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Decision analytical methods for assessing the efficacy of agroecology interventions

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Abstract

Given the extensive impact of humans on ecosystems and the uncertainty faced by decision-makers when choosing among alternatives, formal support is required for decision-making in complex agroecological systems. While approaches for producing reliable impact projections accounting for system complexity and uncertainty do exist, decision-makers rarely use them to assess the costs, benefits, and risks of agroecology development. Here, we review the literature and provide an overview of decision theory as a methodology for supporting decision-making in agroecology. We also outline the conceptual relationships between decision analysis methods and agroecology, and examine how decision analysis methods can be applied to support decision-making for agroecological transitions. These methods support decisions based on intended outcomes, explicitly accounting for risks and uncertainty, and help decision-makers determine the appropriateness of agroecological interventions for achieving desired outcomes. International frameworks and national government commitments and funding mechanisms, as well as the private sector, would benefit from making use of decision analysis methods to determine the suitability of agroecology interventions and to support and scale them when appropriate.

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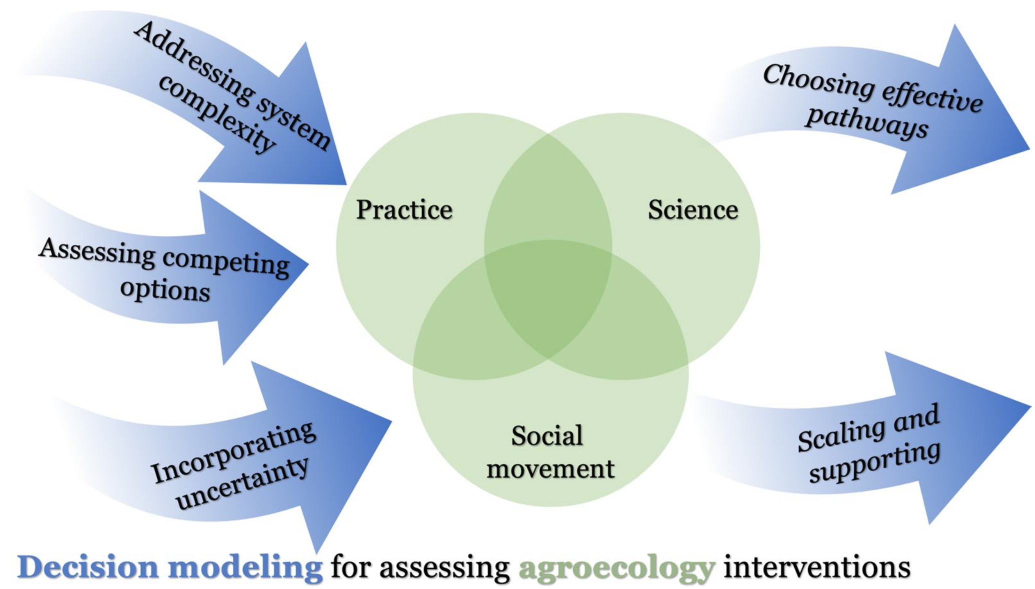
Graphical Abstract



Introduction

Agricultural sustainability is threatened by a host of global challenges, including climate change, biodiversity loss and diminishing soil productivity (FAO 2021; Pörtner et al. 2022). At the same time, agriculture is recognized as one of the major threats to biodiversity as well as a major driver of climate change (Raven and Wagner 2021; Ortiz et al. 2021). Successful transitions towards sustainable agriculture and food systems would likely benefit from holistic and people-centered approaches such as agroecology (FAO 2018; Barrios et al. 2020). Agroecology, a concept that is gaining attention in scientific, agricultural, and political circles, is at the center of numerous initiatives aiming for environmental sustainability, climate resilience, improved livelihoods, and food and nutrition security (Tomich et al. 2011; FAO 2018; Barrios et al. 2020). Despite expressing interest in supporting agroecology interventions, decision-makers have little scientific support for evaluating the potential impacts of such interventions. Agroecological interventions have been touted as potential solutions to many pressing problems (IAASTD 2009; FAO 2014; Wezel et al. 2020), placing agroecology at the center of many initiatives aiming to make farms more sustainable. Agroecology is a dynamic concept that is gaining prominence in scientific, agricultural and political discourse (Wezel et al. 2020). The key benefits include environmental sustainability, climate resilience, improved livelihoods (Silici 2014) and food and nutrition security (Amissah et al. 2020). It is also thought of as a tool for addressing issues such as land degradation, biodiversity loss and climate change, and for strengthening human rights (De Schutter 2010). Agroecology is seen as a shift in agriculture toward diversified agricultural systems (IPES-Food 2016), and as a mechanism for mitigating negative environmental impacts of agriculture (Tomich et al. 2011). Recognizing that the inherent complexity of achieving sustainability may be perceived as a deterrent to decision-making, the Food and Agriculture Organization of the United Nations (FAO) has approved the 10 Elements of Agroecology as an analytical framework to support the design of differentiated paths for agriculture and food system transformation (Barrios et al. 2020). Decision-makers may be motivated to implement agroecology interventions for a variety of reasons. The management goals of agroecology-supported production are similar to sustainable intensification, with the addition of an explicit aim of generating multiple desirable outcomes, including ecosystem services as well as productivity benefits (Wezel et al. 2015). The expected benefits of agroecology differ by location, as well as by ecological and socioeconomic context (FAO 2014).

