landscape decisions	[29]/ 2022
4	Technical report	Net Zero and landscape decisions	[8]/ 2022
5	Peer review paper	Regime shift and ecosystem services	[30]/ 2020
6	Peer review paper	Biodiversity assessment and landscape decisions	[31]/ 2021
7	Peer review paper	peat and peaty soils, and landscape decisions	[32]/ 2021.
8	Peer review paper	Social benefits of protected landscapes, and landscape decisions	[33]/ 2021
9	Peer review paper	Ecosystem service and landscape decisions	[34]/ 2022
10	Peer review paper	Peat soils, and landscape decisions	[35]/ 2021
11	Commentary	Freshwater ecosystem service and landscape decisions	[36]/ 2020
12	Peer review paper	Freshwater ecosystem service and landscape decisions	[37]/ 2020
13	Peer review paper	Bioenergy with carbon capture	[38]/ 2021
14	Peer review paper	Onshore wind energy and landscape decisions	[39]/ 2021

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15	Peer review paper	Freshwater ecosystem service and landscape decisions	[40]/ 2020
16	Peer review paper	Freshwater ecosystem service and landscape decisions	[41]/ 2022
17	Peer review paper	Ecosystem service and landscape decisions	[42]/ 2019
18	Peer review paper	Ecosystem service and landscape decisions	[43]/ 2020
19	Peer review paper	Ecosystem service and landscape decisions	[44]/2021
20	Peer review paper	Ecosystem service and landscape decisions	[45]/ 2021
21	Peer review paper	Net Zero, climate change mitigation, and landscape decisions	[46]/ 2021
23	Peer review paper	Ecosystem service function and landscape decisions	[47]/ 2021
24	Peer review paper	Peat soils, and landscape decisions	[32]/ 2021
25	Peer review paper	Biodiversity assessment and landscape decisions	[48]/ 2020
26	Technical report	Ecosystem service and landscape decisions	[7]/ 2019
27	Peer review paper	Ecosystem service function and landscape decisions	[49]/ 2021
28	Peer review paper	Ecosystem service function and landscape decisions	[50]/ 2022
29	Peer review paper	Public engagement and landscape decisions	[51]/ 2022
30		Freshwater ecosystem service and landscape decisions	[52]/2020
31	Peer review paper	Ecosystem service and landscape decisions	[53]/ 2023

NB: Details on the LDP's 70 projects and the associated research outputs can be found at https://landscapedecisions.org/projects/

This was followed by step 2, where qualitative data analysis software (NVIVO 12) was used to organize the data-emanating from step 1 into codes. Given the diversity of disciplinary knowledge and methodology used in the reviewed studies, the organisation was done 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 organised 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 [54]. In step 5 the emerged dominant themes were defined, the relationship among them was examined and deductions were made on drivers of decisions, dominant methodological approaches used to generate evidence for landscape decisions, the strengths and weakness of the methodological approaches, and finally inferences were made on principles that can inform the development of landscape decisions 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 study, 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 [25]. The thematic analysis process, grounded in the data, was used since 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 Discussions

3.1. Emerging evidence on drivers of decisions: key issues and links to landscape decision-making

The thematic content analysis of the LDP outputs about 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: 1) Recognising and preserving undervalued landscape services, 2) Improving the efficiency of accounting for biodiversity and landscape services interaction, 3) Innovation to improve landscape services quantification, 4) Transition to renewable energy and net zero pathways, 5) Inclusion and participation, 6) Awareness of human impacts on landscape services. The drivers and their applications in landscape decisions as shown in the reviewed document are presented in Table 2.

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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 archetype[1] and the services they provide are sustainably managed. Willcock et al. (2021) provide insight for integrating sanitation ecosystem services in landscape decision framework. Tramblay et al. (2020) provide insight for decisions on management of temporal rivers.	[40, 45]
Improving efficiency of accounting for biodiversity and landscape services 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 responds to environmental change is crucial for decisions on landscape management.	[29, 30, 37, 47]
Innovation to improve landscape services quantification	Landscape services need to be accurately assessed and mapped to be incorporated in policy making and planning decisions. Accurate assessment of multiple landscape services, and the synergies and trade-offs among these services, in order to estimate potential effects of land management and land use change or other impacts is vital.	[17, 34, 35, 42, 43, 53]
Transition to renewable energy and net zero pathways	Transition to renewable energy net zero emission pathways is key to mitigating climate change impact. The dominant decision focus mainstreaming fostering coherence of Government's renewable energy plan/policy with other land use policies.	[8, 38, 39]
Inclusion and Participation	Inclusion and participation are one of the dominant themes on drivers of landscape decision. The dominant decision focus is about the design of participatory process in decision making with an increasing focus being directed towards citizens. Equity in access to relevant information is an important aspect to facilitate this.	[8, 53, 55]
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.	[33]

