A guide to applying TEEBAgriFood for policy assessment

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1. Setting the stage

Motivation for this guidance document

Agriculture and food systems are central to achieving the Sustainable Development Goals and targets set in the 2020 Kunming-Montreal Global Biodiversity Framework. Today's food systems are the source of 60% of terrestrial biodiversity loss, 24% of greenhouse gas emissions, 33% of soil degradation, overfishing of 29% of commercial fish populations and over-exploitation of 20% of the world's aquifers (The Economics of Ecosystems and Biodiversity (TEEB) , 2015). Conversion of natural habitats like forests and grasslands to croplands and pastures directly displaces native plant and animal communities. Agrochemical inputs like fertilizers and pesticides can pollute and degrade adjacent natural areas, further threatening species. Additionally, agriculture accounts for 72% of global freshwater withdrawals (FAO, 2023), which strains aquatic ecosystems. Conversely, agriculture is highly dependent on nature, and specifically on well-functioning ecosystems and biodiversity. Ecosystems provide services that support productive agriculture such as biological pest control, pollination, water flow regulation, and soil biodiversity (Power, 2010). Natural, non-crop ecosystems provide habitat and diverse food resources required for insects, birds, and microbial pathogens that are enemies to agricultural pests, providing biological control services in agroecosystems that can reduce the need for pesticides (Tscharntke, Klein, Kruess, Steffan-Dewenter, & Thies, 2005).

The importance of the agri-food sector from a socio-economic perspective has been analyzed in several reports (Campanhola & Pandey, 2019; Bockel, et al., 2017; Cepal, 2021; Wieben, 2019). The agri-food sector is critical for humankind, offering food production, nutrition and income. However, there are parts of the world where food consumption is not adequate to guarantee sufficient and quality nutrition, and where farming is not economically viable (Adzawla, Bindraban, Atakora, Camara, & Gouzaye, 2022). Intervention options are needed to improve land productivity, support the diversification of supply and withstand ongoing climatic changes (Rahman, Anik, & Sarker, 2022; Do Prado Tanure, Miyajima, Magalhães, Domingues, & Carvalho, 73-90). Transformation of food systems to achieve social and environmental development goals must be made a highest priority. Many, although not all, of the failures of food systems to deliver for people and planet arise because we are systematically failing to measure in economic terms the 'True Costs' of the impacts that food systems have on both people and planet. The 2023 FAO *State of Food and Agriculture* report (henceforth 'SOFA 2023') focuses on True Cost Accounting (TCA). Core to TCA is the evaluation and then economic valuation of hitherto 'invisible' costs and benefits i.e., a form of market failure that economists term 'externalities'. This guide seeks to correct our mutual failure to account for and correct these externalities and true cost in public policy.

In 2018, UNEP launched The Economics of Ecosystems and Biodiversity for Agriculture and Food ('TEEBAgriFood') *Scientific and Economic Foundations* report, with inputs from over 100 academics, International Organisations (such as FAO, IFPRI, the World Bank etc.), policy-makers and civil society groups from over 40 countries.

The TEEBAgriFood schematic below (The Economics of Ecosystems and Biodiversity (TEEB), 2018) (Figure 1) sets out these invisibilities. One grouping is the ecosystem services that well-functioning ecosystems provide to agri-food systems, such as pollination and freshwater provisioning. These are the flows arising from natural capital. Human health impacts on human capital, such as pesticide poisoning, PM2.5 from burning of rice husks, or non-communicable diseases such as Type-II diabetes.

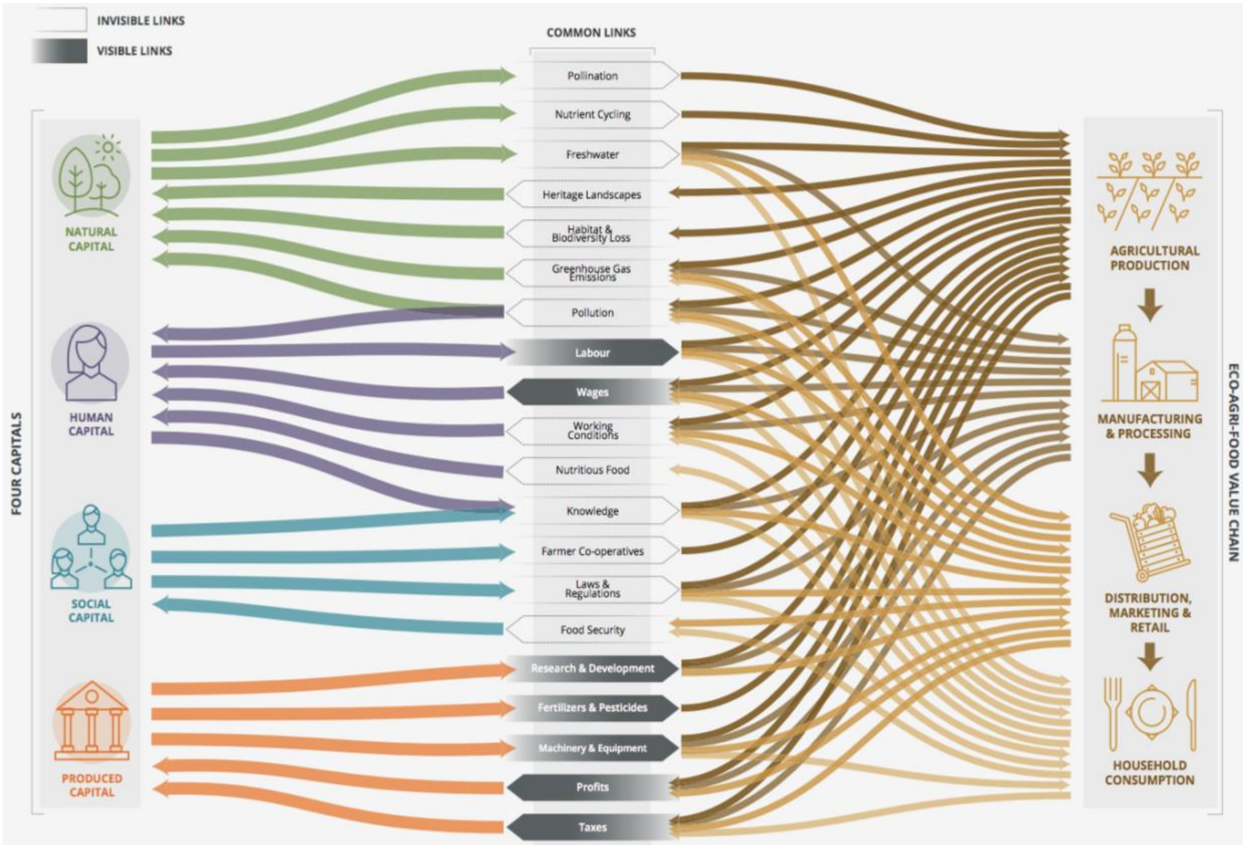

Figure 1: Links between four capitals and the eco-agri-food value chain (The Economics of Ecosystems and Biodiversity (TEEB), 2018).

Objectives

The current report is complementary to the 2023 SOFA, and indeed to the original suite of TEEBAgriFood applications, sharing lessons learned from them.

This guide is not designed to make the case for TCA; this already appears in the 2023 SOFA and the suite of TEEBAgriFood reports. Rather it is a 'how-to' guide and proof of concept, i.e., (i) how to *formulate the policy scenarios* that TEEBAgriFood is applied to, (ii) what *data, methods and disciplinary expertise* are required, (iii) what is the *sequencing*, (iv) what *challenges* apply and how might they be addressed, (v) *how are results mainstreamed into policy making*, and (vi) what was the *measurable impact* of UNEP TEEBAgriFood applications?

Part of the evidence that TCA offers as an input to policy formulation is a snapshot of where we stand today, i.e., the extent to which food systems today are economically inefficient as externalities are not internalized, missed opportunities to provide sustainable livelihoods, and contributions to worsening the triple planetary crisis of the biodiversity and nature loss crisis, the climate crisis and the pollution and waste crisis. This evidence tells us we need to act now, but does not provide the net impacts of a particular policy response from today to 2050. This is precisely what a full TEEBAgriFood application does.

It is critical to consider forward-looking scenarios when conducting policy analysis for agricultural sustainability. This is because the lifetime of the interventions considered may stretch over one or two decades and their effectiveness may increase or decline during this period of time, and under different scenarios (Muhie, 2022). For instance, the value of externalities is likely to change in the future due to factors such as the climate crisis, population growth, and technological advancements (Moretti, Vanschoenwinkel, & Van Passel, 2021). Also, the value of interventions, such as nature-based ones, has been reported to increase under scenarios with a higher number of extreme weather events (Seddon, et al., 2021). The economic viability and effectiveness of intervention options have to be assessed against such changing dynamics. Failing to account for these changes can result in incomplete or ineffective policy recommendations (e.g., if externalities are expected to increase over time, a static policy or investment analysis may result in the underestimation of the benefits of action) (Seddon, et al., 2021). Therefore, policy analysis that incorporates forward-looking scenarios can help identify policies and investments that will maximize direct benefits as well as co-benefits, and contribute to a more sustainable and resilient agricultural sector.

Audience

This guidance document aims to (i) highlight the importance of using scenarios in TEEB assessments, and (ii) offer a practical, step-by-step process for their use. It uses the TEEB approach (stating the context, values, and purpose to be used for valuation) and valuation framework (indicating what impacts should be valued and why), known methodologies for the economic valuation of externalities, and adds forecasting methods and models for the underlying drivers of change of performance in the agri-food sector. This is needed to analyze present and future impacts of intervention options, and to assess their economic viability and effectiveness.

As a result, this guidance document addresses two main audiences: policymakers and modellers. Policymakers set development targets and frame policy questions, selecting potential interventions and investments, raising the need for forward-looking policy assessments, and hence convene and fund modelling teams. The first part of the report is tailored towards this audience, with information relevant to their decision-making processes. The latter part of the report focuses on providing modellers with the necessary information on the available methods and models that can be used to carry out the analysis. This includes detailed explanations of the assumptions, data sources, and limitations of each model, in the context of specific policy options, as well as recommendations for how they can be used in conjunction with other models to create a more comprehensive analysis.

The two audiences are considered to ensure that there is an explicit link between policy and science (highlighting the type of assessment required for policy relevance), and again between science and policy (providing information that is relevant and informs the policy process). This requires that, as presented at the end of this guidance document, knowledge is integrated across policy themes and scientific domains, for the analysis conducted by the modelling team to be relevant and useful for public decision-making processes. The overall goal is to create TEEBAgriFood assessments that are both informative and actionable, and hence effective in addressing upcoming challenges.

2. What is a TEEBAgriFood 'policy scenario'?

The future of sustainability in the agri-food sector is critical for the continued survival and prosperity of human societies. On the other hand, over the next few decades, in addition to current challenges becoming stronger, several additional ones may emerge. These include the pressure caused by the climate crisis and related extreme weather events, as well as trends of land degradation caused by unsustainable land use practices and loss of biodiversity, inevitably challenging current agricultural yields and production methods, in addition to population growth and increased food demand globally (Calicioglu, Flammini, Bracco, Bellù, & Sims, 2019).

Specifically, the climate crisis is causing changes in temperature, rainfall patterns, and weather events that can negatively impact agricultural production. This includes more frequent droughts, floods, heatwaves, and extreme weather events, which can reduce crop yields, increase soil erosion, decrease soil fertility and damage infrastructure. The damage to infrastructure should not be underestimated, with consequences for post-harvest losses and reduced market access, impacting both farmers' profitability and nutrition. Soil degradation is a major threat to the sustainability of the agriculture sector, as it reduces the ability of the soil to support plant growth and ecosystem services. This includes the loss of topsoil, nutrient depletion, soil compaction, and soil pollution, which can reduce crop yields, increase erosion, and contribute to water pollution. Caused by a variety of factors, soil degradation is impacted by both land use practices (e.g., high reliance on chemical fertilizers) and changing weather conditions. Agriculture has been identified as a major driver of biodiversity loss, as it often involves the conversion of natural ecosystems and habitats into agricultural land. This can result in the loss of important ecosystem services, such as pollination, pest control, and soil health, which can reduce agricultural productivity and increase reliance on chemical, inorganic inputs, creating an undesirable lock-in effect.

Population growth is expected to create increasing pressure on the agri-food sector, for all the dynamics of change listed above. It exacerbates the climate crisis, it results in higher demand for food production and, when this cannot be achieved via improved land productivity, it leads to changes in land cover and further loss of biodiversity. When land productivity improves as a result of the use of chemical fertilizers and pesticides, and livestock production increases due to the use of antimicrobials, the quality of ecosystems is likely to decline, creating different, important challenges.

The dynamics described above represent the underlying drivers of a Business as Usual (BAU) scenario, one where investments and practices remain unchanged. Despite the lack of action to increase sustainability, and hence even in a case of no action, change will still happen in the agri-food sector (e.g., due to population growth and the climate crisis, as indicated above). This is triggered by underlying dynamics caused by the interconnections existing between social, economic and environmental indicators. These interconnections have evolved and changed over time, with ecosystem extent, quality and ecosystem services, being different now when compared to the past, and further changing in the future. These underlying changes call for the use of a dynamic, integrated policymaking process and for the use of different scenarios, methods and forecasting tools (Figure 2).

2.1 Scoping and selecting TEEBAgriFood policy scenarios

Early in the process of planning and policy making, in the *problem-identification* or *agenda-setting* stage (Andrews, et al., 2022), the following questions should be asked: What will happen if no policy action is taken? Will the problem worsen, and how quickly? What will be the cost of inaction, if we were to treat symptoms rather than address the cause(s)?

