Challenges in Implementing System Thinking in Agricultural Sustainable Intensification: A Methodological note

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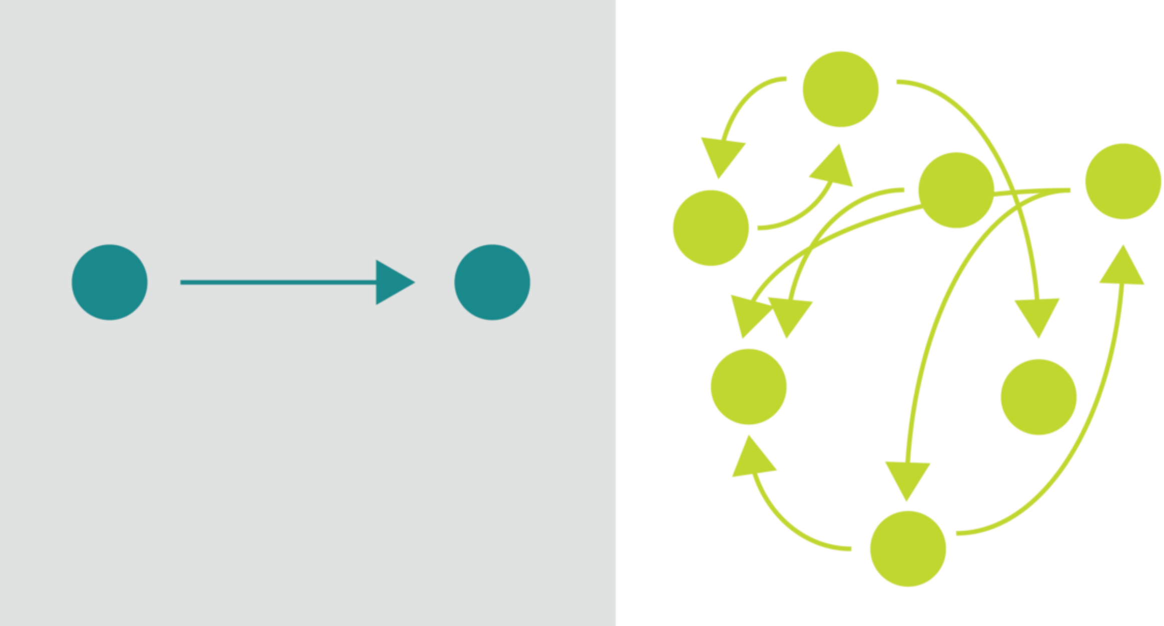

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The Sustainable Intensification of Mixed Farming Systems Initiative aims to provide equitable, transformative pathways for improved livelihoods of actors in mixed farming systems through sustainable intensification within target agroecologies and socio-economic settings.

Through action research and development partnerships, the Initiative will improve smallholder farmers' resilience to weather-induced shocks, provide a more stable income and significant benefits in welfare, and enhance social justice and inclusion for 13 million people by 2030.

Activities will be implemented in six focus countries globally representing diverse mixed farming systems as follows: Ghana (cereal–root crop mixed), Ethiopia (highland mixed), Malawi: (maize mixed), Bangladesh (rice mixed), Nepal (highland mixed), and Lao People's Democratic Republic (upland intensive mixed/ highland extensive mixed).

The Images on the cover picture is taken from
https://www.altus.education/systemsthinking/

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Abbreviations and acronyms

ABC	Alliance of Bioversity International and the International Center for Tropical Agriculture (CIAT)
SDG	Sustainable development Gaols
NDCs	National Determined Contributions
STIBs	Socio-technical innovation bundles
InVEST	Integrated Valuation of Ecosystem Services and Trade-offs model.
FABLE	Food, Agriculture, Biodiversity, Land, and Energy model
APSIM	Agricultural Production Systems sIMulator model
DSSAT	Decision Support System for Agrotechnology Transfer model
WEFE	Water, Energy, Food and Ecosystem nexus model
SI-MFS	Sustainable Intensification of Mixed Farming Systems Initiative
WP	Work Package

Summary

System thinking is relevant to solve complex problems and deliver solutions for sustainable intensification of agricultural systems. Successful implementation of System Thinking in Sustainable Intensification of Agricultural Systems has faced conceptual hurdles that hinder its practical application. This methodological note addressed these challenges by emphasizing on the complexity and difficulty in conceptualizing STIBs and considering the absence of standardized approaches. These issues significantly impact the authentic integration of system thinking into agricultural systems.