Recognizing and preserving undervalued landscape services: While most categories of landscape services are well appreciated in the reviewed studies and landscape management decisions, there are, however, certain landscape services that are less appreciated [40, 44, 45]. In this regard, one of the emerging dominant themes on drivers of landscape decisions targets these undervalued landscape services. The undervalued landscape services that are driving research interests and landscape decisions include sanitation services [45], temporal headwater services [40], and cultural services [7, 17, 34]. In line with Goal 6 of the 2030 Agenda for Sustainable Development which recognizes the importance of ensuring the availability and sustainable management of sanitation, few of the reviewed project outputs target management of landscape sanitation services[44]. Conventionally, engineered systems have been used to manage human waste, however, the approach of nature-based solutions-sanitation services are receiving more policy attention. [45] have paved the way for future research to ensure that sanitation services provided by landscape are properly accounted for in decisions on landscape governance. Other undervalued landscape services that are driving attention in research on landscape decisions are headwater streams that flow intermittently, that is, the Aqua Temporaria Incognita [36], cultural ecosystem services[56]. As pointed out by [56], the scientific discourse about landscape cultural services has lagged behind that of other provisioning and regulating services. It therefore follows that any adopted

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landscape decisions 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 landscape services 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 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 [17, 34, 42, 53]. 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 [29] examined how single species distribution is influenced by environmental factors (which are also influenced by landscape management decisions), [27] recognised that multidimensional approaches are in practice used to inform and evaluate land use decisions. [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. 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 services quantification: Policy goals on biodiversity conservation, food security, net zero emissions, sustainable land and ecosystem services management are dominant themes that drives landscape decisions [1, 2, 15, 57, 58]. The rationale is that a sustainable and multifunctional landscape must be achieved within the context of actualising these policy goals [11, 15, 51, 59]. However, decisions on landscape management that ensure the actualisation of these policy goals require an assessment of the synergies and trade-offs among these goals, 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 well-being, and indeed, the well-being of particular people [16, 59]. 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 by [43] work that linked the planning and implementation of a sustainable development approach in a region to an accurate knowledge of landscape services in the region, and how they might respond to management choices [43]. As a principle, the landscape decision framework should encourage innovations and research on modalities of improving the efficiency and cost-effectiveness of methodological approaches used to quantify/assess the contribution of landscape services to wellbeing [7, 60].

Transition to renewable energy and net zero pathway: The landscape approach is assuming an important role in national policy discourse on climate change, net zero emission pathway, circular economy, and renewable energy. An important emerging theme on 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, 38, 39]. 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, 39]. While the work of [38, 39] 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.

Inclusion and participation: Inclusion and participation are one of the emerged dominant themes on drivers of landscape decisions. The key issue here is about the design of a participatory process in decision-making with an increasing focus being 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 [33, 51]. Participatory approaches to decision-making, including stakeholder engagement, are increasingly gaining policy traction for managing complex socio-ecological challenges with regard to sustainable and multifunctional landscapes [8, 51]. In this regard, several issues were addressed concerning the effective and efficient participatory framework for decision-making. [51] investigated the potential of the participatory design method in Scotland. The study used insight from Dewey's vision

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to demonstrate how Dewey's vision enables the rationalisation of past action and prospect future activity about 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, and for what, whom, and by whom [27, 61]. As a fundamental principle, a holistic landscape decision framework will have to facilitate inclusivity and wider participation to promote ownership and participation of all stakeholders in the landscape decision-making process [53].

Awareness of human impact on landscape services: Another dominant theme on 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, 33]. This driver is mostly associated with protected landscapes and endangered landscape services. For an example [33] 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. This includes nest failure, impaired nestling growth, reduction in the areas suitable for breeding, and 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 conservation priority within the site to reduce the negative impact on landscape functionality [33]. 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.

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 studys' research methods and techniques. The analysis yielded four dominant thematic groupings (Table 3). We use the thematic groupings to provide clarification at a conceptual level about techniques and methodological approaches used to inform landscape decisions. The benefit, strength and weakness of the methods are then discussed, making explicit the relationships between methodology, landscape decisions and landscape sustainability/multifunctionality outcomes. The aim is to provide insights that might improve methodological approaches to decision-making about landscape management.