Practically, to find an answer to these questions policymakers have to be aware of (i) the baseline, i.e., the current situation, and (ii) the main drivers of change in the Business-as-Usual (BAU) scenario, a scenario of inaction, as described above. Driven by policy targets, e.g., the national medium-term development plan (e.g. to 2027), the SDGs, NDCs and the Paris Agreement (e.g. to 2030), or long-term strategies (e.g. to 2050), different considerations for action can be made. The most immediate considerations pertain to whether the BAU scenario is desirable and, if not, this leads to what changes are required, and how effective would such changes (policy, investment, behavioural change) be?

This takes policymakers to the next stage of the decision-making process, the *policy formulation stage.* For a TEEBAgriFood study to be relevant and impactful, this policy formulation stage is critical. Policy options may be formulated based on national or regional goals or targets, using a multi-stakeholder approach (see Text Box 1). For instance, there may be a choice between a country-wide shift to organic production for one specific crop versus a watershed-level application of Good Agricultural Practice for multiple cropping and livestock systems. It may be that both policy scenarios resonate with government policy, so what information is necessary for local decision makers to choose among available options?

Comparing policy options is performed in the *policy assessment* stage of the decision-making process. During this stage, the expected impacts of the policy options developed in the previous stage are modelled and analytically compared. Criteria that might be considered include: (i) the extent to which new economic valuation evidence might swing a decision to adopt the policy; (ii) political economy – the champions of the change, the detractors who have a vested interest or otherwise are reluctant to shift from the Business-as-Usual, and the influence each group has; (iii) the constituency of potential beneficiaries and losers, e.g., would the policy provide livelihood options to communities or sectors of society that have few alternatives. Considerations can be informed by the use of qualitative and quantitative methods, including scenario analysis and simulation models, as explained in more detail in later sections of this document.

Problem identification, *policy formulation* and *policy assessment* stages should be conducted to inform the decision-making process and justify making a decision or implementing a policy. Policy implementation is then followed by monitoring and evaluation to confirm that the policy is achieving its objectives. While in this document we primarily focus on how TEEBAgriFood assessments can make use of forecasting methods to inform decision making, the knowledge gathered in the process of preparing TEEBAgriFood assessments can also support the formulation of an implementation strategy (e.g., identifying roles and responsibilities, formulating an investment plan) and of monitoring and evaluation activities (e.g., identifying relevant indicators, creating a shared understanding and expectations for the impact of the policy).

Text Box 1: Formulating policy scenarios with local stakeholders

A TEEBAgriFood policy scenario has four elements: (i) Where? - which agricultural landscapes; (ii) Who? – which communities, agribusinesses etc. would be affected; (iii) What? - proposed shift in land use/land cover/production methods applied across the value chain; and (iv) How? – the specific combination of regulation and incentives.

Policy scenarios can be developed in two steps: Background review and stakeholder consultation. A background review and analysis would be conducted on: (i) the *types of policy interventions* that have been applied (or alternatively could be applied) to improve livelihood options for farmers, farming communities and those involved in the agri-food value chain, with a focus on lessons learned; (ii) for each change agent (government, food processing and distribution agri-businesses, farmers, civil society etc.) analysis of *respective roles* in the change agenda. The aim of this review is to provide the background for initial discussions with stakeholders. Stakeholders are a heterogeneous group. There will likely be a different level of awareness of the policy landscape, projects and initiatives that have been applied or proposed, constraints and opportunities provided by new technologies and innovations, the governance setup that would determine whether a policy change is adopted etc. Although primarily a desk review-based assessment, a background review could also discuss project goals with key stakeholders (key Ministries) as part of this step to provide inputs to these background assessments and to sensitize these key stakeholders to the project ahead of hosting a workshop format stakeholder consultation.

The principal aim of the stakeholder consultation workshop(s) is to provide options for the TEEBAgriFood assessment including initial responses to questions (i) to (iv). A secondary aim is to sensitize stakeholders to the project and to achieve buy-in for the policy options that are to be explored in the project. One powerful tool for so-doing is the use of Causal Loop Diagrams (CLD) as discussed in Section 3 wherein there is co-creation of and consensus-building with regards the scope and boundaries of the analysis, as well as the linkages and feedback loops in the system.

A workshop would be organized next, bringing together key stakeholders (e.g., national and regional government; the business and finance community; civil society groups; rural community leaders; academia; representatives from other projects/initiatives, etc.) to deliberate over and ultimately agree a short-list of TEEBAgriFood policy scenarios. There are various questions that UNEP would ask stakeholders to consider in their deliberations over policy scenarios in determining this shortlist:

1. If the evidence provided by the TEEBAgriFood study were to lead to full policy adoption, *what would be the projected magnitude of impacts on nature and livelihoods*?

2. *To what extent is the TEEBAgriFood evidence needed*?
   - 2.1. Linked to this, do stakeholders feel that there are material externalities, impacts and dependencies (the 'invisibilities' in the TEEBAgriFood Evaluation Framework) that the study would bring to the fore?
   - 2.2. Might an economic valuation make a difference? Often making the economic case in monetary terms engages and motivates key decision-makers in a manner that does not apply absent valuation.
   - 2.3. TEEBAgriFood analyses include distributional impacts. Would this evidence be important? Might it show that Business as Usual (e.g., allowing land degradation to continue unabated) would disproportionately impact communities that have few alterative opportunities for sustainable livelihoods, or women? Would the policy change this?

3. Is the adoption of the policy scenario *feasible*?
   - 3.1. Are the key stakeholders that would be responsible for the decision on adopting the policy present in the workshop, and if not, could they be engaged in the TEEBAgriFood process?
   - 3.2. Who might the 'change blockers' be, i.e., those who have a vested interest in retaining the Business-as-Usual status quo? Would they need to be convinced of the benefits of policy adoption? If so, is this likely to happen?
   - 3.3. What are likely to be the costs of project implementation, and how acceptable are these costs given budget constraints?

4. What is the *time scale* of the policy intervention?

4.1. Does the time scale for policy adoption cross a political election cycle, and if so, might that limit the chances of policy adoption?
4.2. Are tangible benefits likely to occur soon or in the distant future? Those policy options that have earlier benefits are more likely to be politically palatable.

Workshop participants would not be expected to provide detailed responses to these questions; they are guiding questions to inform the development of the shortlist of policy scenario options.

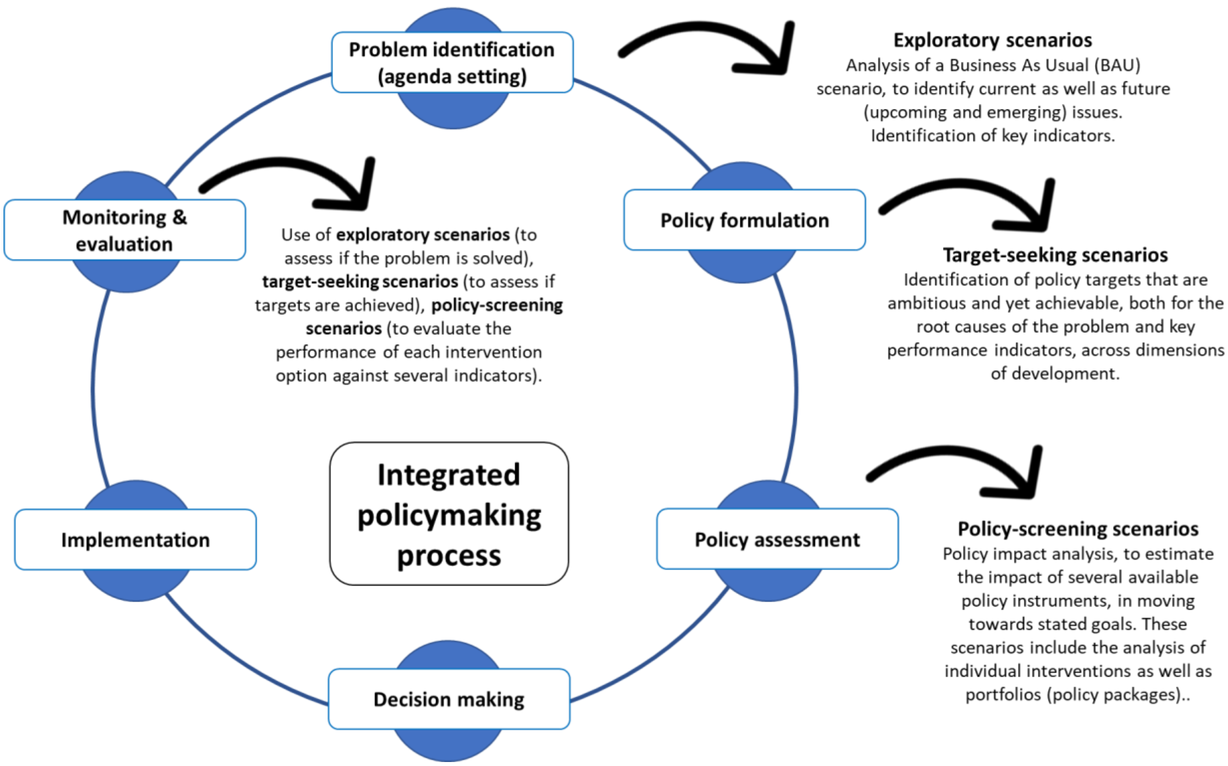

Figure 2: The use of scenarios in TEEBAgriFood, to inform the integrated policymaking process.

2.2. Examples of types of policy interventions

Assessing a scenario of inaction (Business-as-usual) is useful to highlight impending challenges and offers the opportunity to identify intervention options to increase the sustainability of the agri-food sector. Some of the main opportunities include (i) climate change mitigation and adaptation practices, diversification of crops and use of drought-resistant seeds in areas prone to water scarcity, climate smart agriculture for carbon sequestration and storage, (ii) sustainable agriculture practices to reduce soil degradation, water pollution and biodiversity loss, for instance in relation to organic agriculture, agroforestry or integrated crop-livestock systems, (iii) reduction of pre- and post-harvest losses, distribution losses and food waste, coupled with heathier diets, as examples for addressing the challenges posed by population growth. These are solutions that can address problems related to food security, farmer income creation, climate resilience, health impacts from agri-chemicals and/or poor diets and acute environmental pollution from smoke, dust, sedimentation, and agrichemical exposure.

Several policy instruments exist for stimulating and supporting the implementation of these intervention options. These include direct investment, the introduction of incentives and disincentives, the enactment of mandates, and capacity building as well as public awareness activities. These, and more, are presented in several reports in detail (OECD, 2021), including information on how current support could be repurposed towards a more effective and systemic approach to sustainability (UNEP, UNDP, 2021).

In order to support policymaking, information is required on both (i) a policy target to realize, and (ii) the policy instrument(s) to use to make progress towards the target, and ultimately achieve it. Practically, the policy instruments (e.g., direct investment, incentives and disincentives, mandates, and awareness-raising activities) are the intervention options required to steer the agri-food system in the desired direction. These policy instruments are selected by taking into account the interconnected nature of the agri-food system, and the unique features of different countries/contexts.

2.3 Scenario formulation versus policy analysis

As mentioned previously, various challenges need to be addressed in the agri-food sector to enhance sustainability. For instance, the impacts of climate change, extreme weather events on agriculture, or the impacts of agriculture on land degradation and loss of biodiversity, can be used as examples to identify policy priorities, and highlight how the use of a systemic approach to planning can offer an effective solution. However, the selection of methods and models for scenario formulation and policy analysis first and foremost depends on what policy question has to be analyzed. Since each model is built for a purpose, and each method and model have strengths and weaknesses, it is crucial to identify those tools that are well aligned with the policy priorities to analyze.

Aside from the examples used in this guidance document, in reality, policy priorities can emerge from the analysis of the baseline, as well as from future scenarios of action and inaction. In fact, scenario formulation and policy analysis are two distinct matters but related processes that should be used to inform decision-making in different ways. First, scenario formulation involves developing a range of plausible future trajectories that reflect different possible futures. Scenario formulation may consider technological change, demographic growth, economic development trends, and political developments. The purpose of scenario formulation is to explore and understand the range of possible futures that may emerge, and to identify the key drivers of change that are likely to shape these futures. Scenario formulation is often used as a tool to help decision-makers develop long-term strategic plans, identify potential risks and opportunities, and anticipate and prepare for future uncertainties. In the context of TEEB assessments for the agri-food sector, scenarios are useful to formulate BAU trajectories, and determine the extent to which those externalities identified in the baseline (i.e., current situation) will increase in scenarios of inaction. Second, policy analysis involves evaluating and comparing different policy options and their potential outcomes on specific policy goals, and on additional societal outcomes. The purpose of policy analysis is to inform decision-making by identifying the policy options that are likely to be most economically viable and/or effective in achieving the desired policy outcomes, and to assess their outcomes beyond the policy goal, for societal development. Policy analysis is often used to help decision-makers identify and formulate policy options, define the require ambition to reach the stated goals, and estimate the amount of resources required for implementation.

While scenario formulation and policy analysis are distinct processes, they are often used in conjunction to inform decision-making. Scenario formulation provides information on the scale of the challenge, and allows to identify a policy target for action (exploratory scenarios in Figure 2). Policy analysis instead supports the identification and assessment of intervention options that allow one to reach the stated target (target-seeking and policy-screening scenarios in Figure 2). Together, these two processes can help decision-makers develop more robust and effective policies that are better suited to the complex and uncertain challenges of the future. Section 5 of this guidance document provides a step-by-step approach for the use of scenario formulation and analysis in TEEB studies. It highlights that the use of a systemic approach, via the creation of a multi-disciplinary team, is essential to identify key drivers of change and develop plausible BAU scenarios, select key indicators and analyze the implications for sustainability, identify policy priorities and evaluate the outcomes of the implementation of intervention options across dimensions of development, materials indicators and externalities, create awareness, ownership and share the results across relevant audiences.

Going back to the examples introduced earlier, the following flow of information could be considered for the assessment of the impacts of climate change and extreme weather events.

