INTERACTIVE LEARNING MODULES

Synergies and tradeoffs
in food, land and water systems

Interested to dive deeper in the matter? Here we listed suggestions for further reading.

Reference short	*Reference complete*	*Aims/main points*
Module 1: Introduction to trade-offs and synergies in Multifunctional Agriculture & Food Systems		
Campbell et al., 2018	Campbell, B.M., James, H., Janie, R., Clare M, S., Stephen, T., Eva, (Lini) Wollenberg, 2018. Urgent action to combat climate change and its impacts (SDG 13): transforming agriculture and food systems. Curr. Opin. Environ. Sustain. 34, 13–20. https://doi.org/10.1016/j.cosust.2018.06.005	Transformative actions in the food system are crucial (to achieve SDGs etc) but actions need to be carefully considered given the possibility of trade-offs between adaptation and mitigation and other (SD)goals. Focus on actions on climate change (SDG 13).
Kanter et al., 2018	Kanter, D.R., Musumba, M., Wood, S.L.R., Palm, C., Antle, J., Balvanera, P., Dale, V.H., Havlik, P., Kline, K.L., Scholes, R.J., Thornton, P., Tittonell, P., Andelman, S., 2018. Evaluating agricultural trade-offs in the age of sustainable development. Agric. Syst. 163, 73–88. https://doi.org/10.1016/j.agsy.2016.09.010	This paper re- views the field of agricultural trade-off analysis, which has emerged to better understand interactions between agronomic, environmental and socio- economic outcomes from agricultural systems–from field to farm, region to continent.
Struik et al., 2014	Struik, P.C., Kuyper, T.W., Brussaard, L., Leeuwis, C., 2014. Deconstructing and unpacking scientific controversies in intensification and sustainability: Why the tensions in concepts and values? Curr. Opin. Environ. Sustain. 8, 80–88. https://doi.org/10.1016/j.cosust.2014.10.002	The multidimensional nature of intensification needs to be linked to the various notions of sustainability, acknowledging a hierarchy of considerations underlying decision-making on trade-offs, thus allowing political and moral arguments to play a proper role in the strategy towards sustainable intensification
Module 2: Introduction to scales and levels of assessment		
Kanter et al., 2018	Kanter, D.R., Musumba, M., Wood, S.L.R., Palm, C., Antle, J., Balvanera, P., Dale, V.H., Havlik, P., Kline, K.L., Scholes, R.J., Thornton, P., Tittonell, P., Andelman, S., 2018. Evaluating agricultural trade-offs in the age of sustainable development. Agric. Syst. 163, 73–88. https://doi.org/10.1016/j.agsy.2016.09.010	This paper re- views the field of agricultural trade-off analysis, which has emerged to better understand interactions between agronomic, environmental and socio- economic outcomes from agricultural systems–from field to farm, region to continent.
Caron et al., 2018	Caron, P., Ferrero y de Loma-Osorio, G., Nabarro, D., Hainzelin, E., Guillou, M., Andersen, I., Arnold, T., Astralaga, M., Beukeboom, M., Bickersteth, S., Bwalya, M., Caballero, P., Campbell, B.M., Divine, N., Fan, S., Frick, M., Friis, A., Gallagher, M., Halkin, J.P., Hanson, C., Lasbennes, F., Ribera, T., Rockstrom, J., Schuepbach, M., Steer, A., Tutwiler, A., Verburg, G., 2018. Food systems for sustainable development: proposals for a profound four-part transformation. Agron. Sustain. Dev. 38. https://doi.org/10.1007/s13593-018-0519-1	The narrative highlights the needed consistency between global actions for sustainable development and numerous local-level innovations. It emphasizes the challenge ofdesigning differentiated paths for food systems transformation responding to local and national expectations. Scientific and operational challenges are associated with the alignment and arbitration oflocal action within the context of global priorities
Iwanaga et al., 2021	Iwanaga, T., Wang, H., Koralewski, T.E., Grant, W.E., Jakeman, A.J., Little, J.C., 2021. Toward a complete interdisciplinary treatment of scale : Reflexive lessons from socioenvironmental systems modeling 1–28.	The practices, decisions, and workflow that influence the consideration of scale in socioenvironmental systems modeling are explored. They draw out several lessons under the following themes: (1) the fostering of collaborative learning and reflection, (2) documenting and justifying the rationale for modeling scale choices, some of which can be equally plausible (a perfect model is not possible), (3) acknowledging that causality is defined subjectively, (4) embracing change and reflection throughout the iterative modeling cycle, and (5) regularly testing the model integration to draw out issues that would otherwise be unnoticeable.