Key impediments include the identification of stakeholders and the determination of objective functions for STIBs implementation. Moreover, the spatial scale, spanning from the plot to the national level, poses a crucial consideration, as all issues across these scales contribute to effective system thinking. The temporal scale is equally important, encompassing events and phenomena over both short and extended periods.

While efforts have been made to develop tools and approaches for guiding STIBs implementation within specific components or sectors, there is a notable gap in tools that facilitate a comprehensive system approach. Existing tools designed for this purpose are limited in their implementation and are not widely adopted. Alternatively, a critical approach involves selecting tools across scales and chaining them together to address these challenges.

In this context, we designed an example of how tools at the plot, household (HH), landscape, and national scales can be strategically chained to tackle some of the aforementioned challenges, using Ethiopia as a case study. However, it is important to acknowledge the limitations associated with coupling and utilizing these processes effectively.

By exploring the integration of tools across different scales and systematically chaining them, there is potential to overcome the current challenges in STIBs implementation. This methodological exploration aims to contribute to the development of a more holistic and widely applicable framework for successful system thinking in the context of sustainable agricultural intensification.

1. Introduction

Socio-technical innovation bundles (STIBs) represent a critical imperative for the transformation and enhancement of agricultural systems. The judicious selection and monitoring of technologies within these bundles are essential for evaluating their performance and their contributions to the diverse actors operating within the agricultural domain. Traditional analyses often adopt a siloed or sectoral approach, concentrating on specific targets such as individual farmers, aggregated community levels, or the broader federal systems at the national scale. However, genuine system thinking seeks to optimize STIBs implementation within specific contexts to cater to the broader spectrum of stakeholders and institutions involved.

An additional layer of complexity arises from the spatial variation in STIBs implementation. Agricultural processes unfold across a spectrum, encompassing the plot, farm, landscape, and regional/national scales. At the plot level, STIBs address targets like increased yield, biomass productivity, yield quality, feed productivity and quality, soil moisture, soil fertility, and soil health. Scaling up to the farm level, interventions predominantly affect yield and biomass productivity, feed quality, soil fertility, moisture, and farm biodiversity. Landscape interventions introduce additional layers such as biodiversity, landscape fragmentation, and land use dynamics, alongside productivity, water availability, water yield, and feed quality. The community, at the landscape and watershed scale, concerns itself with land fragmentation, water productivity, livestock capacity, and productivity. Zooming out to the zonal, regional, or federal government levels, the focus shifts to SDG indicators like National Determined Contributions (NDCs) and food security. Consequently, the indicators of interest at the plot level, such as soil fertility and moisture status, may not be the analytical targets at regional and national levels. This shift across scales underscores the scale specificity required for assessing the performance of any STIB.

Similarly, the temporal dimension adds nuance to STIBs implementation. Stakeholders' interests, functions, and processes operate at different time scales. Smallholder farmers, seeking returns on investment within a season or a year, operate on shorter time scales. The impacts of certain interventions, such as biophysical structures across a landscape, may manifest in a single storm event, reducing downstream flooding risks (Fig 1). Conversely, processes like crop and forage production unfold at sub-seasonal or seasonal time scales, while commitments like NDCs, soil fertility, and biodiversity-related functions necessitate extended observation periods. The need for comprehensive insights into system-level dynamics, tradeoffs, and synergies associated with any STIB calls for the integration of diverse tools and models across multiple scales or the strategic chaining of models (Fig 2).