When analyzing the impacts of climate change, (a) the policy goal may refer to improved food security, which data may show as worsening. In order to improve food security via the reduction of climate vulnerability, (b) the following indicators could be considered: agriculture land and land productivity, frequency and magnitude of extreme weather events, and resulting pre- and post-harvest losses. The rationale would be that (c) the occurrence of extreme weather events (e.g., two prolonged droughts and one flood at the beginning of the rainy season) has negatively impacted land productivity (e.g., 20% reduction in the past year). This has led to reduced food production and food availability at the local level, as well as reduced farmers' income, resulting in an increase in the cases of malnutrition at the local level (due to lower availability and affordability). With these key indicators considered, and the storyline identified, (d) the following simulation models should be considered: one that is spatially explicit and supports the identification of the area that is at risk of floods and droughts, a second model that, using the outputs of the first one, can estimate the impact of extreme weather events on land productivity, but also on soil loss, water retention, and more, and an economic analysis that considers the number of farmers working in the study area, and their socioeconomic and gender profile in relation to income creation, consumption and diets. With this information, the baseline (current situation) can be assessed, and the BAU forecast can be generated (using also climate forecasts, with an indicator of the possible frequency and magnitude of extreme weather events). At this stage, (e) intervention options can be identified, that may reduce climate vulnerability and avoid the negative impacts of extreme weather events on food production. As an example, if nature-based options are considered, they could be implemented in the spatially explicit model, as changes in land cover result in higher water retention and reduced soil loss. These outputs could then be used to estimate land productivity and production, and hence food availability and income creation (related to affordability). In the context of TEEB, the economic valuation of ecosystem services, i.e., the positive impact of nature on water and soil retention, and possibly added carbon sequestration, to provide a few examples, would be translated into economic values to perform a Cost Benefit Analysis and/or a Cost Effectiveness Analysis of the investment considered.

3. The TEEBAgriFood Framework- a guide for evidence-based systemic planning

The TEEB AgriFood framework provides the foundations for conducting a systemic analysis of agri-food systems (Figure 3), one that is data-driven and science-based (The Economics of Ecosystems and Biodiversity (TEEB), 2018). This approach requires the use of complex models to capture the key features of the systems we are embedded in, to inform policy making for socially, economically and environmentally sustainable outcomes. First, the TEEB AgriFood framework highlights the importance of considering and measuring the foundational capital assets that support individual and societal welfare: natural, produced, human and social capital. Second, it shows the relevance of considering all production inputs and outputs, including ecosystem services and social and environmental externalities that are not represented in economic markets, and resulting outcomes and contributions to human well-being. Third, it stresses the need to consider the full agri-food value chain, rather than a single stage or component. These three aspects can be considered and assessed by using measures of stocks and flows, to capture accumulations and changes over time, as well non-linear relations across indicators.

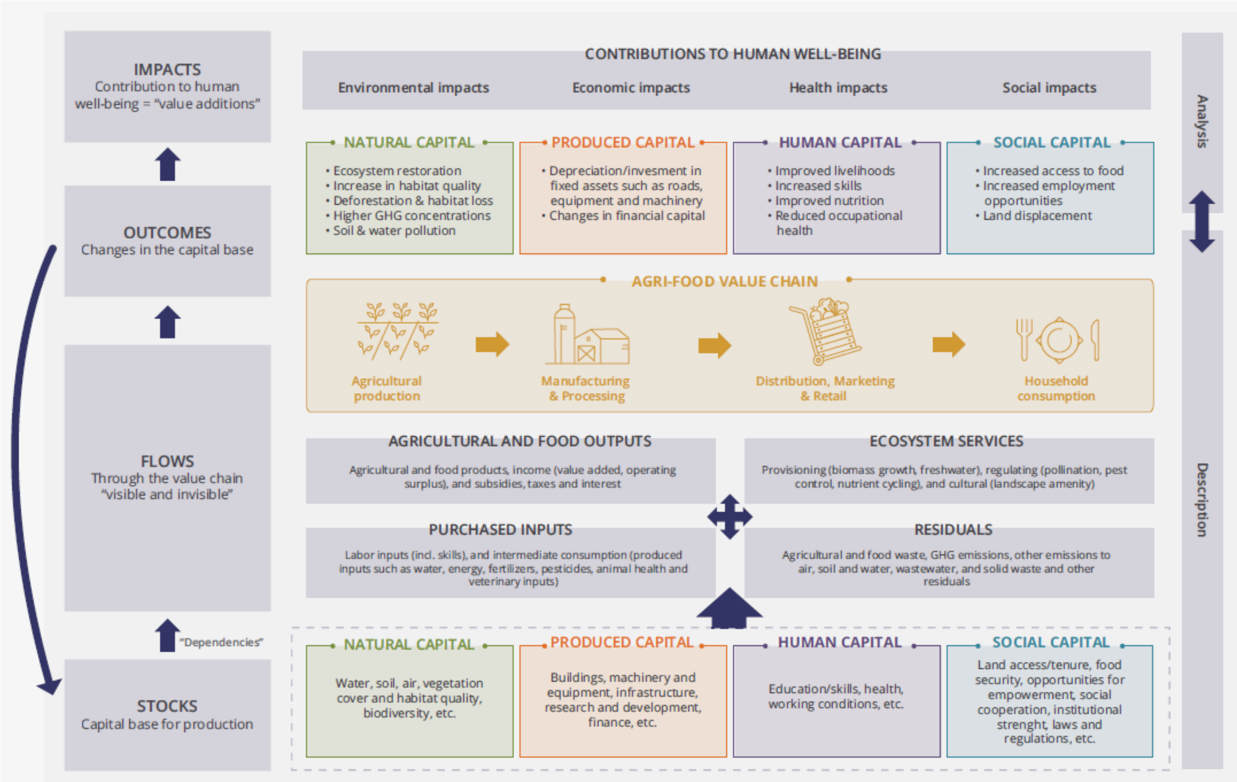

Figure 3: Elements of the TEEBAgriFood Evaluation Framework (The Economics of Ecosystems and Biodiversity (TEEB), 2018)

3.1. Identifying indicators for a comprehensive, and yet customized policy analysis

The TEEBAgriFood framework shows that assessments for food systems and food system policy scenarios need to be systemic, implying that in addition to measuring food production, the analysis should measure or model upstream drivers of food policy, land use, and consumer behavior, as well as unintended downstream impacts (externalities) from food systems. As a result, the list of indicators to measure and forecast must be extended beyond annual yields and market prices.

The selection of indicators that should be used to assess food systems and compare policy scenarios starts with the definition of the objective of the policy exercise. For instance, using the examples mentioned earlier, an assessment that focuses on improving climate resilience (to address the impacts of climate change and extreme weather events on agriculture production) will require forecasts of land productivity, under different climate scenarios; an assessment focused on sustainable land management (to address land degradation and biodiversity loss) will require forecasts of changes in land cover and land use, under different scenarios of farmer adaptation of sustainable practices. The process for identifying and prioritizing indicators can be demonstrated using these two policy issue examples.

For resilience and adaptation of agriculture production to climate change and extreme weather events:

(i) The following indicators of the four capitals that contribute to agricultural productivity should be considered, quantified and forecasted. Natural capital: the ecosystem extent (hectares of agricultural land) and ecosystem condition (land productivity factors, including soil quality, erosion control, water storage, flow control, and agrobiodiversity) that support resilience of agriculture ; Produced capital: yield per hectare, yield per labour unit, profitability of operations, availability of mechanization, infrastructure for irrigation, storage for harvest; Human capital: farmer health, knowledge of climate adaptation practices and adaptability; Social capital: labour supply, strength of governance and enforcement in the agrifood sector, supply of agricultural extension services.

(ii) Various production inputs should be considered in order to forecast land productivity under different climate scenarios, including the availability and use of fertilizers, the availability of water from irrigation, and use of seeds that may be climate resilient. Outputs would include food production and income creation, across the value chain. Outcomes include changes to the extent and condition of natural capital and consequences for ecosystem services (e.g., carbon sequestration, habitat quality, soil and water pollution). Socio-economic impacts to consider include income creation for the community; availability, accessibility and affordability of nutritious and healthy food; exposure to extreme weather events (both in relation to food supply and damage to infrastructure, e.g., from floods); and more.

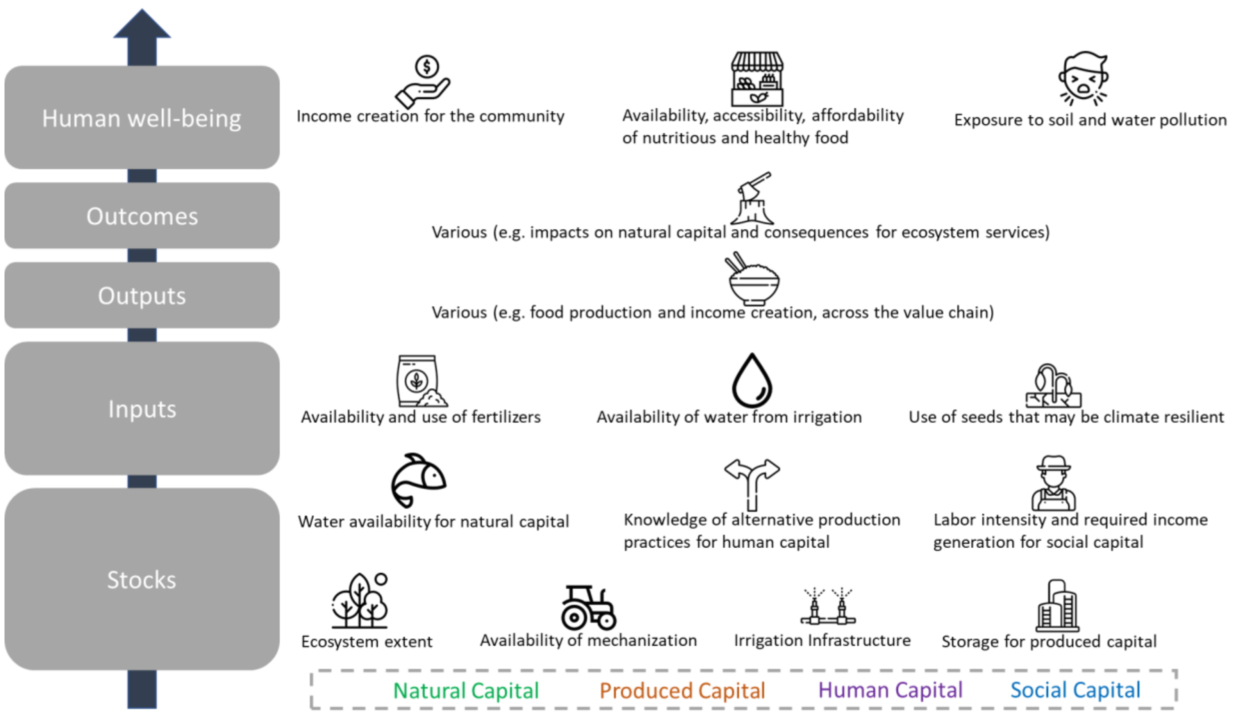

Figure 4: Example of indicators for the analysis of the impact of the climate crisis and extreme weather events on agriculture production.

For assessing policies for soil and biodiversity conservation, the following indicators of the four capitals should be considered, quantified and forecasted:

(i) Natural capital: Soil extent and condition; land cover extent and condition (for habitat for biodiversity and soil erosion regulation);

(ii) Produced capital: presence of infrastructure that may increase or decrease the impact of agriculture on soil loss and desertification;

(iii) Human capital: knowledge of alternative production practices, sustainable soil management, and agricultural land sharing/sparing strategies;

(iv) Social capital: governance for mainstreaming and enforcement of Sustainable Land Management measures and habitat conservation, population at risk for land degradation, population affected by biodiversity loss.

Specifically related to desertification being caused by land conversion and unsustainable land use practices, various production inputs should be considered, including the crops grown and crop rotation, use of fertilizers, availability of water from irrigation, use of nature-based techniques (e.g., half-moons). Outputs would include land productivity (affected by soil erosion and desertification), food production and income creation, across the value chain. Outcomes should include impacts on natural capital and consequences for ecosystem services (e.g., soil health, carbon loss, sedimentation), including assessment of land sparing versus land sharing approaches. Contributions to human well-being should consider income creation for the community; availability, accessibility, affordability of nutritious and healthy food; exposure to soil and water pollution; impacts of biodiversity loss, and more.