For all these reasons, many decision-makers have expressed their interest in supporting agroecology interventions but struggle with uncertainty about the suitability of agroecological measures and their social, environmental and economic outcomes. This is due to the difficulty of accurately projecting intervention impacts given the lack of data, the complex impact pathways of interventions, their implications for multiple sustainability dimensions, and the many associated risks and uncertainties. All of these aspects of agroecology are difficult to factor into intervention planning and therefore often left out. Although they exist, scientific approaches to produce reliable impact projections accounting for system complexity and uncertainty are rarely applied for assessing the costs, benefits and risks of agroecology development. The consequence is that decision-makers have little scientific support to decide if agroecological interventions would have a positive impact.

Here, we define a decision as 'a choice between two or more alternatives that involves an irrevocable allocation of resources' (Howard and Abbas 2015). Decision analysis can be applied in such conditions. It is a discipline that involves identifying and assessing all aspects of a decision, evaluating outcomes using models, and taking actions based on the decision that produces the best outcome. It is the formal study of rational decision-making formed by the joint efforts of many disciplines, from mathematics and economics to philosophy and the social sciences. Decisions are formulated as impact pathway models, which are then applied to run stochastic simulations to forecast possible decision outcomes so that the optimal decision choice can be made. Decision analytical approaches, based on decision theory, have a rich history of applications to real-world problems in many disciplines, including business management (Keeney 2004), ecology (Perera et al. 2011) and conservation (Dee and Gerber 2012; Esmail and Geneletti 2018). These approaches have begun to gain recognition for supporting agricultural development (Shepherd et al. 2015; Luedeling and Shepherd 2016; Lanzanova et al. 2019) and related topics like nutrition and dietary diversity (Whitney et al. 2017; Assima et al. 2022).

Decision analysis is particularly useful for supporting three main contexts that are common in agroecological systems: (1) complex system interactions, (2) choices under uncertainty and (3) decisions among competing options. Decision analysis can help to clarify which agricultural measures make most sense under which conditions given the complexity and challenges of agricultural production systems. Under any combination of these three conditions, decision analysis can aid in decision-making by explicitly accounting for uncertainty and risk, by ranking decision options according to their net benefits and by integrating different tangible and intangible variables in a complex system model. By keeping decision-making at the center of the approach, the methods offer a way to support more objective and efficient decision-making processes.

The use of formal decision theory approaches to support the assessment—and potential application—of agroecology interventions is still rather limited. In this review we point out how such approaches can offer a practical, objective, promising and widely applicable methodology to support decision-making for agroecology. Decision-makers may, in some cases, have access to information and knowledge that offer some support, but they are still unlikely to have a full picture of agroecological interventions with full certainty about all outcomes. Approaches based on decision theory can provide objective decision strategies for the management of agroecology systems, where decision-makers must often choose between courses of action but have uncertainty about the expected payoffs and losses that might result from their actions. We performed a search in the Web of Science Core Collection using the search fields "decision" + "uncertainty" + ("intervention" or "policy") + "Agroecology". The search was published on the searchRxiv (Whitney 2023).

As a field of research, agroecology can be conceptualized within the context of global change and studied as a coupled system involving a wide range of social and natural processes (Tomich et al. 2011). Agroecology is generally defined as the application of ecological principles and concepts to the design and management of agroecosystems (Tomich et al. 2011; FAO 2018; Barrios et al. 2020). There are various interpretations of what agroecology means in practice, with three main manifestations. Agroecology is considered a science, a set of practices and a social movement (Wezel et al. 2009, 2020). For actions related to each of these manifestations to have real-world impacts, a cost–benefit assessment with decision analytical methods can be useful. Decision analysis methods incorporate uncertainty, assess competing options and offer a comprehensive and holistic overview of system complexity (Fig. 1). The methods can help with evaluating the potential impacts and trade-offs of different practices and interventions on key outcomes such as food security and social equity. This can help policymakers and practitioners make informed, evidence-based decisions.