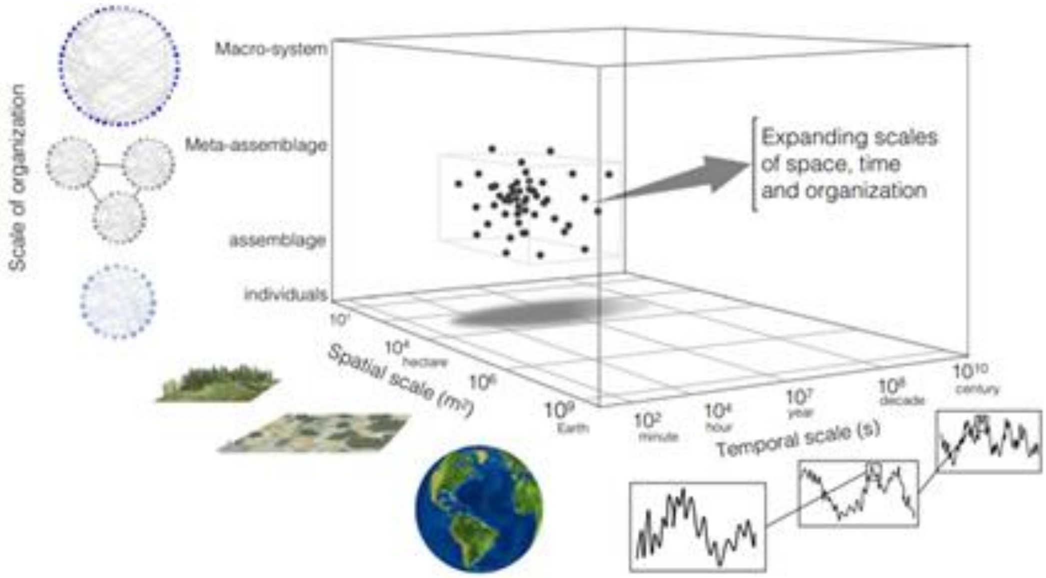


Figure 1. Scales and dimensions of space, time, and organization in process-based research (Gonzalez et al., 2020).

2. Proposed Frameworks (bundles of tools)

Socio-technical innovation bundles (STIBs) represent a critical imperative for the transformation and enhancement of agricultural systems. The judicious selection and monitoring of technologies within these bundles are essential for evaluating their performance and their contributions to the diverse actors operating within the agricultural domain. Traditional analyses often adopt a siloed or sectoral approach, concentrating on specific targets such as individual farmers, aggregated community levels, or the broader federal systems at the national scale. However, genuine system thinking seeks to optimize STIBs implementation within specific contexts to cater to the broader spectrum of stakeholders and institutions involved.

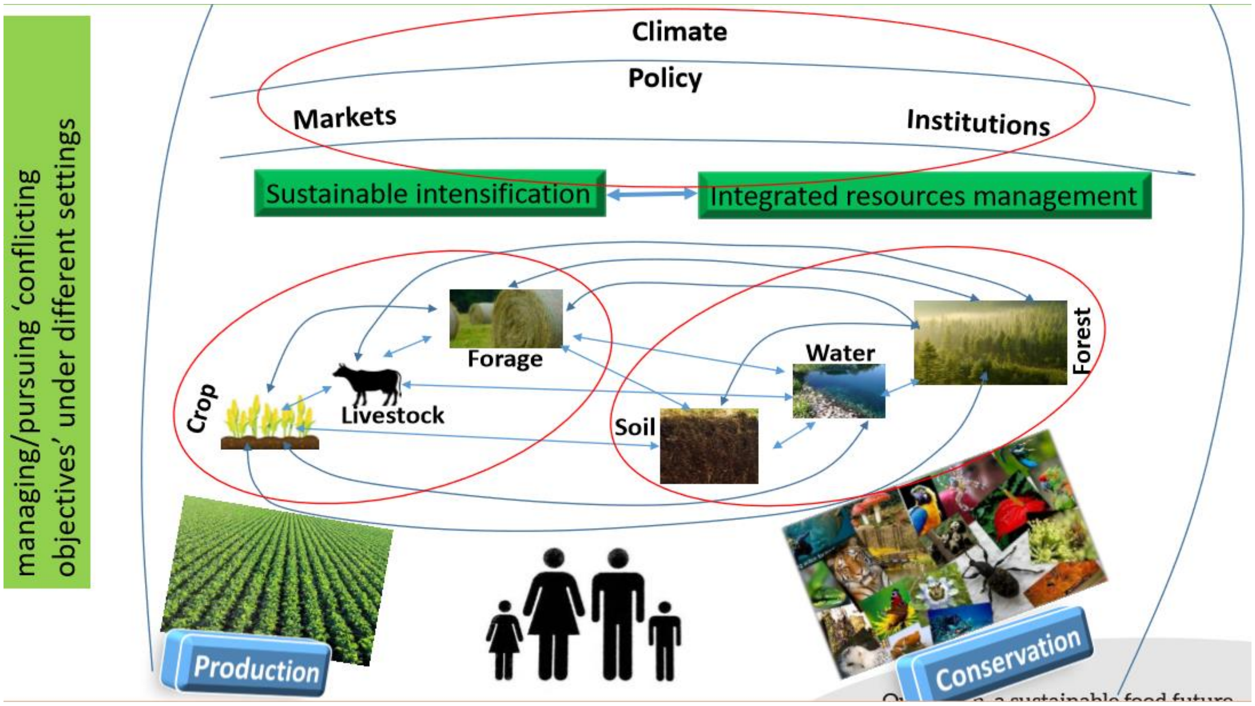


Figure 2. An example for community level system interaction (natural resources, crop system, livestock system, market, institution and climate)