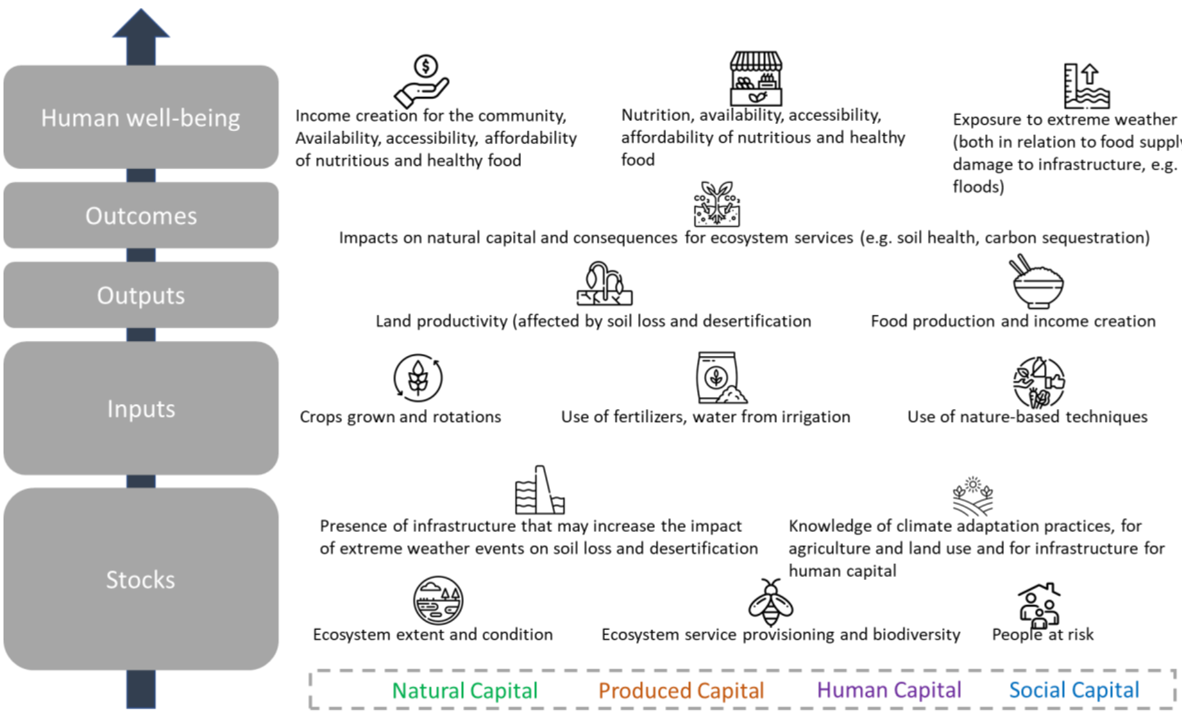

Figure 5: Example of indicators for the analysis of the impact of land degradation and loss of biodiversity.

These two examples demonstrate that a systemic approach is necessary for a comprehensive analysis, i.e. one that captures all key elements of the TEEB AgriFood framework, and that a comprehensive food system assessment must be customized for each policy topic. For any policy topic, all temporal flows – inputs, outputs, outcomes, externalities, and residuals – impact or depend on the extent and condition of the four capital stocks. Such a systemic assessment aids in identifying and investigating the root causes of problems, enabling effective intervention options that address the causes instead of the symptoms. It also generates results that are relevant to multiple audiences, including farmers, policymakers, and local population, thereby fostering multi-stakeholder ownership of the policy process and enhancing implementation effectiveness.

3.2. Modelling costs and benefits of policy action in five steps

A comprehensive approach to modelling, one that combines several methods and models, is required to perform systemic policy analysis that reflects the breadth of the TEEBAgriFood framework. To fully understand the complexity of the policy issue, and of the socio-economic and environmental context in which policy interventions will be applied, multiple models and assessment approaches must be used in concert. These include models that (i) allow us to identify and map the relationships between human activity and ecosystems; (ii) support the estimation of current ecosystem extent, condition and ecosystem services; (iii) quantify and forecast changes in human activity and consequences for ecosystems and ecosystem services, and resulting impacts on human activity and well-being; (iv) perform an economic valuation of present and future ecosystem services, building on the forecasts generated; (v) group the results in a cost-benefit analysis (CBA) and/or Cost Effectiveness Analysis (CEA). CBA and CEA have to consider both financial (only cash inflows and outflows) and welfare indicators (all cash inflows and outflows plus the economic valuation of externalities, including both tangible and intangible factors)

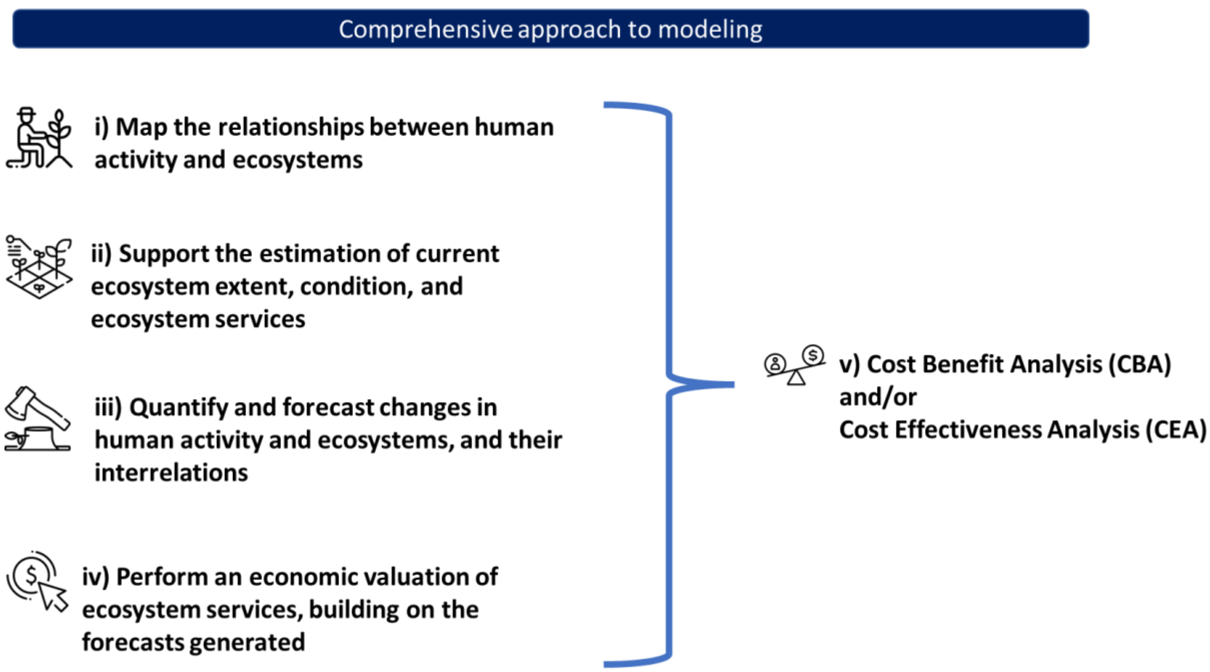

Figure 6: The TEEBAgriFood approach to modelling and forecasting for policy analysis.

First, we need methods and models that allow us to map the relationship between human activity and ecosystems. The method used to create these models, most often qualitative, is based on co-creation and uses a multi-stakeholder approach. A multi-stakeholder approach involves engaging with various actors who have an interest or stake in the agri-food system. This approach allows for the identification of relevant impacts from different perspectives and expertise, promoting a more comprehensive understanding of the impacts of agri-food systems. Co-creation refers to the collaborative process of designing and implementing policies or interventions involving different stakeholders. It emphasizes the importance of involving stakeholders in the development of a shared understanding of how the system functions, the root causes for the emergence of the problem, and the identification of solutions to ensure that policies are relevant, effective, and sustainable.

Second, we need models that support the estimation of current ecosystem extent, condition, and ecosystem services. These models help us to understand the current state of ecosystems and the services they provide, such as clean air and water, food production, climate regulation, soil formation, and habitat for wildlife. The United Nations Department of Economic and Social Affairs (UNDESA) has developed guidelines on biophysical modelling for ecosystem accounting, related to the System of Environmental Economic Accounting (SEEA) Ecosystem Accounting (United Nations, 2022). This guidance document[1] provides information on the availability of modelling platforms and models for ecosystem extent accounts, ecosystem condition accounts, and ecosystem service accounts. If further discusses data availability and data quality.

Third, we need models that allow us to quantify the relationships identified in step one and forecast changes in human activity, ecosystems, and their interrelations. These models help us to forecast the impacts of different policy scenarios on ecosystems and the services they provide, allowing us to make informed decisions about how to manage and protect them. Systems modelling can provide information on how human activity and well-being are impacted by changes in ecosystem extent, condition and ecosystem services. UNDESA has developed a guidance document on the use of SEEA Ecosystem Accounting for policy scenario analysis (United Nations, 2021). This document highlights how the SEEA EA measurement framework and data can strengthen the policy analysis carried out with land use, ecosystem service, macroeconomic, energy, water and infrastructure simulation models. Practically, a direct connection is established between sectoral activity and ecosystem service provisioning. Nested integrated (i.e. models that include a variety of sectors and capitals) and coupled sectoral models (i.e. different models used in connection with one another) such as the Green Economy Model (GEM) can be useful to forecast endogenous land cover and changes in ecosystem services based on the simultaneous relationship between socio-economic activity and the supporting role of nature.

Fourth, we need methods that allow one to perform an economic valuation of ecosystem services, building on the forecasts generated. This helps us to understand the benefits humans receive from ecosystems and the four capitals, and helps us to make decisions that take into account both the economic and environmental costs and benefits. The TEEB Foundations report[2] provides an extensive review of market and non-market valuation approaches to monetize the positive and negative externalities that arise throughout the value chain of eco-agri-food systems. Specifically, market-based valuation tools use prices in markets to measure the value of goods and services, whereas non-market valuation tools aim to measure the value of goods and services that do not have a market price, such as clean air, water, or biodiversity. Both valuations are essential to capture the full value that nature provides to human activity.

Finally, we need to group the results into a Cost Benefit Analysis (CBA) and/or Cost Effectiveness Analysis (CEA). These analyses should consider both financial and economic (welfare) indicators, including externalities (GCF, 2022). Externalities, or unintended consequences of economic activity, are often not included in market prices, leading to undervaluation or overvaluation of goods and services. A financial analysis would normally not consider the economic valuation of externalities, not being relevant to the investor and not resulting in cash inflows or outflows for the investor. An economic (welfare) analysis

[1] Available at https://seea.un.org/content/policy-scenario-analysis-using-seea-ecosystem-accounting
[2] Available at https://teebweb.org/our-work/agrifood/reports/scientific-economic-foundations/

would consider these instead, offering an assessment of the societal value resulting from policy implementation.

In summary, a comprehensive modelling approach is required that (i) can map relationships between human activity and the environment, (ii) estimate current ecosystem extent and condition, (iii) forecast changes, (iv) perform economic valuations, (v) and conduct cost-benefit and cost-effectiveness analyses. In step one, a process of consultation results in a descriptive, qualitative map of the relevant variables and connections between nature, human activity, and policy questions or scenarios. Steps ii, iii, and iv measure these variables and connections using analytical models. CBA or CEA transform the results of these analytical models into an apples-to-apples comparison of policy options to facilitate policy action. Only with this type of systemic assessment can we effectively inform decision-making for the global sustainability of the agri-food system.

3.3. Selecting models and methods for policy analysis

Effective policymaking requires the use of appropriate methods and models for improving the understanding of the causes and effects of emerging problems, as well as predicting the multi-faceted outcomes of intervention options. This is particularly important in agri-food systems, where decision-making can have far-reaching consequences on environmental sustainability and human well-being.

Analysts must select or develop appropriate models for these five steps mentioned above, based on the type of policy question, relevant indicators, and available data. This section focuses on step iii, forecasting the outcomes and impacts of intervention options. This is the most technically complicated step. The selection of the correct method and model can enable economic valuation and cost-benefit analysis (steps iv and v).

To select the best-suited methods and models it is crucial to consider, for the specific issue at hand, the policy context (e.g. the geographic and temporal scope of the issue and/or policy question), the indicators that are important to stakeholders and policy makers, and the availability of data that can be used to measure and forecast changes to those indicators. A UNEP Guide titled "Using Models for Green Economy Policymaking" focuses on the selection and use of green economy models, and provides several criteria to consider (UNEP, 2014)[3]. These include factors relevant to model creation (e.g., ease of customization, transparency, data needs, implementation time) and to model use (e.g., time horizon considered, effort for maintenance, complementarity with other models, target audience) (see Figure 7). To this end, the focus of this section is on the integration of methods and models rather than on the selection of specific models, which largely depends on the specific policy process to inform.

Table 1 provides a few examples of the types of indicators that could be used to analyze policies or other interventions for priority topics, including agriculture production and nutrition, desertification, freshwater supply, rural livelihoods, climate resilience, and eco-tourism.

The table shows that several different indicators should be evaluated to perform a complete assessment of a policy topic, as mentioned earlier. Evaluating this range of indicators will require the use of several types of models (see Section 3.3.2 and Table 4). For instance, biophysical models for ecosystems and sectoral performance should be used in conjunction with one another. When these are coupled with

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[3] Available at https://www.uncclearn.org/wp-content/uploads/library/unep_models_ge_for_web.pdf

models that generate forecasts of socioeconomic activity, CBA and CEA can be carried out to determine the financial and economic viability of the policies and investments identified.