Agroecology can also be said to encompass the overlap between science, practice and movement (Fig. 1), occurring when there is a convergence of these approaches (Méndez et al. 2020; Anderson et al. 2020; Dale 2020). In this way agroecology can be understood as a transdisciplinary approach that integrates research, action and societal change (Gliessman 2018). Decision analysis models provide a systematic and intuitive approach to guiding the decision-making process (Ghazoul and McAllister 2003). They make use of methods from the natural and social sciences (Jeffrey 1990), with the aim to create comprehensive and widely accepted support for decisions (Ghazoul and McAllister 2003). Decision

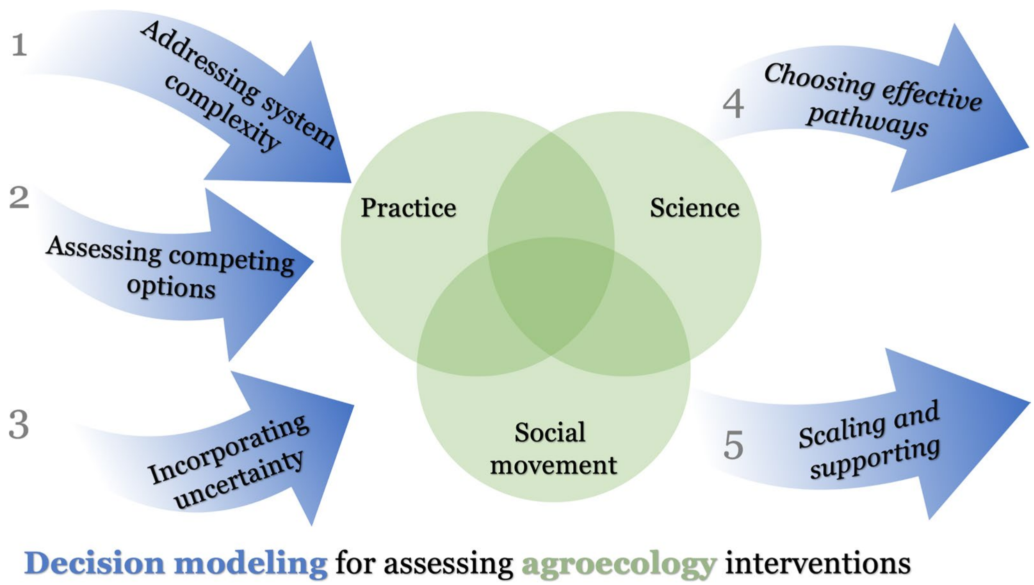


Fig. 1 Conceptual relationships between decision analytical methods and agroecology—overview of how decision analysis methods can be applied for supporting decision-making for agroecology interventions. The Venn diagram illustrates agroecology as a science, practice and social movement. The five arrows surrounding the Venn diagram represent the various decision analysis capabilities that can be used to assess and communicate the costs and benefits of agroecological practices and interventions

analysis in agriculture has the broad focus to provide a holistic comparative assessment of the effectiveness of interventions (Shepherd et al. 2015). The approach can support decisions so that the best choices are clear in terms of their impact on the outcomes of interest. Adapting such an approach can help provide an overview of the implications of agroecology-based interventions or changes at the local or landscape scale. The application of the approaches of decision analysis for supporting agroecology are outlined in the following five sections (following the five arrows in Fig. 1).

1. Addressing system complexity

Decision-makers are often in need of decision-relevant information that can provide meaningful support for any options aimed at impacting complex agricultural systems. Scientists struggle to provide reliable information about agroecology at a level that is meaningful for policy-makers. The difficulty, for example, of translating many smaller-scale case studies into possible implications at the landscape level makes it challenging to assess the potential of agroecology at that scale (Dalgaard et al. 2003). Farmers and other stakeholders often have comprehensive systems understanding. This knowledge-base can be applied to unpack system complexity and begin to understand the potential impacts of agroecology.

Farmers are often the best source of information about risks as well as management, for example with crop selection (Mbinda et al. 2021) and pesticide application (Bhandari 2014). They can provide intangible local knowledge for agroecology management (Moore et al. 2016) and agroecology practices that are ecological and profitable (Aouadi et al. 2021). They can also help to clarify the frequently complex trade-offs of a decision where conflicting criteria affect the decision outcome (Oliver et al. 2012; Moore et al. 2016).

Decision modeling tools make use of a multi-actor engagement for understanding system complexity (Whitney et al. 2018). More of such participatory, ecologically-based decision-making by farmers is needed in agricultural development (IAASTD 2009) and in agroecology (Biber-Freudenberger et al. 2018). Such holistic approaches can provide support for decision-making by making use of these existing agricultural knowledge bases. Farmers innovate and experiment, their accumulated knowledge and expertise can provide valuable information about the practical implications and potential efficacy of agroecology interventions at the farm (Sachet et al. 2021) and landscape level.

Participatory methods form an important part of decision analysis as it is applied in agricultural development research (Whitney et al. 2018). Participatory model development is undertaken with the central understanding that the stakeholders—those who will be directly impacted by any decisions in the agricultural systems—are the primary experts for impact pathway development (Shepherd et al. 2021). Farmers are considered the key stakeholders and the primary experts regarding agricultural interventions (Oliver et al. 2012; Whitney et al. 2018).