Iwanaga et al., 2021	Iwanaga, T., Wang, H.H., Hamilton, S.H., Grimm, V., Koralewski, T.E., Salado, A., Elsawah, S., Razavi, S., Yang, J., Glynn, P., Badham, J., Voinov, A., Chen, M., Grant, W.E., Peterson, T.R., Frank, K., Shenk, G., Barton, C.M., Jakeman, A.J., Little, J.C., 2021. Socio-technical scales in socio-environmental modeling: Managing a system-of-systems modeling approach. Environ. Model. Softw. 135, 104885. https://doi.org/10.1016/j.envsoft.2020.104885	This paper describes socio-technical practices and challenges that arise in the consideration of scale throughout the socio- environmental modeling process. The authors identify key paths forward, focused on explicit consideration of scale and uncertainty, strengthening interdisciplinary communication, and improvement of the documentation process.
Wittman et al., 2017	Wittman, H., Chappell, M.J., Abson, D.J., Kerr, R.B., Blesh, J., Hanspach, J., Perfecto, I., Fischer, J., 2017. A social–ecological perspective on harmonizing food security and biodiversity conservation. Reg. Environ. Chang. 17, 1291–1301. https://doi.org/10.1007/s10113-016-1045-9	Conceptualizes rural landscapes as social–ecological systems embedded within intersecting multi-scalar processes. Aims to set empirical research in the context of system properties that may influence food security, biodiversity conservation, or both.
Cumming et al., 2006	Cumming, G.S., Cumming, D.H.M., Redman, C.L., 2006. Scale mismatches in social-ecological systems: Causes, consequences, and solutions. Ecol. Soc. 11. https://doi.org/10.5751/ES-01569-110114	Mismatches between the scales of ecological processes and the institutions that are responsible for managing them can contribute to a decrease in social-ecological resilience, including the mismanagement of natural resources and a decrease in human well-being. Solutions to scale mismatches usually require institutional changes at more than one hierarchical level.
Module 3: Examples of Relevant Synergies, Trade-offs & Competing Objectives		
Power et al., 2010	Power, A.G., 2010. Ecosystem services and agriculture: Tradeoffs and synergies. Philos. Trans. R. Soc. B Biol. Sci. 365, 2959–2971. https://doi.org/10.1098/rstb.2010.0143	The tradeoffs that may occur between provisioning services and other ecosystem services and disservices should be evaluated in terms of spatial scale, temporal scale and reversibility. Maximizing provisioning services from agroecosystems can result in tradeoffs with other ecosystem services, but thoughtful management can substantially reduce or even eliminate these tradeoffs. As more effective methods for valuing ecosystem services become available, the potential for 'win–win' scenarios increases.
Baudron et al., 2014	Baudron, F., Giller, K.E., 2014. Agriculture and nature: Trouble and strife? Biol. Conserv. 170, 232–245. https://doi.org/10.1016/j.biocon.2013.12.009	Two models have been proposed to increase agricultural production whilst minimising the negative consequences for biodiversity: 'land spar- ing' and 'land sharing'. Although often polarized in debates, both are realistic solutions, depending on the local circumstances. We propose a number ofcriteria that could guide the choice towards one or the other.
Mockshell et al., 2018	Mockshell, J., Kamanda, J., 2018. Beyond the agroecological and sustainable agricultural intensification debate: Is blended sustainability the way forward? Int. J. Agric. Sustain. 16, 127–149. https://doi.org/10.1080/14735903.2018.1448047	This study employs a theoretical framework based on the economic, social, and ecological dimensions of sustainable agriculture within a policy and institutional space. Based on the sustainability dimensions, a discourse analytical technique is applied to unravel the debate.