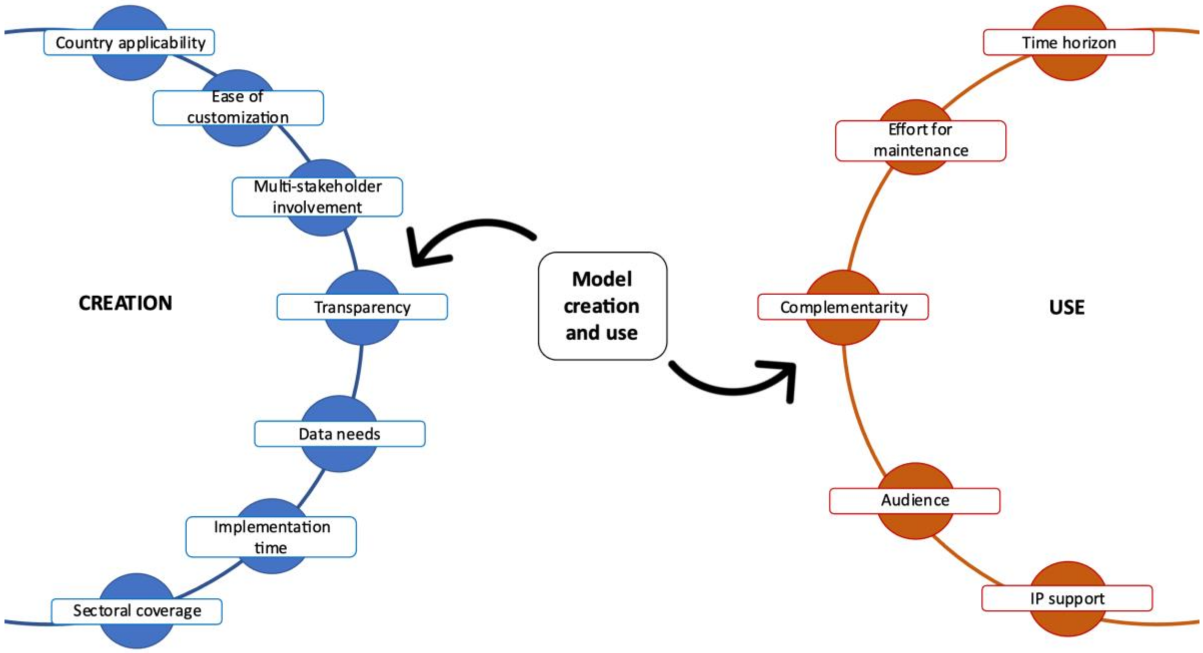

Figure 7: Assessment framework of green economy models, adapted from (UNEP, 2014)

Policy Area	Map relationships	Measure relationships		
		Drivers	State/change	Impact/welfare
Food security and nutrition	Causal Loop Diagram (CLD), Tree diagrams - Including natural, produced, human and social capital	• Food demand: Incomes, preferences, demographics • Food supply: Trade, climate change, farm productivity, food processing and distribution capacity, marketing, prices	• Trade agreements; import rules and regulations; diversity of trade partners • Food production, natural factors: soil and water resources; climate and soil suitability; land degradation • Food production, human factors: labor; knowledge/capacity; infrastructure; finance	• Economic/welfare: number of people food secure/insecure; nutrition/malnutrition; externalities of increasing food supply. • Financial, for the investor: profits within the food value chain.
Desertification and land degradation		• Climate change (temperature, rainfall, wind) • Land cover (deforestation, agriculture or livestock expansion) • Land use (farm practices e.g. tilling, intensive grazing, fallow periods)	• Land cover (e.g. agriculture, pasture land), land use practices with those land cover classes • Soil erosion/retention • Soil nutrient loss/degradation • Loss of food productivity	• Economic/welfare: food supply/prices related to land degradation; health costs of air or water pollution • Financial, for the investor: reduced farm productivity effects on incomes; capital cost and O&M cost of sustainable land management (e.g., tree planting, half-moons)
Freshwater supply, water quality and quantity		• Surface and ground water resources • Climate change (temperature, rainfall) • Agriculture and livestock water demand • Landcover (e.g. forestland, agriculture land)	• Water balance (demand and supply), and water quality. • Agriculture production, meat and dairy production, income creation. • Land cover (e.g. forestland, wetlands), water retention.	• Economic/welfare: water cost and access to clean water; health costs of water pollution • Financial, for the investor: increased land and labor productivity, resulting in higher revenues; direct avoided costs (e.g., water purchase); capital cost and O&M cost (e.g., tree planting, half-moons)
Farm incomes and farmer livelihoods		• Farm size; productivity (climate change impacts on land and livestock productivity) • Input availability and cost • Level of mechanization/infrastructure • Market access/demand • Value chain bottlenecks	• Farm yield • Input factors (soil health, water availability and quality, irrigation demand) • Road and other infrastructure, for access to markets and social services.	• Economic/welfare: improved nutrition; employment creation, income generation for households, and increased income tax revenue for the government • Financial, for the investor: farm income creation; direct avoided costs (e.g., fertilizer purchase); capital cost and O&M cost (e.g.,

Policy Area	Map relationships	Measure relationships		
		Drivers	State/change	Impact/welfare
				sustainable agriculture practices, tree planting)
Climate change adaptation, mitigation, and resilience		• Weather conditions and climate trends (e.g. temperature, rainfall, wind speed). • Assets at risk (e.g. infrastructure).	• Agriculture production • Land cover (e.g. forestland, wetlands), habitat quality and biodiversity, water retention. • Infrastructure availability and integrity (road, water and power supply and distribution).	• Economic/welfare: reduced climate risk, impacts on human health, and lower investment for reconstruction as well as reduced interruptions of economic activity • Financial, for the investor: lower revenue losses, or increases above baseline; capital cost and O&M cost (e.g., tree planting), direct avoided costs (e.g., infrastructure damage, food assistance).
Eco-tourism		• Habitat quality and integrity, and biodiversity • Air and water pollution • Infrastructure availability and integrity (road, water and power supply and distribution)	• Land cover (e.g. forestland, wetlands), habitat quality and biodiversity, water pollution. • Agriculture production	• Economic/welfare: employment and income creation, improved water and air quality. • Financial, for the investor: direct revenue from tourism activities; direct avoided costs (e.g., water, energy purchase); capital cost and O&M cost (e.g., ecosystem conservation)

Table 1: Overview of required indicators for the assessment of a few, selected policy priorities. Emphasis on indicators for drivers, state/change, impact/welfare.

Several methods and models can be used to estimate the indicators included in *Table 1*. The following sections present several examples on the modeling approach chosen to tackle specific policy questions, and the rationale for their use (e.g. based on whether the goal is to support policy formulation -via target setting- or policy evaluation -via the assessment of specific policy provisions-). In addition, Figure 8 provides an overview of the methods and models available to carry out assessments that are integrated, focus on socio-economic, or environmental outcomes. Several of these methods and models can be used to carry out a systemic analysis, either by using an integrated model or by employing a multi-method approach.

Specifically, qualitative visualization tools such as Causal Loop Diagrams (CLD) and Tree diagrams can be used to map the relationships between biophysical and socio-economic activity (see Section 3.3.1). These tools can help analysts identify the linkages between components in sectors that have a myriad of natural, social, and economic inputs and outputs, such as food systems. Quantitative models can be used to quantify the indicators and relationships presented in the CLD and Tree diagrams. An agricultural production model can be used to forecast food supply, climate forecasts can be used to inform the estimation of land productivity and agriculture production (with differentiated impacts for different crops), and spatial landscape modelling facilitates estimation of land cover change over time, including soil loss and nutrient export resulting from climate impacts. Changes to land use practices, which are likely a key component of alternative policy scenarios, could be made by assumption or modeled from household survey data. Household or farm-level land use decisions can then be extrapolated across a region and integrated into the spatial landscape model.

The value of ecosystem services such as water purification and carbon sequestration, as well as the avoided costs of health services, and reduced morbidity and mortality can be quantified using economic models based on individuals' stated or revealed welfare benefits, costs, or preferences. The results of these sectoral assessments, as well as the use of macroeconomic models, could be used for the CBA and CEA. At the societal and macro level, indicators such as employment , income generation for households, labour productivity, and income tax revenue for the government can be considered, in addition to the potential avoided costs of public service provisioning and reconstruction (due to improved ecosystem services, and resulting gains in climate resilience for example).

To evaluate a policy initiative such as climate resilience, for example, land cover, soil and water retention can be estimated using biophysical modelling, which can be used as inputs to a food production model. Demand for infrastructure such as road, water, and power supply and distribution can be estimated using additional sectoral models. The economic value of ecosystem services, or the resulting avoided costs for public service provisioning and reconstruction, can be considered in the assessment of the economic viability of the policy and resulting investment. Capital cost and operation and maintenance cost (e.g., tree planting), direct avoided costs (e.g., infrastructure damage, food assistance) and benefits (e.g., agriculture revenues) can be used in the estimation of the financial viability of climate resilience investments. And finally an extended cost-benefit analysis can be used to assess the return on investment of climate adaptation strategies for societal welfare.

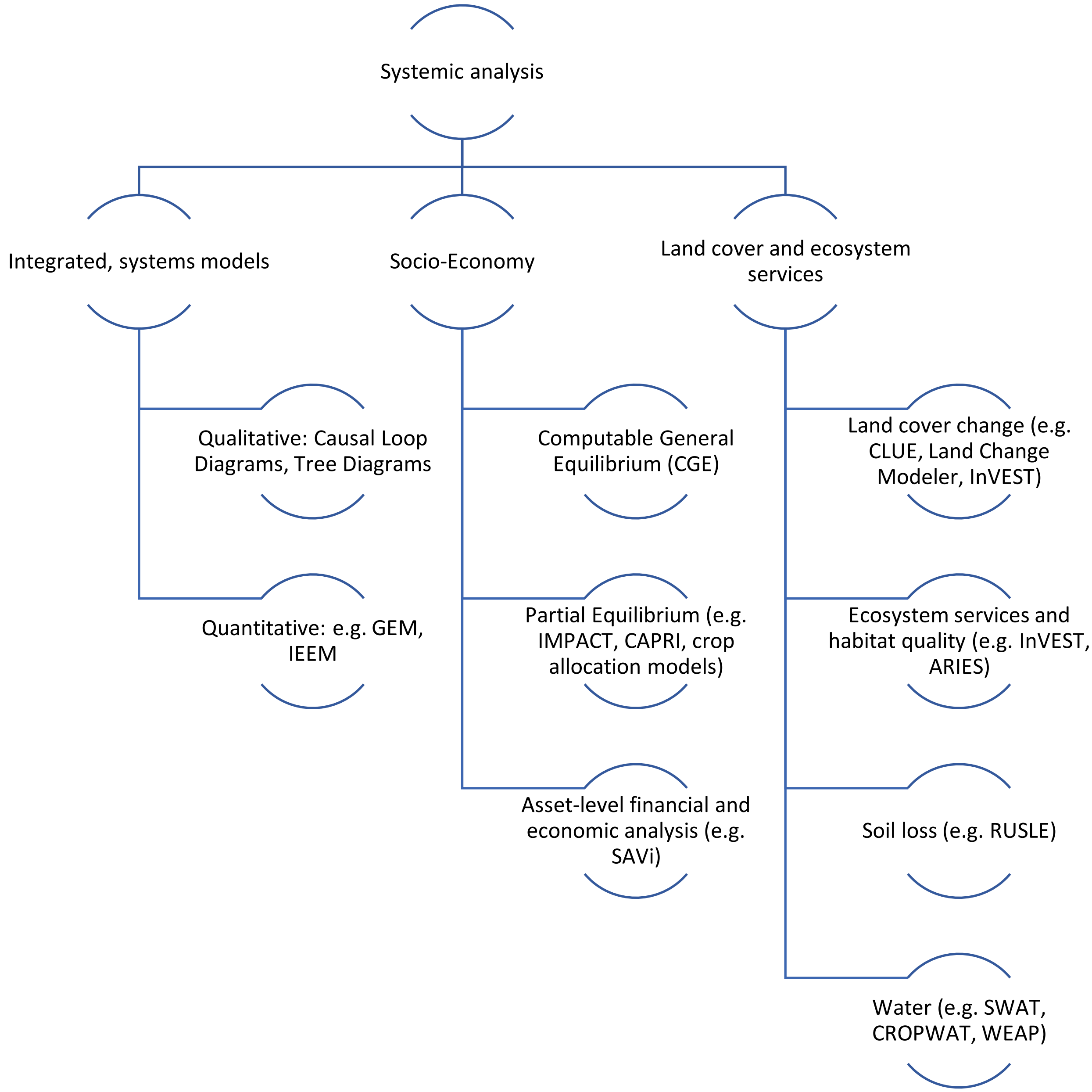

Figure 8: Overview of methods and models available to carry out a systemic policy assessment in alignment with the TEEB AgriFood Framework.

3.3.1. Setting the stage, qualitative, system mapping methods

Qualitative methods play an important role in the assessment of policy impact for agri-food sustainability. They support (i) the identification of key indicators of social, environmental, and economic welfare and their interrelations; (ii) the framing of the analysis via the use of a systemic approach that results in a shared understanding among all participants and stakeholders; and (iii) the interpretation of quantitative model results, based on all indicators of relevance, both those that can and cannot be quantified. Qualitative models complement quantitative methods.

In the context of agri-food sustainability assessments, qualitative methods are particularly valuable. They offer a means of capturing the intricate and interconnected relationships and processes that exist within agri-food systems, which can be challenging to model solely through quantitative approaches. As indicated earlier, two common qualitative methods that facilitate holistic assessments of agri-food sustainability are CLDs and Tree Diagrams.

CLDs and Tree diagrams are effective tools for representing and understanding the causal relations existing between and among variables within a system. CLDs, in particular, go a step further than Tree Diagrams by incorporating feedback loops, which are fundamental drivers of change in complex systems. These qualitative tools allow researchers, policymakers, and stakeholders to visualize and comprehend the intricate dynamics and interdependencies that shape agricultural sustainability.

What is a Causal Loop Diagram (CLD)?

A CLD is a visual representation that illustrates the causal relations existing among key variables in a system. It is a map of the system analysed and a way to explore and represent the interconnections between the key indicators in the analysed sector or system (Probst & Bassi, 2014). It is a tool used in systems thinking to analyze and understand the behaviour of complex systems.

"A causal diagram consists of variables connected by arrows denoting the causal influences among the variables. The important feedback loops are also identified in the diagram. Variables are related by causal links, shown by arrows. Link polarities describe the structure of the system. They do not describe the behaviour of the variables. That is, they describe what would happen if there were a change. They do not describe what actually happens. Rather, it tells you what would happen if the variable were to change." – From Business Dynamics: Systems Thinking and Modelling for a Complex World (Sterman, 2000).

In a CLD, variables are represented as nodes, and the causal relationships between them are depicted using arrows. The arrows indicate the direction of influence, showing how changes in one variable affect another variable. The arrows can be either positive (+) or negative (-), indicating a causal relation (see Table 2). A causal link from variable A to variable B is positive if a change in A produces a change in B in the same direction. A causal link from variable A to variable B is negative if a change in A produces a change in B in the opposite direction.