Decision analysis features the construction of causal models—models that describe the mechanisms through which impact will be delivered—that are co-developed by experts, stakeholders and analysts through facilitated participatory processes (Whitney et al. 2018). Decision analysis models make use of available information in a rigorous statistical framework, involving stakeholders in the modeling process (Ghazoul and McAllister 2003). The models are formalized following well-established and robust modelling approaches (Luedeling et al. 2021). The approaches allow for formal representation of causal models in the form of intervention impact pathways. The resulting models illustrate comparative assessments of the costs, benefits and risks of agroecology interventions and the impact on outcomes of importance such as farmers' livelihoods.

The involvement of different actors in the co-development of decision models helps in addressing system complexity thanks to the integration of different points of view and different (academic and non-academic) knowledge (Whitney et al. 2018). Transdisciplinary approaches in decision model development ensure that farmers and other stakeholders can be included at all stages of model development, together with additional decision-makers (those with the power to decide or the money to invest etc.) (Luu et al. 2022). This enhances the chance that any decision-supporting advice resulting from the modeling procedures will be seen as trustworthy in providing clarity and insight for navigating potential trade-offs in scaling and supporting agroecology.

2. Assessing competing options

Decisions in agroecology happen at the farm level and the landscape level, as well as at the national and international policy levels (Agarwal et al. 2018; Wezel et al. 2020). A shift to agroecological approaches can include trade-offs between various ecosystem services (González-Esquivel et al. 2015) related to intensification vs. extensification (Nemecek et al. 2011; Tilman et al. 2011) and in terms of agricultural productivity related to land-sparing vs. land-sharing (Fischer et al. 2008; Schwarz et al. 2022). Competing decision options may range from the farm to wider policy and regulatory contexts (IAASTD 2009). Each of these levels of decision-making in agroecology would benefit from reliable decision support. When faced with the complexity of agricultural systems and agroecology interventions, decision-makers such as farmers, policy-makers and businesses must weigh the costs against the potential benefits.

Decision modeling is based on cost–benefit analysis for assessing competing options. This includes both multicriteria evaluation and multiscale assessments. Modeling approaches can allow for the simultaneous consideration of multiple possible impact pathways. They also allow for the integration of different types of information from many sources, reflecting scientific judgement as well as existing empirical data (Ghazoul and McAllister 2003) and expert knowledge (Do et al. 2020). Decision analysis models take into account the key uncertainties involved in decisions (Shepherd et al. 2021) and explicitly convey uncertainties in the potential decision outcomes (Ghazoul and McAllister 2003; Shepherd et al. 2021). The approaches can build on existing knowledge and be well suited to adaptive management and decision-making under uncertainty (Ghazoul and McAllister 2003). In this way researchers and analysts work effectively with incomplete information, combine expert knowledge with other sources of information and can adequately consider risks and uncertainties. Such modeling approaches can be a useful way to work in application-oriented fields such as agroecology, where system dynamics are complex.

Agroecology interventions are often applied to maintain or improve sustainability, yet they also have associated costs, risks and uncertainties. Analysis of these should be conducted for any implementation of agroecological solutions (Amissah and Aflakpui 2020). These costs, benefits and risks depend very much on local systems and contexts, which must be thoroughly considered in order to support decision-making (see Seufert and Ramankutty 2017, who studied similar challenges in organic agriculture). Any assessments of farm productivity should include the many valuable outputs and outcomes, including agricultural products as well as provisioning, supporting and cultural ecosystem services (Amissah and Aflakpui 2020), and consider economic, ecological and social outcome dimensions.

All the possible trade-offs regarding agroecology interventions should be considered, at the farm and at the landscape level. The wider implications of agroecological interventions for nature can, for example, be positive at the farm level (land sharing with low-yielding, wildlife-friendly agriculture) but have negative impacts on a landscape level. Land-sparing strategies such as high-yielding agriculture, on the other hand, may increase the area of natural and semi-natural areas and improve environmental outcomes (Finch et al. 2021). Land sparing and sharing may both be needed to balance management needs for the multifunctionality of agricultural landscapes (Grass et al. 2019), including agroecology (Kremen 2015). Determining the best option for overall ecological impact should not be restricted to the small scale (Lin and Fuller 2013), but instead be considered at the landscape level.

3. Incorporating uncertainty

Agricultural research can provide evidence to help understand the impacts of agroecology practices, but it is not always clear how evidence should be used to support decisions. The current frameworks that attempt to convey information about agroecology from science to decision-makers have had limited success (Dalgaard et al. 2003). However, complex agriculture and agri-food systems are characterized by emergent properties and uncertainty that requires a broad perspective, beyond the analysis of particular interactions and factors (Foran et al. 2014; Leeuwis et al. 2021). One of the major issues is that agroecological research is generally at small spatial scales whereas related decisions around implementation are at larger national and geopolitical scales (Dalgaard et al. 2003; Tittonell et al. 2020; Barrios et al. 2020). There are cases where the application of agroecology practices can have a positive effect, but the mechanisms by which this impact can be achieved are difficult to assess beforehand. This is largely due to uncertainty about the outcomes that agroecology can generate (similar to organic agriculture; Seufert and Ramankutty 2017). The potential risks of agroecology interventions could be related to a variety of processes, from management challenges to market access. In the case that an intervention leads to reduced yields, for example, it can cause cascading impacts on society and on land use.