Multiscale modeling emerges as a potent method to predict target variables based on interventions deployed across various scales. The objective of developing multiscale models is to glean insights into the status of target variables at each spatial and temporal scale, emphasizing that the goal is not to devise overly intricate modeling solutions. Consequently, two approaches are conceivable: 1) constructing a singular numerical or conceptual model that spans from the smallest unit (e.g., plot) to the system level (e.g., national or landscape), which requires unified description of the underlying governing equations in multiphysics modelling and 2) interconnecting existing stand-alone and expert-specific models by linking them at the input and output levels. The former offers advantages such as seamless integration across scales and precise discretization of space and time throughout all functional levels. Despite attempts to build comprehensive models encapsulating various facets of system thinking, their adoption remains limited due to the requisite investment in new model development and their inherent operational complexity, deterring researchers and decision-makers.

In contrast, the latter approach involves coupling existing subject- and scale-specific models, leveraging the benefits of already established tools with a focus on linking them at the input and output levels. However, this method faces challenges stemming from potential disparities in modeling units and functions across existing tools, as illustrated in Fig 3.

The selection of either approach hinges on factors such as calibration, expertise availability, and the specific target indicators under examination. In the forthcoming year, our focus will be on formalizing these approaches, developing protocols, and creating systems that guide the selection of tools tailored to different indicators, contexts, and situations.

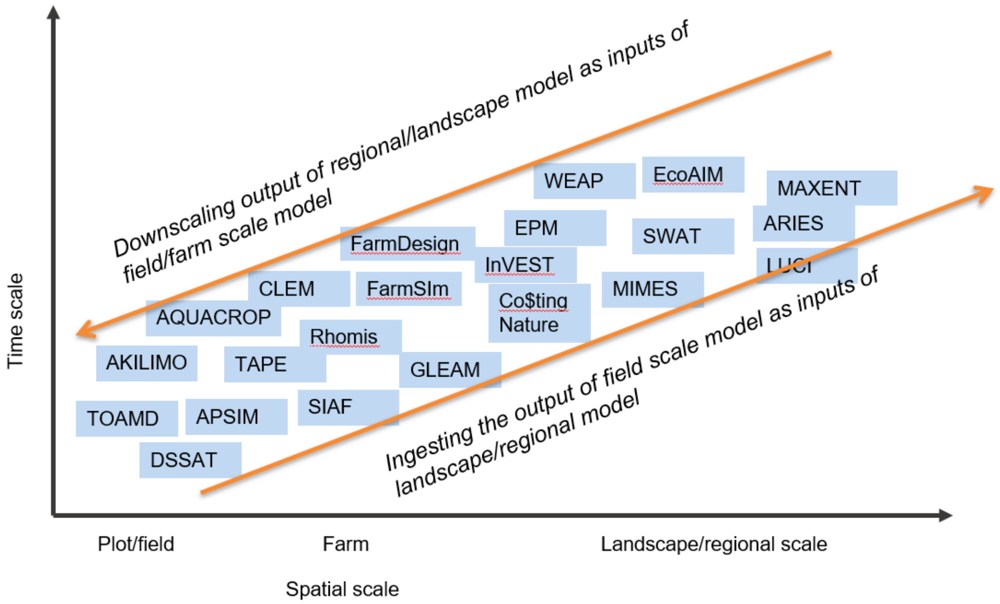


Figure 3. Large set of agricultural and process-based models. Developing multiscale models requires the integration of these models at the output and input level across scale.

3. An Example of Modelling Framework Across Scale: An Application in Ethiopia

In our pursuit of optimizing nutrient management at both plot and farm levels in Ethiopia, we employ in-situ observations and site-specific modeling solutions, such as APSIM/DSSAT modeling, supplemented by machine learning algorithms. The system intricately utilizes various model components, including crop growth, nutrient management, and pest control, to fine-tune recommendations for optimizing yield, soil health, nutrient cycling, and pest management at the field or plot level.

Recognizing that farmers face challenges that extend beyond the optimization of inputs and management on a single farm or plot, there arises a need for household-scale modeling. This approach is essential for capturing the dynamics, tradeoffs and / synergies across all farms within a household, enabling the optimization of resource distribution. To address this, we leverage FarmDESIGN, a tool that integrates agronomic models with socioeconomic factors to simulate farm-level decision-making and resource allocation (Groot et al., 2012). Importantly, inputs generated at the plot/farm level, such as yields, animal (number and productivity), labor requirements (crop and animal), soil organic matter balance (SOM), and socio-economic and environmental indicators, serve as inputs for household-level modeling.