Table 2. Causal relations and polarity

Variable A	Variable B	Sign
↑	↑	+
↓	↓	+
↑	↓	-
↓	↑	-

The main purpose of a CLD is to identify and understand the main driver of change in a system, or feedback loop. Feedback loops are circular relations, where the output of one variable becomes the input for another variable, which then affects the original variable. There are two types of feedback loops: reinforcing and balancing. The former can be found when an intervention in the system triggers other changes that amplify the effect of that intervention, thus reinforcing it (Forrester, 2002). The latter, balancing loops, tend towards a goal or equilibrium, balancing the forces in the system (Forrester, 2002).

CLDs are particularly useful for visualizing and analyzing the dynamic behaviour of systems over time. They help stakeholders gain insights into the complex interdependencies and interactions within a system, identify unintended consequences, and explore the impacts of policy changes or interventions.

What is systems thinking (why CLDs are systemic)

System Thinking (ST) is a methodology that enables the analysis of a system and its parts. It allows one to better understand and forecast the outcomes of our decisions, across sectors, and economic actors, over time and in space, based on an accurate understanding of a system's dynamics (Probst & Bassi, 2014). Systems Thinking recognizes that the behaviour of a system emerges from the interactions and feedback among its components, and seeks to understand the underlying structures, patterns, and dynamics of the system. The approach emphasizes that a system is more than the sum of its parts and emphasizes the interrelationships, interactions, and dependencies among the components within the system.

Causal Loop Diagrams are visualization and modelling tools based on the framework of Systems Thinking. CLDs provide a visual representation of the systemic nature of a complex system, showcasing the cause-and-effect relationships and the circular feedback loops that drive the system's behaviour. The generation of CLDs builds a shared understanding of how the system works, and hence helps to identify effective entry points for intervention, such as public policies. When this is done using a participatory approach, it helps to bring people together, creating the required building blocks for the co-creation of a shared and effective theory of change.

CLDs also help us recognize that changes in one part of the system can have ripple effects throughout the entire system. They highlight the dynamic relationships and dependencies that exist within a system, allowing us to understand how changes in one variable can influence other variables, leading to both intended and unintended consequences. By representing these relationships and feedback loops, CLDs enable us to grasp the systemic nature of a complex system and gain insights into its behaviour.

Implementation steps

Creating a causal loop diagram involves several steps that are described next. Creating a CLD is an iterative process that may require multiple iterations of analysis, validation, and refinement. The goal is to develop a comprehensive and accurate representation of the system's causal relations and feedback loops.

1. Identify the sector: Determine the specific domain or sector you want to analyze. This could be anything from a business operation to a social or environmental system.
2. Identify the main problem/investment opportunity: Clearly define the primary issue or potential investment opportunity within the chosen sector. This step helps establish the focus of your causal loop diagram, by determining the boundaries and scope of the system.
3. Identify key variables: Select the key variable that best represents the problem or opportunity you identified in the previous step. This variable should capture the essence of the issue and serve as

the central element in your diagram. These variables can be tangible quantities (e.g., population, land use) or intangible factors (e.g., attitudes, policies).

4. Identify the main factors influencing the problem/opportunity: Determine the main factors that contribute to the problem or opportunity you identified. These factors could be internal or external to the system under analysis and should significantly impact the central variable. Ask questions like "How does Variable A influence Variable B?" or "What factors contribute to changes in Variable C?" Identify the cause-and-effect relationships among the variables.
5. Add them, as new variables, to the diagram: Incorporate the factors identified in step 4 as new variables in your diagram. These variables represent the key elements that interact with and influence the central variable.
6. Add the polarity (+ or – sign for each arrow): Establish the direction and nature of the relationships between variables. Use positive (+) or negative (–) signs to indicate whether the relationship is direct or opposite. Positive relationships indicate that changes in one variable will lead to similar changes in the same direction, while negative relationships imply that changes in one variable will cause opposite changes in the other.
7. Identify the factors influencing the cause of the problem/opportunity: Analyze the factors identified in step 4 to identify additional factors that influence the cause of the problem or opportunity. Repeat steps 5 and 6 to incorporate these new factors into your diagram. This iterative process allows you to capture the interconnectedness and feedback loops within the system.

By following these steps, a CLD can be built that visually represents the cause-and-effect relations and feedback loops within a complex system.

Checklist for the co-creation of a CLD with a diverse audience

The creation of CLDs can be informed, and coupled with other qualitative methods, such as focus groups, interviews, and workshops, which involve engaging with stakeholders to understand their perspectives and experiences. The following table presents 16 items to take into consideration when collaboratively creating causal loop diagrams, with a diverse audience, using a co-creation approach.

Table 3. Checklist for the co-creation of a CLD

#	Item	Description
1	Identify the problem, data, possible scenarios	Begin by clearly defining the problem at hand. Engage with local stakeholders and decision makers, or project counterparts, to confirm the problem at hand. Review relevant data and information to gain a comprehensive understanding of the situation. Consider different scenarios that could contribute to the emergence of the problem. Analyze the root causes, contributing factors, and dynamics at play. Also, identify the main feedback loops responsible for the emergence of the problem.
2	Focus on predetermined priorities	When conducting a CLD session, it is important to have a clear focus and predefined priorities based on item 1. Avoid asking the audience for their priorities, as it may give the impression of favoritism. Stick to the predetermined focus to ensure an inclusive and balanced discussion.
3	Prepare and reference your CLD	Prior to the live session, create a CLD and keep it next to your laptop during the discussion. This ensures that all key variables are included and properly placed within the diagram. Having a visual reference helps maintain accuracy and facilitates effective communication.

4	Start with the problem, then add causes	Begin the CLD session by clearly stating the problem and then proceed to identify its causes. By following this approach, you can systematically analyze the reasons behind the problem, leading to a better understanding of potential solutions.
5	Avoid overcrowding the diagram	Instead of placing the key variable at the center of the CLD, consider starting from one side and adding causes on the other side. This approach helps prevent overcrowding and improves the clarity and readability of the diagram.
6	Focus on one variable at a time	To prevent overwhelming the audience, introduce and discuss one variable at a time. By doing so, participants can better engage with each variable and understand its impact on the system.
7	Include polarity when adding arrows	When adding arrows to the CLD, ensure to indicate the polarity of the relationship (positive or negative). This adds depth to the analysis and helps create a coherent "story" that relates to real-world situations. Introduce arrows one by one to facilitate understanding and avoid overwhelming the audience.
8	Add variables regularly	Keep the discussion lively and engaging by frequently adding variables to the CLD. Avoid long periods without introducing new variables, as it can lead to audience disinterest. However, maintain a balance to ensure the conversation flows naturally.
9	Continuously update and fix the CLD	If issues or problems arise during the CLD session, address them promptly. Failing to update and resolve problems within the CLD may result in a shift in the discussion's direction, causing participants to lose focus. Regularly review and refine the diagram to keep it aligned with the evolving conversation.
10	Put yourself in the situation being analyzed	To effectively identify variables, arrows, and feedback loops, try to imagine yourself in the situation under analysis. This perspective allows you to observe the dynamics and capture a holistic understanding of the system.
11	Engage everyone in the discussion	Encourage active participation from all participants by involving them in the discussion. Ask targeted questions to elicit their insights and perspectives. This inclusive approach enhances the effectiveness of the conversation and ensures diverse viewpoints are considered.
12	Be cautious when sharing personal experiences	As a facilitator, focus on the new/local landscape rather than your personal experiences. Facilitate the discussion by sticking to the collective knowledge and insights of the participants. If any incorrect information is shared, trust that others in the room will correct it.
13	Implement proposed changes in the CLD	When new proposals for variables and arrows are suggested, incorporate them directly into the CLD. This approach allows everyone to visualize and evaluate the proposed changes. Discussing proposed changes without visual representation may hinder effective communication and understanding.
14	Focus on the story, not the diagram	The audience may not fully understand the intricacies of the CLD, but they can follow the story being constructed. Listen attentively to participants, interpret their contributions, and add them to the CLD. Once variables are included in the diagram, the audience can better comprehend the story and appreciate their input.
15	Regularly review the CLD to match reality	Take breaks every 10-15 minutes to review the CLD and ensure it accurately represents the discussed realities. Use these moments to share the evolving "story" emerging from the CLD, facilitating a deeper understanding among the participants.
16	Determine the model's ownership	Clarify whether the CLD being discussed is the facilitator's model or one developed collectively by the local stakeholders. This distinction helps set expectations and aligns everyone involved in the analysis process.

Example of a CLD for Tanzania food systems

The CLD exercise conducted for Tanzania's food systems (World Food Programme, 2021) is presented in Figure 9 as a full CLD, and by highlighting the main thematic areas included in the diagram (Figure 10).

The process of co-creation of the CLD started with the acknowledgement that a farmer's decision on what crops to grow depends on specific crop profitability. A discussion followed on what makes production profitable, including increased land productivity, reduced pre-harvest, post-harvest and distribution losses, and demand for high-value crops, fresh fruits and vegetables.

First, on the consumption side, it was discussed that women are better aware of the need to have a diversified diet that comprises of grains, vegetables, and fresh fruit. It, therefore, emerged that, if awareness about the advantages of healthy diets increases, and women are empowered, a positive, reinforcing feedback loop (R1) could be triggered.

Second, it was mentioned that diversifying production is expected to increase land productivity. This stems from improved soil quality resulting from crop rotation, intercropping with legumes and vegetables, and reduced soil erosion. Increased land productivity stimulates more investments in diversified production, creating a second reinforcing loop (R2). Importantly, land productivity is stimulated primarily by strengthening natural capital, via reforestation (to reduce soil losses, increase water retention) and the use of organic fertilizers (to increase soil quality by increasing soil organic matter).

Third, alongside efforts in diversification, investments in food processing were discussed, with mention of the multiple benefits these can generate. As an example, farmers would see increased revenues from selling higher quantities of processed goods (R3 in the CLD), as a result of a higher amount of products being sold (as opposed to lost in distribution). In fact, food processing reduces potential food losses, boosting profitability for farmers while also making nutritious food more convenient, especially in urban areas or situations where time for caregiving is limited.

Fourth, from the CLD it emerged that the additional production of diversified and nutritious food, coupled with an expanded value chain through food processing, leads to increased availability of non-perishable nutritious food in local markets. Processed food enhances the convenience of consuming nutritious meals, further stimulating demand. This heightened demand signals to farmers the importance of investing in diversified production and nutritious food (R4 in the CLD). A direct connection between supply and demand was therefore created, one that is bi-directional and forms a feedback loop.

Fifth, it also emerged that reducing food losses during distribution is crucial. Food processing minimizes the risk of losses, while a more efficient transport network ensures timely delivery and proper storage of fresh produce. By introducing cold storage facilities, more fresh produce can reach the market, generating revenue. In the absence of an established food processing value chain, improving transport infrastructure and food storage facilities become the most immediate positive impact on farmers' profitability (R5 and R6).

Considering the aforementioned factors, four main incentives were identified for investments in sustainable food systems that deliver benefits to all actors: (1) meeting the nutritional needs of farmers and their families, (2) increased profitability resulting from reduced distribution losses through improved road networks, food storage infrastructure, and expanded food processing, (3) heightened consumer demand due to improved education and access to nutritious food, and (4) potential higher demand for exports facilitated by export promotion activities. Three of these factors represent demand, while one reflects the economic viability of the investment.

Lastly, improving the sustainability of the food system yields benefits beyond production and distribution. Enhanced access, affordability, and desirability of nutritious food are expected to improve human health.

Improved human health, in turn, leads to higher labour productivity and reduced health costs for both households and the government. Additionally, the government can expect increased revenues from improved economic performance. The combination of reduced costs and increased revenues can free up resources for new investments, such as improved food storage facilities and rural road networks, further creating synergies and maximizing value for money (R7 in the CLD).

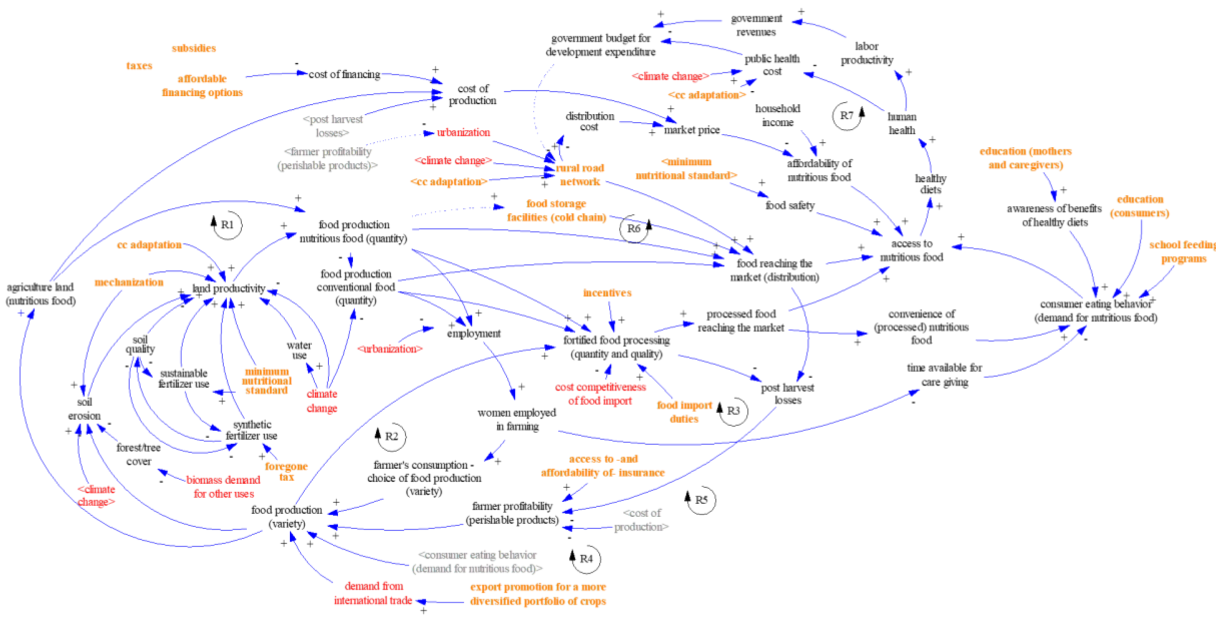

Figure 9. Full Causal Loop Diagram for Food Systems in Tanzania (World Food Programme, 2021)