Decision analysis techniques include stochastic modeling approaches that can be useful in socially and ecologically complex environments like agroecology. They have strong potential to improve development decisions (Hubbard 2014; Howard and Abbas 2015). Stochastic models offer an intuitive way of communicating decision problems in terms of probability, which can be easily understood by non-scientists (Ghazoul and McAllister 2003). They work by condensing the decision problem into an impact pathway and performing a cost–benefit analysis of the difference between the baseline ("do nothing") and any interventions. This assessment can be customized for interventions at the farm, landscape or regional level.

There is strong potential for improving the communication of uncertainty in the outputs of decision models at the landscape level. Landscape level decisions can, for example, be informed through a mix of expert knowledge and remote sensing data to map current land use and the potential effects of farm practices changes. They have been applied for land use management forecasting for flood-based farming systems (Liman Harou et al. 2020) and in finding suitable areas for aquifer storage and recharge (Owusu et al. 2017). Spatial decision analysis has been applied to generate future agricultural land use maps in Denmark (Vogdrup-Schmidt et al. 2019), to assess regional differences in subsidy effects on women's diets in Mali (Assima et al. 2022), for generating suitability maps for medicinal species in New Zealand (Moore et al. 2016) and for managing agroecological viticulture in France (Aouadi et al. 2021). Communicating expected decision outcomes in a geographical format could have powerful implications for addressing the issue of lack of scientific support for scaling-up agroecology.

4. Choosing effective pathways

Holistic decision modeling approaches can make use of existing knowledge and project outcomes to help in choosing between decision options in agricultural development (Luedeling and Shepherd 2016). Some promising developments in decision analysis for agricultural development include efforts to merge decision analysis and evidence synthesis methods, e.g. for selecting suitable agricultural management practices based on consideration of their ability to provide ecosystem services (Shackelford et al. 2019). Decision modeling with cost-effectiveness frameworks uses similar evidence-base assessments and makes use of rigorous quantitative methods for comparisons between public health interventions (Dias et al. 2013), proving useful in identifying interventions that are both effective and cost-efficient (Welton 2012). Similar approaches could be applied for assessing agroecology interventions.

Decision analysis methods can help in the assessment of short- and long-term impacts of agroecology, as they have been applied for assessing agricultural sustainability (Talukder et al. 2017). In this regard decision analytical approaches in agriculture have a lot to learn from the diverse applications of decision analysis in nature conservation (Esmail and Geneletti 2018). These include many types of participatory approaches that aim at eliciting the values, preferences and knowledge of stakeholders (Esmail and Geneletti 2018; Hemming et al. 2022). They also often include a spatial component, for example in generating protection zones to reduce collision risks with manatees (Udell et al. 2019). Given the many overlaps between agroecology and conservation, there may be other useful synergies, such as formulations of key decision-support frameworks and tools for assessing the application of decision analysis (Hemming et al. 2022).

5. Scaling and supporting

Decision analysis can be used for scaling and supporting agroecology interventions (Shepherd et al. 2021; Luu et al. 2022). It has been applied at national scales to support agro-climate services for agricultural planning and management (Luu et al. 2022) and to model nutrition-related outcomes of agricultural development plans (Whitney et al. 2017). It has also been applied for performance evaluation of land restoration initiatives

(Shepherd et al. 2021) and for prioritizing farm management interventions to meet international certification standards (Netter et al. 2022; Fernandez et al. 2022).

Decision analysis can also be used to adaptively manage the scaling of agroecology by incorporating new information as it arises (e.g., from monitoring outcomes and collecting new data) with implementation research. Implementation research is a collection of scientific inter- and transdisciplinary approaches for assessing the process by which research outputs can be put into practice (Denich and Whitney 2021). Combining decision analysis and implementation research could help identify barriers to the implementation of research-based agroecology innovations and support the development of solutions. Such approaches could also be applied for monitoring agroecology impacts as interventions are rolled out. When new information is acquired, uncertainty about either the conditions for the changes or about their outcomes can be reduced. This can improve the process of understanding the implications of agroecology and help with the uptake and scaling of any meaningful interventions.

Conclusions

Decision sciences can provide practical decision support in the face of system complexity, uncertainty, risks and unclear benefits of agroecology interventions. Decision analysis approaches can allow scientists and managers to explicitly address decision-making and systematically compare the outcomes, utilities, and uncertainty associated with decision options. This approach can aid decision-makers in evaluating the potential effects of various management or policy actions related to agroecology. The approach provides transparent and useful information about the types of trade-offs and the level of risk associated with any resulting decisions. Results from the modeling procedures can help support decisions according to intended outcomes, with risks and uncertainty explicitly included, and help decision-makers identify where agroecology interventions make sense for achieving desired outcomes. Given the extent of human impacts on agroecosystems and the uncertainty that decision-makers face when choosing among alternatives, this approach shows promise for decision-making in complex agroecological systems. Relevant international and national government processes and funding mechanisms, as well as the private sector, should make use of decision analytical methods for determining if and when agroecology interventions are appropriate, and for supporting and scaling them when they are.