Insert table 3

Modelling-remote sensing technique in landscape decisions: Modelling using remote sensing techniques is one of the emerging thematic groupings on 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 technique were used to analyse relationships between slope, elevation and organic layer depth to guide decision on Peat landscape thickness to aid land management strategy [12, 31, 32, 62, 63]. For example, [32] used information from digital elevation models to analyse organic layer depth of peat landscape. Some projects used it for assessing soil ecosystem services in order to improve decisions on how land use might improve their diversity and functionality [35]. [35] applied linear mixed models' technique to remote sensing technique to analyse the spatial variation of soil property by analysing the relationship among relevant covariates such as radiometric data, satellite imagery or elevation. Conventional approach to soil measurements is generally costly and time consuming and often require samples of soil to be collected and taken to a laboratory for preparation and analyses. Also, many such samples are required for broad scale prediction of the variation of 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 [32]. While it is clear from the synthesis that modelling using remote sensing technique is gaining momentum in landscape decisions, it is still not clear how lessons and experience from this technique application can inform decision principle to guide the development of landscape decision framework.

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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 variation of landscapes. Slope and elevation are (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 may also be beneficial in estimation of organic horizon depth	The approach used in the study contribute to improvements on 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.	[32, 35]
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, this 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 services change with respect to land management strategies	[17, 34, 42, 53]
Model prediction- eDNA for rapid biodiversity assessment	As eDNA surveys become increasingly used as monitoring tools, they have the potential to replace traditional survey methods that rely on direct observation of 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 services conservation. Makes data collection easy, but data interpretation difficult.	eDNA can provide metrics for decisions on biodiversity conservation.	[28, 29, 31, 62]

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	especially for difficult to detect species.				
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 did all participants have access to the required information?	Enhances bottom-up approaches to landscape governance	Integration of stakeholders' value in a landscape decision framework could provide a starting point for conversations across disciplines.	[33, 51, 53]

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 [17, 34, 37, 38]. Though single model were the most commonly used approach for predicting impact pathways of landscape management decisions in the reviewed studies [30], there is a growing realization 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 [17, 23, 53]. The study by [43], 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 uncertainty from single model use [17, 53]. [43] 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 regards to the landscape archetype and socioecological challenge being addressed [42, 43]. There is therefore a knowledge gap on how to make ensemble modelling standard practice for evidence-based decisions on landscape governance and management [21, 43, 53]. 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 [36]. Such integration may not only encourage better "evidence-based decisions", but it may also help move us closer to robust decision framework for landscapes.

Model prediction- eDNA for rapid biodiversity assessment: Conventionally, field survey has been used to evaluate 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 long processes of field survey [31, 62]. eDNA is one of the emerged thematic groupings on methodological approaches used in landscape decisions. eDNA-based surveys are increasingly being adopted for biodiversity monitoring and landscape decision-making [62]. This is because; (1) using observations from thousands of sites permits reliable and large-scale estimates of species distributions. Secondly, it provides opportunities to explore how species distribution and detection rates are influenced by land management practices [29, 41]. The method is suitable for rapid biodiversity (e.g., species distributions) assessment. eDNA provides opportunities for data exploration which 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 concentration 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.

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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.

Participatory approach to landscape decisions: Stakeholders' 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 [55]. This is because basing landscape decisions on evidence generated through research in silos without input from stakeholders have been shown to be insufficient to drive multifunctional and sustainable landscape management [51]. Also, sustaining a productive interaction between landscape users/practitioners and decision-makers by government intervention alone is not possible without well planned stakeholders' engagement [55, 64]. Integration of stakeholders' value in 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 [15]. In addition, pathways towards sustainable and multifunctional landscape governance are largely driven by stakeholder's decisions and actions, underpinned by multiple types of motivations and values. Therefore, understanding how stakeholders' values underpins their landscape management decisions represents a key aspect of landscape decisions framework development [65]. However, stakeholders' participation is a complex process and its effective implementation remains a challenge. This is a topic of considerable ongoing research and discussion.

3.3. Framing evidence to inform landscape decisions: a roadmap to a holistic landscape decisions framework

Previous sections have 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 which currently does not exist is a robust decisions 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, environment, development and infrastructure that impacts landscape governance to facilitates 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 decision makers with frameworks to systematically account for the consequences of their decisions [27].

The development of a landscape decisions framework in the UK has become a priority policy instrument for actualising policy objectives on biodiversity, environment, climate change mitigation and adaptation, net zero commitments, and the transition to a renewable energy pathway [8]. There has 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, 66]. The landscape lens in policymaking is challenging because of the diverse landscape archetypes, socio-ecological challenges, and diverging and temporally shifting policy targets that they address[3, 67]. Decision-makers 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 decisions 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 decisions framework.