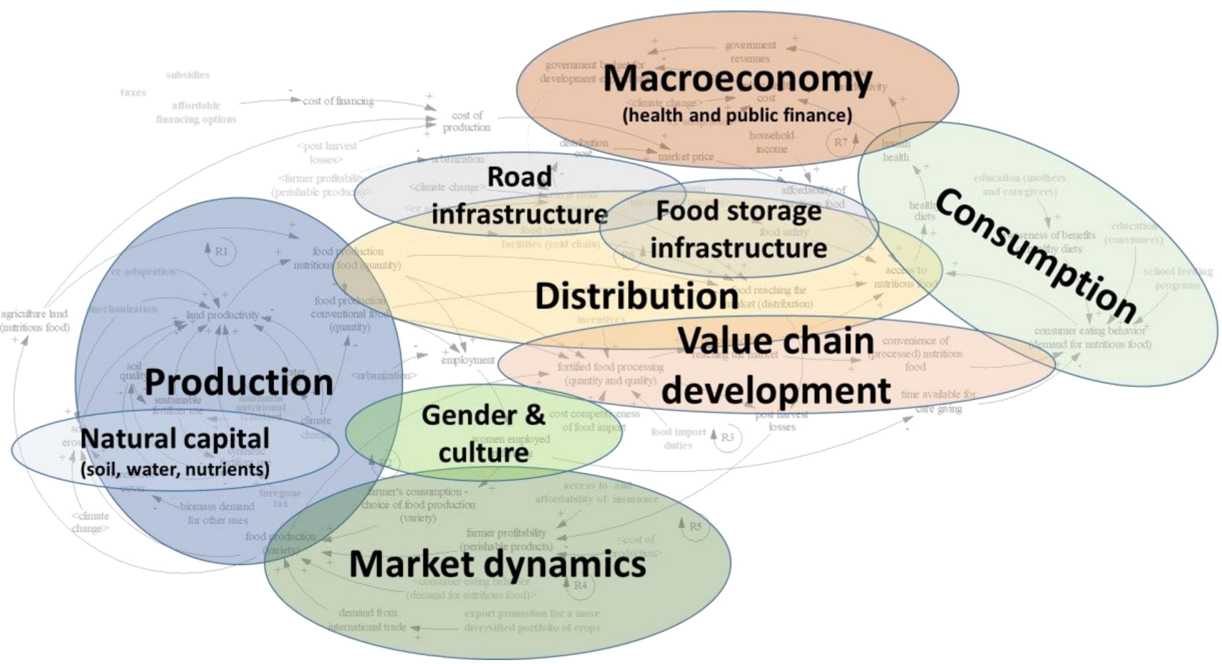

Figure 10. Thematic areas included in the full CLD, including production, distribution, consumption and infrastructure (food storage and roads) (World Food Programme, 2021)

3.3.2. Policy performance indicators, and model selection for measurement of indicators

In order to understand the importance of each of the connections identified in the CLD we must measure the magnitude of impacts on the indicators. Tools or models must be selected to measure each indicator based on the type of information desired and the data available. If possible, quantitative analysis should be conducted so that indicators can be compared more easily. However, some indicators, especially those for social capital, can only be evaluated using qualitative measures. To develop a comprehensive comparison of the policy scenarios, many types of biophysical, economic, and social-systems models must be integrated. In this section we provide examples of how to measure the priority indicators introduced in Section 2. Detailed descriptions of the models and measurement methods introduced here are provided in section 3.3.3.

- **Food security and nutrition**

The core of a food system assessment is quantifying food production and food security for target populations. This is done with an agricultural production model or a food supply and demand model.

Several models are available to estimate crop production, using different approaches. The Horizon 2020 MATS project (Making Agricultural Trade Sustainable) examined the literature on models utilized to assess production and its drivers, including climate impacts, as well resulting consumption and trade dynamics (MATS, 2022). MATS grouped models as follows: (i) macroeconomic models (e.g. CGE models), (ii) sectoral, partial equilibrium models (e.g. IMPACT, CAPRI), (iii) systems models (e.g. Green Economy Model) and (iv) spatially explicit models (e.g. InVEST, ARIES). These models consider different drivers of agriculture production, including (a) hectares of agriculture land and land productivity, with the latter being impacted by ecosystem services, (b) availability of capital and labor, using an approach that focuses more on technology and economies of scale, or (c) a path-dependence analysis, with an extrapolation of historical trends of production into the future. More details on this are provided next, for selected model typologies.

CGE models are an extension of the standard theory of market equilibrium (Solomon, Simane, & Zaitchik, 2021). These models provide a comprehensive representation of economic activities at the country, regional, or global level using national accounts data. Agriculture is a key sector of the economy, and affects a variety of other sectors at the macroeconomic level. A primary critique of economic models is the lack of integration between the assessment of economic performance and the state of the environment. However, by utilizing information derived from spatial models, it becomes feasible to establish a closer connection between economic indicators and biophysical indicators (United Nations, 2021). This allows economic performance to be influenced by the availability of natural resources and ecosystem services, while also impacting the condition of ecosystems and the provision of ecosystem services. Spatial data could provide valuable insights into the potential changes in production costs resulting from the decline in ecosystem services. Consequently, economic growth projections at both the sectoral and national levels could be impacted, leading to more comprehensive assessments of economic development. The Integrated Economic-Environmental Modelling Platform (IEEM) has been developed to incorporate an expanded set of parameters, specifically the environmental dimension and its influence on production costs, into the optimization algorithm. IEEM was designed to use data from the System of Environmental Economic Accounts (SEEA), the UN standard for environmental statistical accounting, to capture the contribution of natural capital assets to the economy. Additionally, supplementary indicators could be considered, such as the Gross Ecosystem Product (total value-added of final ecosystem services) or the total value of ecosystem assets. These indicators would not affect the calculation of existing indicators but rather serve as additional tools for interpreting the economic performance of the analyzed area, complementing more traditional indicators like sector-based value-added or GDP.

Partial equilibrium models (such as IMPACT or CAPRI) focus on a single sector or a small group of sectors (MATS, 2022). Specifically, in the context of the agricultural market, these models treat the market as an isolated system without connections to the wider economy. This allows to explore the dynamics of agriculture production in more detail, e.g. offering a higher disaggregation of crops.

System dynamics (SD) models provide an approach to address complex, large-scale, and dynamic systems with both linear and nonlinear interactions (Wang, Li, Liu, Lian, & Hong, 2022). By emphasizing causality and structure as determinants of behavior, SD offers models that capture the internal microstructure of a system, emerging from the interaction of social, economic and environmental dynamics of change.

These three types of models can receive input and be calibrated with the help of Linear Programming Models, which forecast agricultural product output considering agrometeorological events (Ivanyo, Fedurina, & Varanitsa-Gorodovskaya, 2020), and stochastic models that are developed to analyze the variability of factors such as heavy rainfall, early snowfall on crop yields.

Climate impacts can be embedded in spatially explicit models also. In 2021, the FAO updated its global agro-ecological zones (GAEZ) data portal, which combines agro-climatic potential yields with soil/terrain evaluation results. This accounts for yield reduction factors caused by soil limitations and terrain slope constraints. A recent development in this field is the Sen2-Agri system, which utilizes high-resolution Earth Observation (EO) data to generate various products, including monthly dynamic cropland masks and cultivated crop type maps at a 10-meter resolution for main crop groups. The Sen2-Agri system is free and open source, requiring national data that can be used as a training dataset for validating the EO data. While it offers excellent spatial and temporal detail, it only covers five main crop types per region.

It should be noted that food security encompasses not only food production but also factors such as seasonality, regional supply and demand, food transportation and storage facilities, and market prices, determining affordability (United Nations, 2022). To account for the temporal variability of crop harvesting, data should ideally be collected on a monthly basis, and simulation models should account for the consideration of seasonality. Further, the integration of production, distribution and consumption should be considered, allowing to identify synergies for interventions across the food systems (World Food Programme, 2021).

Lastly, but perhaps most important to the development of of specific policy intervention strategies, human behavioral responses to policy initiatives, regulations, or incentives must be estimated. Consumer and producer decisions can be predicted based on past behavioral responses (revealed preferences) or based on primary surveys, such as choice model surveys (stated preferences). Behavior estimates could be statistically deterministic or probabilistic (Bayesian). Behavior modelling options include econometric models of historic time-series data (before/after, control/intervention), randomized control trials, agent-based models, causal-descriptive models and social network analysis.

Table 4: Summary of the literature review carried out by the MATS project (MATS, 2022).

Modelling approach	Models	Goal	Dataset	Regional Coverage	Forecasting Time Frame
Computable General Equilibrium (CGE) models	• National Computable General Equilibrium model • Dynamic CGE (DCGE) model • MAGNET model • MyGTAP model	CGE models capture macroeconomic dynamics, primarily targeting fiscal and monetary policy.	GTAP Database; Social Accounting Matrix (SAM).	• Global • National • Regional	~2050
Partial Equilibrium models	• IMPACT • CAPRI • UKAMM • AGMEMOD	Partial equilibrium models confine themselves to one sector or a small group of sectors. In the case of the agricultural market, partial models consider the market as a closed system without linkages with the rest of the economy. Partial models can provide product detail that cannot be obtained from CGE models.	Various data sources, such as EUROSTAT, FAOSTAT, OECD.	• Global • National • Regional	~2050, up to 2100
System Dynamics (SD) Models	• Green Economy Model (GEM)	The SD modelling framework has been widely used in research related to agricultural land, soil, and water resources management, as well as in the examination of the resilience in food systems to address complex and non-linear feedback systems (Sterman, 2000).	Various bio-economic datasets	• Global • National • Regional	Depends on the setup of the experiment.
Spatial models	• InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs)	Spatially explicit models can be used to map and value key ecosystem services allowing users to address questions at local, regional, or global scales (The Natural Capital Project, 2020).	Various bio-economic datasets	• Global • National • Regional	Depends on the setup of the experiment.
Optimal Crop Allocation models	• Flower Pollinated Algorithm • Linear Programming Models • Stochastic and math Algorithm	Identify optimal crop choices in a given landscape, region.	Various bio-economic datasets	• Global • National • Regional	Depends on the setup of the experiment.

- **Land degradation, soil erosion, and desertification**

Degradation of soils, soil erosion, and desertification reduce agricultural productivity and threaten food security globally. In some regions, land degradation is being exacerbated by the climate crisis. Assessments can measure the positive value of the contribution of healthy soils to agricultural productivity (the ecosystem service), or the loss of productivity from degradation. Impacts of land degradation could also include damages from sedimentation, nitrification, air pollution or landslides.

Indicators of land degradation include soil loss, soil organic matter, soil nutrients, and more. Approaches for measurement range from broad estimates of net primary productivity (Sutton, Anderson, Costanza, & Kubiszewski, 2016) to detailed assessment of crop productivity (Adiku, MacCarthy, & Kumahor, 2022). Soil degradation can be spatially modeled by integrating GIS with soil loss models such as the Revisited Universal Soil Loss Equation (RUSLE) (Brandolini, Kinnaird, Srivastava, & Turner, 2023). With respect to food systems, analytical assessment of land degradation or sustainable land management policy responses could be evaluated as specific case of food security intervention and integrated with the approaches above. Conversely, it could be evaluated as one of the unintended outcomes of policies that encourage intensive agricultural production or the absence of agricultural production regulations.

Sediment and soil retention modelling can be approached in two ways: one that relies on globally available data sets and pre-constructed ecosystem service models (e.g., InVEST, ARIES, ESTIMAP, LUCI/Nature Braid) and requires minimal user input, and another that utilizes national data sets with some customization and instream sediment measurements for validation (United Nations, 2022). Concerning the former, SWAT (Soil and Water Assessment Tool), a model that can estimate annual soil retention, is a semi-distributed model that operates at a daily temporal scale and utilizes spatial inputs such as land use and elevation (Swain, et al., 2022). SWAT's soil retention model requires a wide range of inputs and is typically applied at the local or watershed scale rather than the national level. Calibration of the SWAT model often involves using daily stream flow data. Concerning the latter, and data availability, the Copernicus European Earth monitoring program serves as a global land service to address the requirements of various policy areas, including land degradation, desertification, and rural development (United Nations, 2022). A specific example is the South Asia Drought Monitoring System (SADMS), which was established in 2014. SADMS produces and maintains weekly maps depicting drought conditions and is managed by the International Water Management Institute (IWMI). To offer comprehensive drought monitoring and assessment information for diverse applications, multiple drought indices have been developed. These include the Integrated Drought Severity Index, Standardized Precipitation Index, and Soil Moisture Index. By utilizing these indices together, not only can an accurate representation of specific drought events be depicted, but valuable decision-making tools can also be provided.

- **Freshwater quality and quantity**

Water provisioning can be a challenging ecosystem service to measure and value because it has many dimensions. Total available freshwater, the timing of water flows, surface runoff, groundwater infiltration, and water quality are all important water indicators. Both too much water and too little water impact agricultural productivity and human welfare. Although water is a natural capital asset, total freshwater availability is mostly a function of climate (rain and snowfall) and therefore cannot be impacted by regional or local policy decisions. However, the timing of water flows, rates of runoff and infiltration, and water sedimentation, pollution and contamination are affected by policy decisions related to land use and land cover, industrial, agricultural and sanitation activities, and the presence and enforcement of water and land use rules and regulations. Analysts must determine, through the process of developing causal loop diagrams or other surveys of policy concerns, which aspects of water quality and quantity are material to a given scenario. For example, a reduction in water supply may be observed as a result of deforestation. Reduced water retention and percolation may have resulted in lower groundwater recharge and higher water runoff. Impacts may include increased frequency of floods and loss of topsoil, resulting in negative consequences for land productivity (from water scarcity and from floods). When fertilizers are used to offset the reduction of land productivity, water pollution may emerge as a new issue. This example highlights the importance to take a systemic approach, to avoid the creation of side effects of policy decisions, or “fixes that fail”. Again, water issues could be both the motivation for or a result of food security or agricultural policy.