Billen et al., 2015	Billen, G., Lassaletta, L., Garnier, J., 2015. A vast range of opportunities for feeding the world in 2050: Trade-off between diet, N contamination and international trade. Environ. Res. Lett. 10. https://doi.org/10.1088/1748-9326/10/2/025001	The results show that feeding the projected 2050 world population would generallyimplyhigher levels ofinter-regional trade and ofenvironmental nitrogen contamination than the current levels, but that the sce- narios with less recourse to inter-regional trade generallyproduce lessNlosses to the environment.
Module 4: Tools for Assessing and Anticipating Synergies & Trade-offs		
Groot et al., 2009	Groot, J. C. J., Rossing, W. A. H., Tichit, M., Turpin, N., Jellema, A., Baudry, J., … van de Ven, G. W. J. (2009). On the contribution of modelling to multifunctional agriculture: Learning from comparisons. Journal of Environmental Management, 90(SUPPL. 2), 147–160.	In this paper a set of criteria is proposed for the evaluation of the potential contribution of modelling tools to strengthening the multifunctionality of agriculture. The four main areas of evaluation are (1) policy relevance, (2) the temporal resolution and scope, (3) the degree to which spatial and socio- institutional scales and heterogeneity are addressed and (4) the level of integration in the assessment of scientific dimensions and of
Jager et al., 2007	Jager, W., Mosler, H.J., 2007. Simulating human behavior for understanding and managing environmental resource use. J. Soc. Issues 63, 97–116. https://doi.org/10.1111/j.1540-4560.2007.00498	Behavioral determinants and processes as identified in social-scientific theory may be formalized in simulated agents to obtain a better understanding ofman–environment interactions and ofpolicy measures aimed at managing these interactions. A number of exemplary agent-based simulation studies is discussed to demonstrate how simulations can be used to identify behavioral determinants and processes underlying environmental problems, and to explore the possible effects of policy strategies.
Van Wijk et al., 2016	van Wijk, M.T., Klapwijk, C.J., Rosenstock, T.S., Van Asten, P.J.A., Thornton, P.K., Giller, K.E., 2016. Methods for Measuring Greenhouse Gas Balances and Evaluating Mitigation Options in Smallholder Agriculture, in: Methods for Measuring Greenhouse Gas Balances and Evaluating Mitigation Options in Smallholder Agriculture. pp. 1–203. https://doi.org/10.1007/978-3-319-29794-1	This paper reviews the strengths and weakness of different techniques available for performing trade-off analysis. The strengths and weaknesses of the different approaches are identified and discussed, and suggestions for a tiered approach for situations with different data availability are made.
Module 5: Using Assessment Results		
Iwanaga et al., 2021	Iwanaga, T., Wang, H., Koralewski, T.E., Grant, W.E., Jakeman, A.J., Little, J.C., 2021. Toward a complete interdisciplinary treatment of scale : Reflexive lessons from socioenvironmental systems modeling 1–28.	The practices, decisions, and workflow that influence the consideration of scale in socioenvironmental systems modeling are explored. They draw out several lessons under the following themes: (1) the fostering of collaborative learning and reflection, (2) documenting and justifying the rationale for modeling scale choices, some of which can be equally plausible (a perfect model is not possible), (3) acknowledging that causality is defined subjectively, (4) embracing change and reflection throughout the iterative modeling cycle, and (5) regularly testing the model integration to draw out issues that would otherwise be unnoticeable.

DeClerck et al., 2016	DeClerck, F.A.J., Jones, S.K., Attwood, S., Bossio, D., Girvetz, E., Chaplin-Kramer, B., Enfors, E., Fremier, A.K., Gordon, L.J., Kizito, F., Lopez Noriega, I., Matthews, N., McCartney, M., Meacham, M., Noble, A., Quintero, M., Remans, R., Soppe, R., Willemen, L., Wood, S.L.R., Zhang, W., 2016. Agricultural ecosystems and their services: the vanguard of sustainability? Curr. Opin. Environ. Sustain. 23, 92–99. https://doi.org/10.1016/j.cosust.2016.11.016	This paper proposes a framework to operationalize ecosystem services and resilience-based interventions in agricultural landscapes and call for renewed efforts to apply resilience- based approaches to landscape management challenges and for refocusing ecosystem service research on human well- being outcomes.