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Author contributions
CW analyzed and interpreted the literature and wrote the manuscript, LBF and EL reviewed, updated and made major contributions in writing the manuscript. All authors read and approved the final manuscript.

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References

Agarwal B, Anderson M, Belay M, et al. Breaking away from industrial food and farming systems: Seven case studies of agroecological transition. IPES-Food 110. 2018.

Amissah L, Aflakpui GKS, et al. Achieving Food and Nutrition Security: The Role of Agroecology. In: Leal Filho W, Azul AM, Brandli L, et al., editors. Zero Hunger. Cham: Springer International Publishing; 2020. p. 8–17.

Anderson CR, Pimbert MP, Chappell MJ, et al. Agroecology now—connecting the dots to enable agroecology transformations. Agroecol Sustain Food Syst. 2020;44:561–5. https://doi.org/10.1080/21683565.2019.1709320.

Aouadi N, Macary F, Delière L, Roby J-P. New scenarios for a shift towards agroecology in viticulture. Agric Sci. 2021;12:1003–33. https://doi.org/10.4236/as.2021.1210065.

Assima A, Zanello G, Smale M. Articulating fertilizer subsidy effects on women's diet quality by food supply source in Mali. CABI Agric Biosci. 2022;3:42. https://doi.org/10.1186/s43170-022-00085-8.

Barrios E, Gemmill-Herren B, Bicksler A, et al. The 10 Elements of Agroecology: enabling transitions towards sustainable agriculture and food systems through visual narratives. Ecosyst People. 2020;16:230–47. https://doi.org/10.1080/26395916.2020.1808705.

Bhandari G. an overview of agrochemicals and their effects on environment in Nepal. Appl Ecol Environ Sci. 2014;2:66–73. https://doi.org/10.12691/aees-2-2-5.

Biber-Freudenberger L, Denich M, Whitney C, et al. More inter- and transdisciplinary research needed in agroecology. Rural. 2018;21(52):31–3.

Dale B. Alliances for agroecology: from climate change to food system change. Agroecol Sustain Food Syst. 2020;44:629–52. https://doi.org/10.1080/21683565.2019.1697787.

Dalgaard T, Hutchings NJ, Porter JR. Agroecology, scaling and interdisciplinarity. Agric Ecosyst Environ. 2003;100:39–51. https://doi.org/10.1016/S0167-8809(03)00152-X.

De Schutter O. Report submitted by the Special Rapporteur on the right to food. 2010.