Expanding our focus to the landscape level, communities aspire not only to optimize household resources but also to enhance the amenity of the landscape. This includes considerations for ecosystem services linked to the landscape, such as farm and landscape biodiversity, pollination services, aesthetic values, integrated water regulations for community drinking, and energy supply. To address this multifaceted challenge, we deploy the Integrated Valuation of Ecosystem Services and Trade-offs (INVEST) model.

Between the landscape and national scale, a prime development issue is the growing challenges of food security amidst population growth, land scarcity, and water stresses. To address this issue, we developed a spatially explicit basin/ sub basin scale, ecosystem, food, and energy (WEFE) based nexus framework. Our framework helps to prioritize WEFE issues across diverse administrative divisions, guiding policy formulation and development interventions. The framework comprises two fundamental components: an Excel-based data registration system for data management and a spatial toolkit for identifying types of nexus interactions among different administrative divisions. The WEFE-based nexus approach is considered a best practice for harmonizing development initiatives, ensuring a balance among system components and fostering sustainable resource management (Mpandeli et al., 2022).

Finally, the interconnectedness of these landscapes necessitates a comprehensive approach to provide foresight analysis and national-scale targets encompassing diverse sectors of the country. To achieve this, we utilize the FABLE (Food, Agriculture, Biodiversity, Land, and Energy) model at the national level. This compressive model integrates multiple sectors to assess the sustainability of national food and land use systems, offering insights into overarching decadal and mid-century goals such as food and biodiversity targets. The model utilizes an Excel-based framework developed by the global FABLE consortium, which has been adapted and tailored to the specific context of Ethiopia. This is particularly aimed at aligning modeling outcomes with policy objectives and decision-making needs at the respective scale, recognizing that modeling informs different stakeholders and decision levels.

Table 1: An example of modelling solutions chained across scale in Ethiopia.

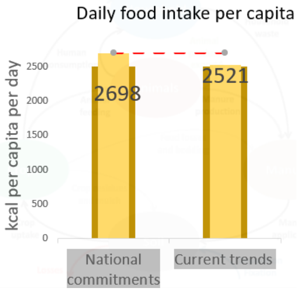
>10 years

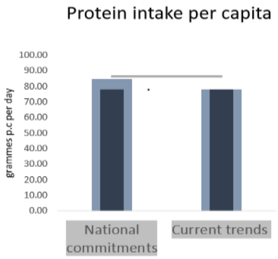
FABLE: We used FABLE calculator to understand the development pathways of the food and land-use systems, and track progress towards food security, climate mitigation, and biodiversity conservation at the national scale (Getaneh et al, 2023)