The following principles were deduced that could underpin landscape decisions framework:

1. **Drivers of decision must be supported by appropriate methodology and techniques**: To be most effective, drivers of decisions in landscape frameworks should be guided by appropriate methodology and techniques which are analysed and presented in a way that ensure that decisions are informed by appropriate evidence. The methods and techniques used to generate evidence to inform decisions and policy plays critical role in landscape decisions.

2. **Systems Thinking:** The LDF emphasizes understanding landscapes as complex systems with interconnected ecological, social, and economic components. It recognizes that decisions in one part of the landscape can have cascading effects on other parts and 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 recognizes 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 by better data analysis. However, there are challenges associated with achieving the necessary levels of integrated methodological research methods required for a sustainable and multifunctional landscapes. 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 recognizes 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 balance ecological conservation, socio-economic 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. 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, 21, 57, 68].

4. Conclusions

Landscape decisions require robust research methods and techniques for the assessment of the likely consequences of decision drivers, balancing conflicting policy objectives, and the diversity of stakeholders' preferences and values. This requires grounded decision principles for improved integration of evidences 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. Regardless the strength and weakness of modelling techniques in landscape decisions,

the solutions to the complex challenge of decision making on sustainable and multifunctional landscapes are unlikely to lie solely in new technologies [61].

By analysing methodological techniques used in evidence synthesis in respect of landscape decision process, this study provokes reflective thinking with regards to 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. 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 decision makers 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 drivers of decisions. This reinforces the needs for decision principles that could underpins the functioning of the landscape decision framework. A landscape decisions framework that takes into consideration the relationship between drivers of decisions and the research methods and techniques used to generate evidence for decisions, and the way policy interaction influences decisions may be useful for providing high level information to decision makers, but it may require an integrated transdisciplinary approach to evidence generation. As can be deduced from this study, interdisciplinary methodological framework allows the synthesis of different values involved in the process of landscapes landscape decisions. Combining perspectives from multi-disciplinary research allows for a broader understanding of the complex challenges of decision making on sustainable and multifunctional landscapes.

Using 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 placing those in the social framing of landscape decisions. As affirmed by Cole et al. (2022), achieving the target of sustainable and multifunctional landscape will benefit from integrating diverse evidence into the decision framework. Insights from the emerged thematic group on participatory landscape planning and management have demonstrated the importance of interaction between decision-makers and stakeholders in integrating stakeholders' preferences and values in the landscape decision process, and its influence in achieving a sustainable and multifunctional landscape. Participatory approaches to landscape decisions entail synthesising, prioritizing and integrating, interests and values from stakeholders into landscape decisions. However, to date, much effort to the development of landscape decision framework is prescriptive, rather than participatory, and existing participatory research studies have not aimed at landscape decision framework development. What this means is that landscape stakeholders' values and experience are yet to be meaningfully integrated in landscape decision framework development.

Landscape decision frameworks are particularly important in operationalising the concept of multifunctionality in landscape decisions. The approach to landscape decisions through the principle of multifunctionality and sustainability by drawing on the synthesis of evidence from drivers of decisions and methodological approach that underpins decisions as demonstrated in this study, offers prospects for informing decision principles that its capable of guiding the development of landscape decisions framework. The results identify decision principles that can be applied to all landscape archetype towards actualising the goal of sustainable and multifunctional landscape. Hence, the approach has demonstrated its suitability in the development of a national scale landscape decision framework.

A confluence of drivers of decisions and methodological approach to evidence generation necessitates a strategic rethink of the way decisions are made about how landscapes and the services they provide are managed. The emerging evidence from technically driven projects through modelling have helped improved technical understanding of how landscape services are impacted by management practices and provide insights for decisions on sustainable and multifunctional

landscapes. However, many issues still remain to be resolved to fully develop a national scale landscape decisions framework for landscape planning, management and governance:

There exists knowledge gap about the space for transdisciplinary application in the functioning of a landscape decision framework. Hence, the goal for further studies will be to identify specific options for the application of trans-disciplinary evidence synthesis/research technique for handling large volumes of complex interconnected data used to inform landscape decisions.

Supplementary Materials: The following supporting information can be downloaded at the website of this paper posted on Preprints.org, Description of all the 70 projects funded under the LDP, their outputs and website.

Author Contributions: For research articles with several authors, a short paragraph specifying their individual contributions must be provided. The following statements should be used "Conceptualization, Ofoegbu C, Balzter H.; writing—original draft preparation, Ofoegbu, Balzter H, Willcock S, Phillips M.; writing—review and editing, Ofoegbu, Balzter H, Willcock S, Phillips M.; project administration, Balzter H, Phillips M, Ofoegbu C.; funding acquisition, Balzter H, Phillips M. All authors have read and agreed to the published version of the manuscript."

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