Dee L, Gerber L. Applications of decision theory to conservation planning and management. Nat Educ Knowl. 2012;3:11.
Denich M, Whitney C. Closing the adoption gap. Rural. 2021;21(1):34–5.
Dias S, Welton NJ, Sutton AJ, Ades AE. Evidence synthesis for decision making 1. Med Decis Making. 2013;33:597–606. https://doi.org/10.1177/0272989X13487604.
Do H, Luedeling E, Whitney C. Decision analysis of agroforestry options reveals adoption risks for resource-poor farmers. Agron Sustain Dev. 2020;40:20. https://doi.org/10.1007/s13593-020-00624-5.
Esmail BA, Geneletti D. Multi-criteria decision analysis for nature conservation: a review of 20 years of applications. Methods Ecol Evol. 2018;9:42–53. https://doi.org/10.1111/2041-210X.12899.
FAO. Agroecology for food security and nutrition: proceedings of the FAO International Symposium : 18–19 September 2014, Rome, Italy. Food and agriculure organisation, Rome. 2014.
FAO. Committee on agriculture. 26th session: agroecology: from advocacy to action. Rome: Food and Agriculture Organization of the United Nations; 2018.
FAO. The state of food and agriculture 2021. Rome: FAO; 2021.
Fernandez E, Do H, Luedeling E, et al. Prioritizing farm management interventions to improve climate change adaptation and mitigation outcomes—a case study for banana plantations. Agron Sustain Dev. 2022;42:76. https://doi.org/10.1007/s13593-022-00809-0.
Finch T, Day BH, Massimino D, et al. Evaluating spatially explicit sharing-sparing scenarios for multiple environmental outcomes. J Appl Ecol. 2021;58:655–66. https://doi.org/10.1111/1365-2664.13785.
Fischer J, Brosi B, Daily GC, et al. Should agricultural policies encourage land sparing or wildlife-friendly farming? Front Ecol Environ. 2008;6:380–5. https://doi.org/10.1890/070019.
Foran T, Butler JRA, Williams LJ, et al. Taking complexity in food systems seriously: an interdisciplinary analysis. World Dev. 2014;61:85–101. https://doi.org/10.1016/j.worlddev.2014.03.023.
Ghazoul J, McAllister M. Communicating complexity and uncertainty in decision making contexts: Bayesian approaches to forest research. Int for Rev. 2003;5:9–19. https://doi.org/10.1505/IFOR.5.1.9.17433.
Gliessman S. Defining agroecology agroecol sustain. Food Syst. 2018;42:599–600. https://doi.org/10.1080/21683565.2018.1432329.
González-Esquivel C, Gavito M, Astier M, et al. Ecosystem service trade-offs, perceived drivers, and sustainability in contrasting agroecosystems in central Mexico. Ecol Soc. 2015. https://doi.org/10.5751/ES-06875-200138.
Grass I, Loos J, Baensch S, et al. Land-sharing/-sparing connectivity landscapes for ecosystem services and biodiversity conservation. People Nat. 2019;1:262–72. https://doi.org/10.1002/pan3.21.
Hemming V, Camaclang AE, Adams MS, et al. An introduction to decision science for conservation. Conserv Biol. 2022;36:e13868. https://doi.org/10.1111/cobi.13868.
Howard RA, Abbas AE. Foundations of decision analysis. NY: Prentice Hall; 2015.
Hubbard DW. How to measure anything: finding the value of intangibles in business. 2nd ed. Hoboken, New Jersey: John Wiley & Sons; 2014.
IAASTD. Global report. Washington, DC: Island Press; 2009.
IPES-Food. From uniformity to diversity: a paradigm shift from industrial agriculture to diversifed agroecological systems. International Panel of Experts on Sustainable Food systems. IPES-Food. 2016.
Jeffrey RC. The logic of decision. Chicago, IL: University of Chicago Press; 1990.
Keeney RL. Making better decision makers. Decis Anal. 2004;1:193–204. https://doi.org/10.1287/deca.1040.0009.
Kremen C. Reframing the land-sparing/land-sharing debate for biodiversity conservation. Ann NY Acad Sci. 2015;1355:52–76. https://doi.org/10.1111/nyas.12845.
Lanzanova D, Whitney C, Shepherd K, Luedeling E. Improving development efficiency through decision analysis: reservoir protection in Burkina Faso. Environ Model Softw. 2019;115:164–75. https://doi.org/10.1016/j.envsoft.2019.01.016.
Leeuwis C, Boogaard BK, Atta-Krah K. How food systems change (or not): governance implications for system transformation processes. Food Secur. 2021;13:761–80. https://doi.org/10.1007/s12571-021-01178-4.
Liman HI, Whitney C, Kung'u J, Luedeling E. Mapping flood-based farming systems with bayesian networks. Land. 2020;9:369. https://doi.org/10.3390/land9100369.
Lin BB, Fuller RA. FORUM: Sharing or sparing? How should we grow the world's cities? J Appl Ecol. 2013;50:1161–8. https://doi.org/10.1111/1365-2664.12118.
Luedeling E, Shepherd K. Decision-focused agricultural research. Solutions. 2016;7:46–54.
Luedeling E, Goehring L, Schiffers K, et al. decisionSupport—Quantitative support of decision making under uncertainty. Contributed package to the R programming language. Version 1.106. 2021.
Luu TTG, Whitney C, Biber-Freudenberger L, Luedeling E. Decision analysis of agro-climate service scaling—a case study in Dien Bien district. Vietnam Clim Serv. 2022;27:100313. https://doi.org/10.1016/j.cliser.2022.100313.
Mbinda W, Kavoo A, Maina F, et al. Farmers' knowledge and perception of finger millet blast disease and its control practices in western Kenya. CABI Agric Biosci. 2021;2:13. https://doi.org/10.1186/s43170-021-00033-y.
Méndez VE, Bacon CM, Cohen R, Gliessman SR. Agroecology: a transdisciplinary, participatory and action-oriented approach. 1st ed. Boca Raton: CRC Press; 2020.
Moore A, Johnson M, Lord J, et al. Applying spatial analysis to the agroecology-led management of an indigenous farm in New Zealand. Ecol Inform. 2016;31:49–58. https://doi.org/10.1016/j.ecoinf.2015.11.009.
Nemecek T, Huguenin-Elie O, Dubois D, et al. Life cycle assessment of Swiss farming systems: II extensive and intensive production. Agric Syst. 2011;104:233–45. https://doi.org/10.1016/j.agsy.2010.07.007.
Netter L, Luedeling E, Whitney C. Agroforestry and reforestation with the gold standard-decision analysis of a voluntary carbon offset label. Mitig Adapt Strateg Glob Change. 2022;27:17. https://doi.org/10.1007/s11027-021-09992-z.
Oliver DM, Fish RD, Winter M, et al. Valuing local knowledge as a source of expert data: farmer engagement and the design of decision support systems. Environ Model Softw. 2012;36:76–85. https://doi.org/10.1016/j.envsoft.2011.09.013.
Ortiz AMD, Outhwaite CL, Dalin C, Newbold T. A review of the interactions between biodiversity, agriculture, climate change, and international trade: research and policy priorities. One Earth. 2021;4:88–101. https://doi.org/10.1016/j.oneear.2020.12.008.
Owusu S, Mul ML, Ghansah B, et al. Assessing land suitability for aquifer storage and recharge in northern Ghana using remote sensing and GIS multi-criteria decision analysis technique. Model Earth Syst Environ. 2017;3:1383–93. https://doi.org/10.1007/s40808-017-0360-6.
Perera AH, Drew CA, Johnson CJ. Expert knowledge and its application in landscape ecology. Berlin: Springer Science & Business Media; 2011.
Pörtner H-O, Roberts DC, Tignor MMB, et al. Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. 2022.
Raven PH, Wagner DL. Agricultural intensification and climate change are rapidly decreasing insect biodiversity. Proc Natl Acad Sci. 2021;118:e2002548117. https://doi.org/10.1073/pnas.2002548117.
Sachet E, Mertz O, Le Coq J-F, et al. Agroecological transitions: a systematic review of research approaches and prospects for participatory action methods. Front Sustain Food Syst. 2021;5:709401.
Schwarz G, Vanni F, Miller D, et al. Exploring sustainability implications of transitions to agroecology: a transdisciplinary perspective. EuroChoices. 2022;21:37–47. https://doi.org/10.1111/1746-692X.12377.
Seufert V, Ramankutty N. Many shades of gray—the context-dependent performance of organic agriculture. Sci Adv. 2017;3:e1602638. https://doi.org/10.1126/sciadv.1602638.
Shackelford GE, Kelsey R, Sutherland WJ, et al. Evidence synthesis as the basis for decision analysis: a method of selecting the best agricultural practices for multiple ecosystem services. Front Sustain Food Syst. 2019;3:83.
Shepherd K, Hubbard D, Fenton N, et al. Policy: development goals should enable decision-making. Nature. 2015;523:152–4.
Shepherd KD, Whitney CW, Luedeling E. A decision analysis framework for development planning and performance measurement. Nairobi: World Agroforestry; 2021.
Silici L. What it is and what it has to offer, IIED Issue Paper. IIED. 2014.
Talukder B, Blay-Palmer A, Hipel KW, VanLoon GW. Elimination method of multi-criteria decision analysis (MCDA): a simple methodological approach for assessing agricultural sustainability. Sustainability. 2017;9:287. https://doi.org/10.3390/su9020287.