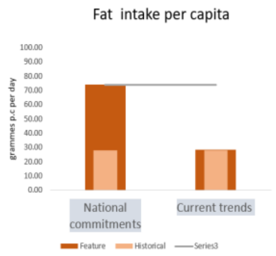
2 ZERO HUNGER

Food

- Food intake per capita by 2050



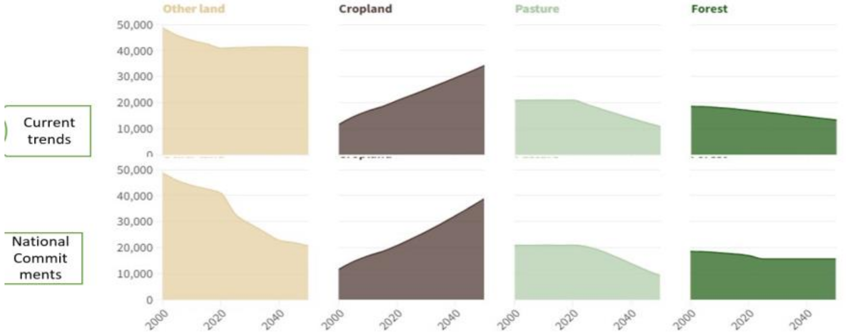




15 LIFE ON LAND

Land

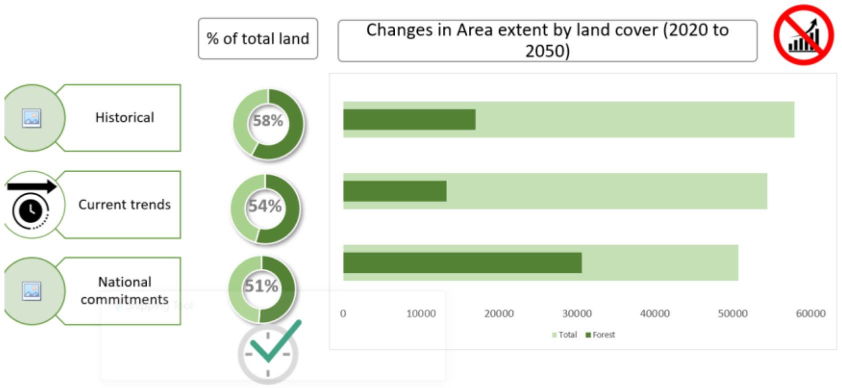
- Mid-Century Anticipated Land cover changes (2050)



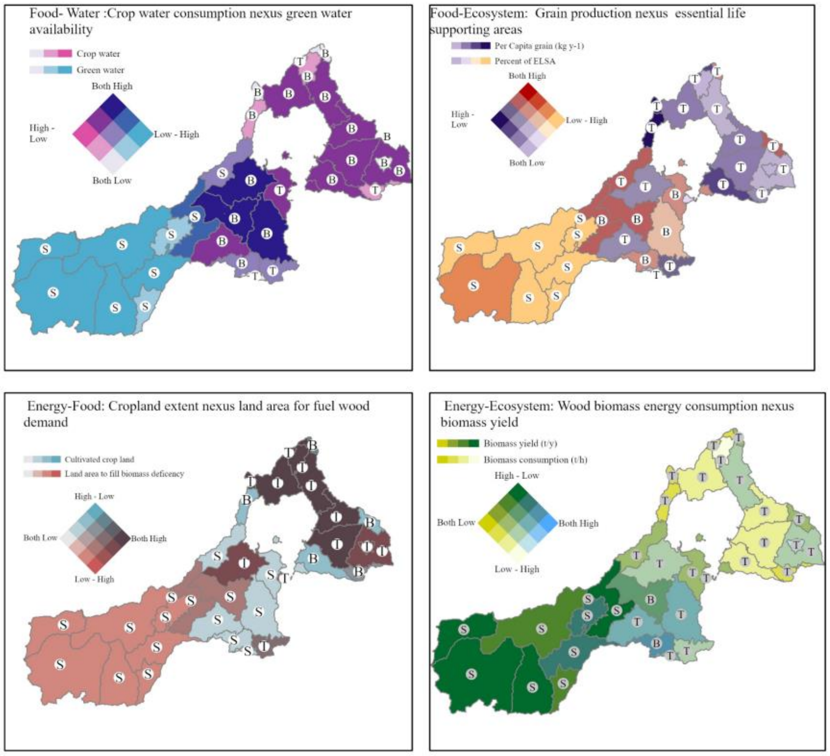
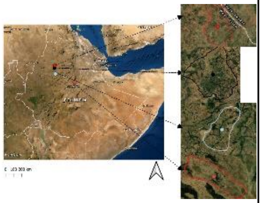
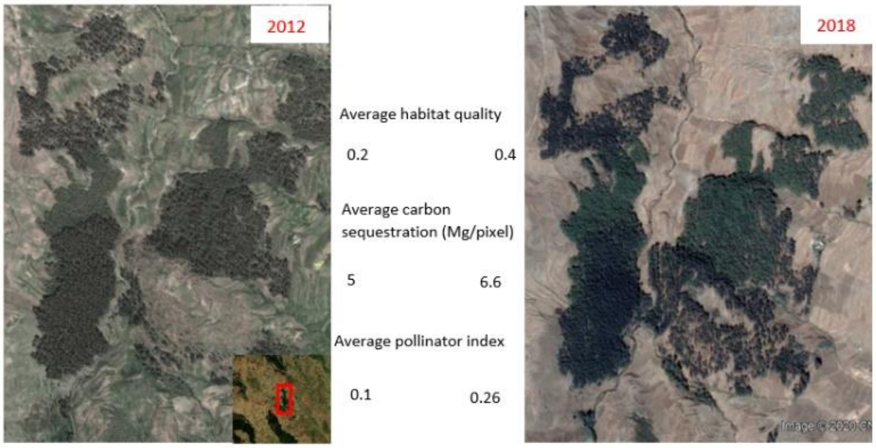
15 LIFE ON LAND