Module 6: Long-term Sustainability Issues		
Scheffer et al., 2000	Scheffer, M., Brock, W., Westley, F., 2000. Socioeconomic mechanisms preventing optimum use of ecosystem services: An interdisciplinary theoretical analysis. Ecosystems 3, 451–471. https://doi.org/10.1007/s100210000040	This paper links theory on ecosystem response to theories from the socioeconomic branches of science to analyze the mechanisms behind two widespread problems associated with such political solutions. The analysis suggests that the following three key ingredients are needed to correct the problems of bias and compromise: (a) clear insight into ecosys- tem dynamic responses to human use, (b) a broad inventory of credible measurements of ecosystem utilities, (c) avoidance of bias due to differences in the organizational power of groups of stakeholders.
Nyström et al., 2019	Nyström, M., Jouffray, J.B., Norström, A. V., Crona, B., Søgaard Jørgensen, P., Carpenter, S.R., Bodin, Galaz, V., Folke, C., 2019. Anatomy and resilience of the global production ecosystem. Nature 575, 98–108. https://doi.org/10.1038/s41586-019-1712-3	This paper shows that the simplification and intensification of these systems and their growing connection to international markets has yielded a global production ecosystem that is homogenous, highly connected and characterized by weakened internal feedbacks. Steering the global production ecosystem towards a sustainable trajectory will require the redirection of finance, increased transparency and traceability in supply chains, and the participation of a multitude of players, including integrated 'keystone actors' such as multinational corporations.
Pahl-Wostl, 2009	Pahl-Wostl, C., 2009. A conceptual framework for analysing adaptive capacity and multi-level learning processes in resource governance regimes. Glob. Environ. Chang. 19, 354–365. https://doi.org/10.1016/j.gloenvcha.2009.06.001	This paper develops a conceptual framework addressing the dynamics and adaptive capacity of resource governance regimes as multi-level learning processes. Change is conceptualized as social and societal learning that proceeds in a stepwise fashion moving from single to double to triple loop learning. Informal networks are considered to play a crucial role in such learning processes. The framework supports flexible and context sensitive analysis without being case study specific.
Mockshell et al., 2018	Mockshell, J., Kamanda, J., 2018. Beyond the agroecological and sustainable agricultural intensification debate: Is blended sustainability the way forward? Int. J. Agric. Sustain. 16, 127–149. https://doi.org/10.1080/14735903.2018.1448047	This study employs a theoretical framework based on the economic, social, and ecological dimensions of sustainable agriculture within a policy and institutional space. Based on the sustainability dimensions, a discourse analytical technique is applied to unravel the debate.
Billen et al., 2015	Billen, G., Lassaletta, L., Garnier, J., 2015. A vast range of opportunities for feeding the world in 2050: Trade-off between diet, N contamination and international trade. Environ. Res. Lett. 10. https://doi.org/10.1088/1748-9326/10/2/025001	The results show that feeding the projected 2050 world population would generallyimplyhigher levels ofinter-regional trade and ofenvironmental nitrogen contamination than the current levels, but that the sce- narios with less recourse to inter-regional trade generallyproduce lessNlosses to the environment.
Recommended websites		
International Science Council	https://council.science/publications/a-guide-to-sdg-interactions-from-science-to-implementation/	The International Science Council examined the interactions between the various Sustainable Development Goals (SDGs) and targets, determining to what extent they reinforce or conflict with each other. It provides a blueprint to help countries implement and achieve the goals.
Food and Agricultural Organization	FAO. 2021. Synergies and trade-offs in climate-smart agriculture – An approach to systematic assessment. Rome. https://doi.org/10.4060/cb5243en	The aim of this report is to develop a systematic characterization of possible synergies and trade-offs in Climate Smart Agriculture (CSA), as well as provide a tool to guide CSA practitioners through the assessment of synergies and trade-offs during the design and planning of CSA strategies or interventions.
Course content on Decision Analysis	http://htmlpreview.github.io/?https://github.com/CWWhitney/Decision_Analysis_Course/blob/main/Index.html	The Decision Analysis and Forecasting for Agricultural Development webpage offers an online learning environment that provides a set of approaches that are aimed at capturing what is known and applying this knowledge to generate forecasts of decision outcomes.