Tilman D, Balzer C, Hill J, Befort BL. Global food demand and the sustainable intensification of agriculture. Proc Natl Acad Sci. 2011;108:20260–4. https://doi.org/10.1073/pnas.1116437108.
Tittonell P, Piñeiro G, Garibaldi LA, et al. Agroecology in large scale farming—a research agenda. Front Sustain Food Syst. 2020. https://doi.org/10.3389/fsufs.2020.584605.
Tomich TP, Brodt S, Ferris H, et al. Agroecology: a review from a global-change perspective. Annu Rev Environ Resour. 2011;36:193–222. https://doi.org/10.1146/annurev-environ-012110-121302.
Udell BJ, Martin J, Fletcher RJ Jr, et al. Integrating encounter theory with decision analysis to evaluate collision risk and determine optimal protection zones for wildlife. J Appl Ecol. 2019;56:1050–62. https://doi.org/10.1111/1365-2664.13290.
Vogdrup-Schmidt M, Olsen SB, Dubgaard A, et al. Using spatial multi-criteria decision analysis to develop new and sustainable directions for the future use of agricultural land in Denmark. Ecol Indic. 2019;103:34–42. https://doi.org/10.1016/j.ecolind.2019.03.056.
Welton NJ. Evidence synthesis for decision making in healthcare. Chichester, West Sussex: Wiley; 2012.
Wezel A, Bellon S, Doré T, et al. Agroecology as a science, a movement and a practice. Rev Agron Sustain Dev. 2009;29:503–15. https://doi.org/10.1051/agro/2009004.
Wezel A, Soboksa G, McClelland S, et al. The blurred boundaries of ecological, sustainable, and agroecological intensification: a review. Agron Sustain Dev. 2015;35:1283–95. https://doi.org/10.1007/s13593-015-0333-y.
Wezel A, Herren BG, Kerr RB, et al. Agroecological principles and elements and their implications for transitioning to sustainable food systems. Rev Agron Sustain Dev. 2020;40:40. https://doi.org/10.1007/s13593-020-00646-z.
Whitney C. Decision analysis and agroecology. searchRxiv. 2023;2023:20230007453. https://doi.org/10.1079/searchRxiv.2023.00095.
Whitney C, Tabuti JRS, Hensel O, et al. Homegardens and the future of food and nutrition security in southwest Uganda. Agric Syst. 2017;154:133–44. https://doi.org/10.1016/j.agsy.2017.03.009.
Whitney C, Shepherd K, Luedeling E. Decision analysis methods guide; agricultural policy for nutrition. Nairobi: World Agroforestry Centre; 2018.

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