Biodiversity

- land which can support biodiversity conservation

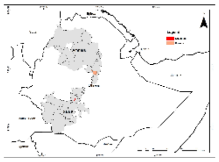


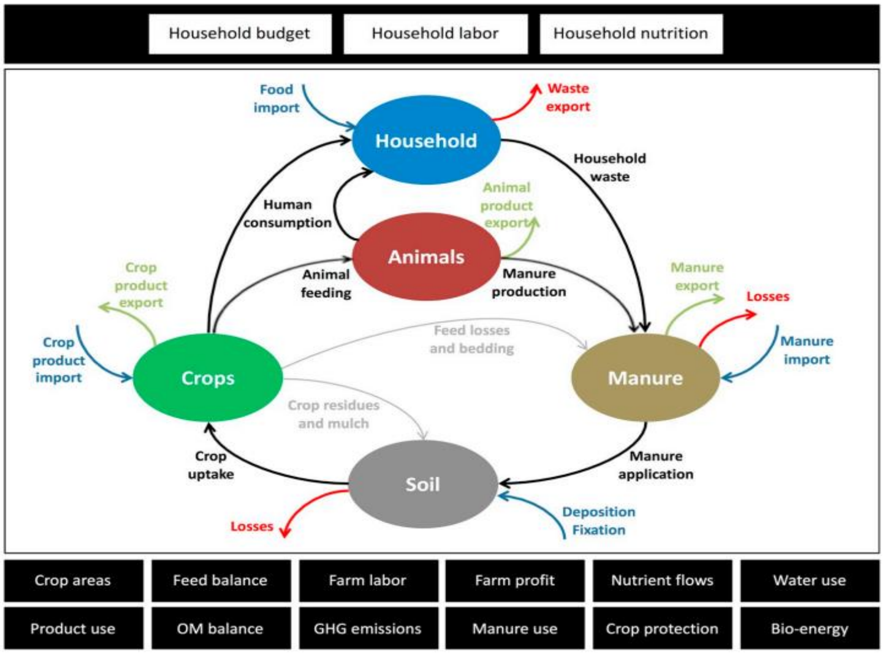
National/regional scale

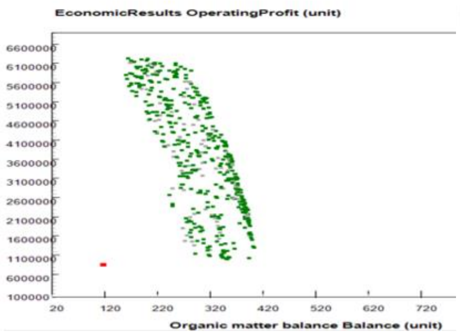
5-10 years	**WEFE framework**: Maps of nexus interactions in Tana-Beles of Ethiopia developed through a spatially explicit WEFE framework. Types of nexus interactions are labelled as T (trade-off), S (synergy), and B (balanced) (Abera et al., 2023).  	Regional scale
5-10 years	**InVEST**: We used InVest to estimate key landscape level ecosystem services, track any progress, and guide landscape interventions for optimal landscape investment. WE applied in 4 landscapes across Ethiopia (Tamane et al., 2022).   	Landscape scale

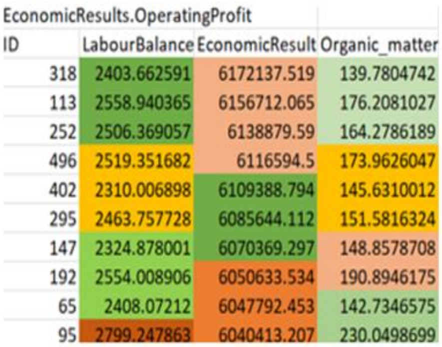
1-5 years

FarmDESIGN: We used FarmDESIGN model at household level to analyze the current household and their farm condition and suggest optimization solution for land use management at two districts (e.g Eshetae et al., 2023)









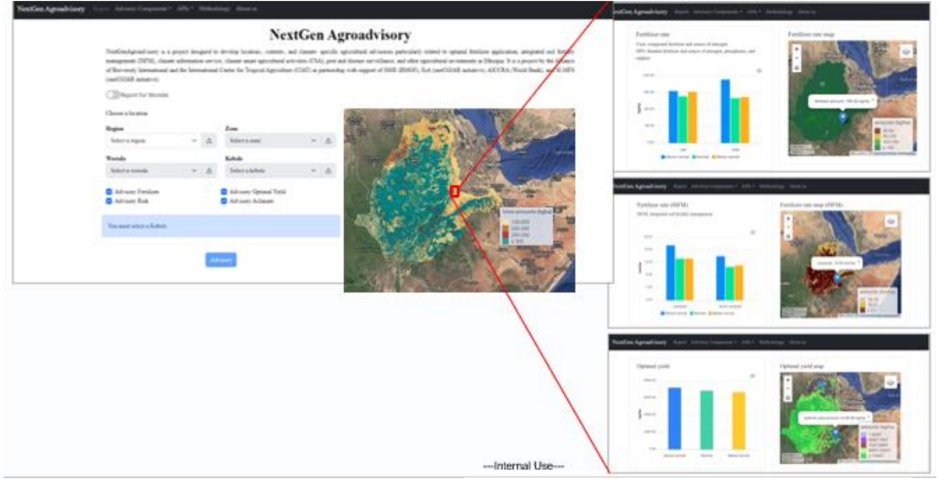
EconomicResults.OperatingProfit			
ID	LabourBalance	EconomicResult	Organic_matter
318	2403.662591	6172137.519	139.7804742
113	2558.940365	6156712.065	176.2081027
252	2506.369057	6138879.59	164.2786189
496	2519.351682	6116594.5	173.9626047
402	2310.006898	6109388.794	145.6310012
295	2463.757728	6085644.112	151.5816324
147	2324.878001	6070369.297	148.8578708
192	2554.008906	6050633.534	190.8946175
65	2408.07212	6047792.453	142.7346575
95	2799.247863	6040413.207	230.0498699

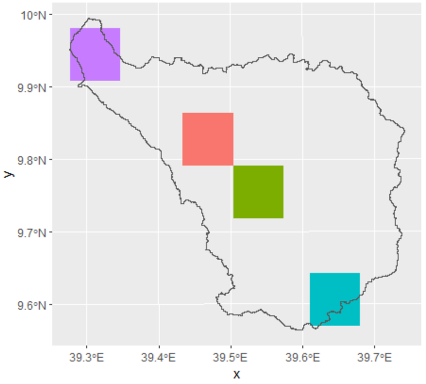
key components of the FarmDESIGN (above) and sample tradeoff analysis for Doyogena area in Sothern Ethiopia.

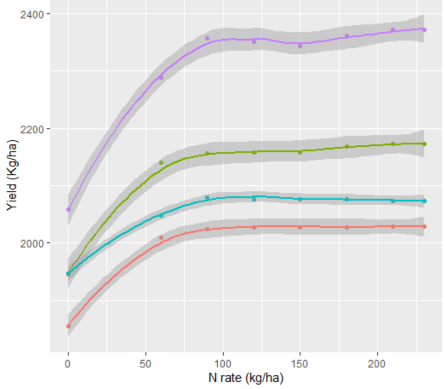
Farm/Household scale

<table>
<tr>
<td><1 year</td>
<td>

Data-driven (point process-based model like APSIM): we used Big-data analytics and/or process-based model to optimize soil nutrient (fertilizer) recommendation at point (plot) level across highland of Ethiopia (Abera et al., 2022).







The NextGen agroadvisory system generating optimizer fertilizer recommendation for any location of interest (above) and the sample crop-nutrient response curve for 4 sample plots along the watershed in Basona worena (Gudoberet watershed).

</td>
<td>Field/plot scale</td>
</tr>
<tr>
<td>Time scale</td>
<td>Models and analysis being done so far to address tradeoff, synergies and foresight issues across scale</td>
<td>Spatial scale</td>
</tr>
</table>

4. Next steps

Systems approaches can help us respond to otherwise unmanageable problems by providing a different perspective (seeing all parts, and their interconnections), as well as the tools and methods that can be used to explore the system, keeping in mind the dynamic nature of the parts and their relationships. In our next phase, we acknowledge the existing gap in methodologies for system simulation and analysis, particularly in the context of sustainable intensification. While progress has been achieved in applying multiscale system modeling to disciplines like biology, physics, and engineering, its utilization in agricultural research remains constrained. Capitalizing on the strides made in data availability and computational capacity, our focus is to tackle challenges in agricultural system research by establishing and illustrating the efficacy of coupling continuous and discrete systems. This approach adeptly captures vital agricultural system information across spatial and temporal scales, employing modeling techniques refined for diverse stakeholders. Unlike deterministic sciences such as biology, physics, and engineering, agricultural systems incorporate societal, local, and governance factors that necessitate inclusion for comprehensive system analysis. Recognizing this intricate landscape, our efforts are channeled into developing context-specific farming system models tailored to individual systems and countries. Through this ongoing initiative, we aim to enhance and optimize methodologies, nurturing a nuanced understanding and promoting sustainable management of agricultural systems.

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