When conducting water demand modelling, it is beneficial to consider individual economic activities separately (United Nations, 2022). It is ideal for national water-use reports to present a comprehensive summary of water usage across both space and time in a consistent manner throughout the country. Agriculture commonly stands as one of the primary water consumers. To model agricultural water usage, one can employ coefficients that represent water requirements per crop type and climate, taking into account various crops along with relevant crop statistics. Additionally, information from water permits or the number of wells and boreholes can be utilized to model irrigation. Agricultural surveys may also provide valuable data in this regard.

Besides agriculture, several other sectors use water, for different types of services. Typically, information regarding water usage can be obtained from company reports or water permit data. Additionally, data from water distributors might be accessible. Certain countries conduct dedicated surveys to gather information on water consumption by different industries. Household water usage data may be available through household surveys as well. These datasets are also compiled and made accessible through FAO's AQUASTAT, which offers information on water usage by industry and country (United Nations, 2022).

A range of water-related models exists, ranging from simple water balance and precipitation models to advanced integrated water resource planning models with spatially explicit features (United Nations, 2022).

The Soil and Water Assessment Tool (SWAT) is a model designed for large, complex watersheds, aiming to quantify the impact of land management practices. Operating at a daily time step on a continuous time basis, SWAT forecasts the effects of land management practices on water, sediment, and nutrientsover extended periods.

CROPWAT, developed by the Land and Water Development Division of FAO, is a decision support tool for calculating crop water requirements and irrigation needs based on soil, climate, and crop data. The program facilitates the development of irrigation schedules under different management conditions and determines the required water supply for varying crop patterns.

The Water Evaluation and Planning (WEAP) tool, developed by the Stockholm Environment Institute, takes an integrated approach to water resource planning. By considering water supply, demand, quality, and ecological aspects, WEAP addresses the challenges associated with freshwater management.

The Precipitation-Runoff Modelling System (PRMS) is a physically-based modelling system that assesses how land-use changes and the climate crisis influence watershed characteristics and hydrological responses.

The InVEST software package includes models to estimate Seasonal Water Yield, Water Purification, Sediment Retention, Reservoir Hydropower Production, Urban Storm water Retention and Urban Flood Risk Mitigation.

- **Rural livelihoods**

The livelihoods and income of rural families and communities are a major policy priority in most countries, especially in developing countries with large proportions of the population that depend on agriculture, livestock, and natural resource use. Although TEEBAgriFood is focused on food systems, rural populations may earn their livelihoods through eco-tourism, wildlife, hunting, fishing, logging, mining or a combination of these sectors. Individuals face trade-offs and opportunity costs in choosing their livelihood strategies. The main indicator is household income, but policy makers may also care about rural municipality tax revenues, employment/unemployment, enterprise development, womens' incomes, and child labor. Models are needed that can shed light on the synergies and trade-offs emerging from the use of different approaches to income creation. It is important to determine how rural households make the decisions they make and how those decisions could be changed (e.g. identifying how short term income creation opportunities may cause environmental degradation and hence curb the potential for income creation in the future). Systems models are required to integrate different economic activities and decisions, as well as their multi-dimensional outcomes (considering natural capital implications), in a single framework of analysis.

In this context, a study (Mbanda & Ncube, 2021) examined the impacts of government interventions on the rural economy, specifically in agriculture. The authors focused on assessing the economy-wide effects as well as the distributional impacts of rural development interventions, considering factors such as location and gender. To accomplish this, they utilized CGE modelling to estimate the macro-level consequences of reallocating land from commercial agriculture to smallholder agriculture in South Africa. The findings of the macro analysis were then used to evaluate the resulting welfare effects. CGE models are highly suitable for analyzing the broad impacts of policies in various sectors of the economy, including agriculture (Verkerk & Pyka, 2021). The study encompassed two simulations: the first one explored the redistribution of land from commercial agriculture to smallholder agriculture, while the second simulation examined the increase in capital for the predominantly rural agricultural sector. Both simulations indicated that providing support to small farmers could have positive outcomes for the South African economy. Based on these findings, it is recommended that the government implements a policy of allocating land from commercial to smallholder agriculture, as this policy change is expected to significantly reduce gender inequality and poverty, as evidenced by the study.

The integration of SEEA EA data into CGE models is facilitated by the Integrated Economic-Environmental Modelling (IEEM) platform (United Nations, 2021). This platform serves as a framework for combining non-material, regulating, and cultural/aesthetic ecosystem services by linking IEEM with spatial ES modelling, referred to as IEEM+ESM. The connection between these two modelling frameworks is established through a module dedicated to Land Use Land Cover change (LULC) modelling. Several LULC change models, such as the Conversion of Land Use and its Effects (CLUE) modelling framework, can be utilized for this purpose. Through IEEM, the impacts of policies can be observed through their effects on various aspects such as GDP, employment, income, environmental resources, wealth, and environmental quality.

ARIES is a web-based technology that provides a global user base with a valuable tool for conducting rapid ecosystem service assessment and valuation (ESAV). Its primary purpose is to assist users in discovering, comprehending, and quantifying environmental assets and their associated values within specific geographic areas. ARIES, and similar models like InVEST, can be used to quantify ecosystem services and ecosystem goods, to then proceed with their economic valuation, especially in the context of income creation.

- **Eco-tourism**

Eco-tourism can offer an important economic contribution, as well as an opportunity to diversify income creation. Eco-tourism can be analyzed and modeled in several ways. Certain models use infrastructure (e.g. roads, hotels) to determine offer; while other focus on demand, and assess primarily the quality of ecosystems. Both dimensions are important, as well as their interconnections (e.g. the extent to which ecosystem integrity attracts tourists, and the extent to which tourism activities affect ecosystem quality and integrity).

The Green Economy Model (GEM) was specifically developed for the purpose of analyzing scenarios related to the green economy (Bassi, 2015). It encompasses various sectors that span social, economic, and environmental dimensions, including the tourism sector. In GEM, conventional and eco-tourism are represented separately, including the impact that natural capital integrity can have on the attractiveness of a given area for eco-tourism. The model also considers the impact of tourism volumes and tourism activity on the quality and integrity of ecosystems.

The InVEST Recreation Model offers a spatially-explicit approach and utilizes a dataset of geotagged photographs obtained from the social media platform Flickr (United Nations, 2022). These photographs have demonstrated a correlation with park survey data, providing valuable insights into recreational activities.

Similarly, the ESTIMAP model employs a sophisticated approach to estimate the provision of recreation services (United Nations, 2022). It achieves this by comparing the predicted demand for the service with the potential supply. Among these services, the recreation potential considers factors such as the attractiveness of an area for recreation, which is based on land cover type and ecological characteristics like water quality and conservation status. Additionally, accessibility for recreation is assessed by considering infrastructure elements such as roads and proximity to residential areas. These two dimensions form a recreation opportunity spectrum, assigning scores ranging from 1 (indicating low accessibility and potential) to 9 (indicating high accessibility and potential). The model then focuses on areas with the highest scores, referred to as "areas for daily recreation." Subsequently, the demand for recreation services is estimated using a trip generation function combined with population density. The actual service flow is determined by overlaying the supply and demand, yielding the predicted number of visitors to areas designated for daily recreation. This analysis also provides estimates of unmet demand, indicating populations with limited access to local recreational sites.

Finally, ARIES includes a simplified version of ESTIMAP that does not take water quality into account when estimating recreation potential (United Nations, 2022). On the other hand, ARIES integrates park visitation data with tourism statistics to estimate nature-based tourism in both physical and monetary terms.

- **Climate change mitigation, adaptation, and resilience**

Climate change mitigation, adaptation, and resilience are a high priority for many countries and ministries. Indicators related to climate change mitigation include carbon sequestration and storage and carbon and methane emissions. These indicators measure progress related to countries' Nationally Determined Contributions (NDCs) under the Paris Climate Agreement. Carbon sequestration may offer income opportunities in regions where carbon offsets can be verified and sold.

Measurement of climate adaptation and resilience is developing rapidly as countries grapple with the foreseen and unforeseen impacts of climate change. For food systems, indicators of climate resilience include the diversity of crop and food sources domestically and the strength and breadth of trade relationships. Indicators of adaptation include levels of implementation of farming methods to mitigate extreme weather, agrobiodiversity, investments in weather prediction services, and food and water storage and transportation systems. Several models are available to measure the impact of climate change on socio-economic activity and the environment. The Inter-Sectoral Impact Model Intercomparison Project (ISIMIP) provides a library of models, and related datasets[4]. An additional example is the GEM-CPP model (Green Economy Model-Climate Prosperity Plan)[5], co-developed by Aroha and the Vulnerable Group of 20 (V20) to support the formulation and evaluation of national climate adaptation and mitigation plans. This model includes more than 30 damage functions across sectors, assets and human health impacts, allows the simulation of various climate scenarios (based on data obtained from the EU Copernicus database) and offers the possibility to create an integrated Cost Benefit Analysis for more than 50 climate adaptation options. Further, the Climate Vulnerability Monitor (CVM) provides modeled impacts for several biophysical, economic and health indicators that can be used directly in a variety of simulation models[6].

There are essentially two primary methods for assessing climate change mitigation via carbon sequestration and storage in ecosystems, as outlined by Edens et al. (2019). The first approach, known as the stock-difference method in IPCC guidelines, involves measuring changes in carbon stocks over time. This can be done by analyzing forest inventories and soil carbon measurements, considering both above and below ground carbon stocks in various forms. This indirect method calculates sequestration as a residual, using stocks as a proxy for the carbon retention component of the service. In this respect, the InVEST carbon storage and sequestration model differentiates between four carbon reservoirs: the amount of carbon present in aboveground biomass, belowground biomass, soil, and dead organic matter. The second approach, called the Gains-Loss method in IPCC guidelines, directly estimates carbon sequestration. It involves quantifying all significant inflows and outflows of carbon per ecosystem unit to determine the net ecosystem carbon balance. ARIES for SEEA assesses vegetation carbon and soil carbon as distinct components (United Nations, 2022).

3.3.3. Integration of knowledge and modelling methods for policy analysis

Numerous methods and models exist to facilitate decision-making across the proposed and analyzed policy areas. However, it's crucial to recognize that each model is designed for a specific purpose. Therefore, the first step is to identify the policy question that requires analysis and determine the specific policy instruments under consideration. Once this is clarified, the appropriate model can be selected, one

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[4] Available at https://www.isimip.org/
[5] Available at https://www.ke-srl.com/gem
[6] Available at https://www.v-20.org/climatevulnerabilitymonitor

that was developed precisely to address and inform the identified policy question while utilizing the relevant policy instruments.

A few examples are proposed next, with emphasis on (i) food security and nutrition, and specifically on food production, (ii) land degradation, soil erosion and desertification, and specifically on soil loss, and (iii) freshwater quality and quantity, and specifically on water allocations and water management.

Rural economic development, food security and nutrition

Modelling serves various purposes in estimating rural economic development, including as a result of crop provisioning services (United Nations, 2022), resulting food security and nutrition. It offers methods to analyze the economic contribution of crop production to farmers and rural livelihoods. Additionally, modelling can be utilized to estimate crop yields based on the suitability of the environment for specific types of agricultural production. Moreover, biophysical modelling enhances our understanding of ecological contributions to crop provisioning by establishing connections with ecosystem conditions and reporting on intermediary services related to crop production.

The choice of approaches for modelling rural economic development depends on (i) the sources of income (e.g. crop production, livestock, ecosystem goods), (ii) the geographical location and the availability and detail of (iii) agricultural statistics, such as yield and management practices, as well as (iv) on the type of intervention options considered. Below, we provide suggestions on how to approach modelling rural economic development, considering all crop provisioning at the farm and sectoral level, macroeconomic implications of trade policy, value chain development and food, energy and water nexus, using different policy entry points.

Policy entry point 1: crop production potential, by location

Some spatial models, like the InVEST Crop Production Model, can generate yield maps and tables that can be standardized into SEEA EA tables, providing an initial estimate of crop provisioning services. This model allows a detailed analysis of the costs and benefits of agriculture production, including evaluating alternative cropping systems, the impact of intensification on ecosystem services, and strategies for meeting food demand while minimizing the impact on ecosystems (Natural Capital Project, 2022). However, a limitation of this approach is the lack of consideration for yield variations based on landscape characteristics, such as slopes or valley bottoms, as the model only incorporates climate, fertilization, and irrigation factors.

For more accurate yield models, national data can be utilized. For instance, LUCI / the Nature Braid estimates crop production potential based on factors like soil fertility, aspect (orientation of hill slope, such as north or south-facing), and climate, which can be linked to yield estimates (United Nations, 2022). This model enables the identification of regions where modifications in land use could be advantageous in unlocking the landscape's maximum capabilities (Nature Braid, 2022). Alternatively, it identifies areas where maintaining the current land use practices is preferable to prevent any degradation. If available, detailed information on tillage techniques, fertilizer usage, and irrigation can be incorporated. Otherwise, regional averages are assumed, but these averages are currently compiled for only a limited number of countries in the Asia-Pacific region.

Policy entry point 2: implication of macroeconomic policy, including trade

Computable General Equilibrium (CGE) models are particularly well-suited for assessing the comprehensive effects of policies across the economy (e.g. fiscal, trade policy), specifically in areas such as agriculture, energy, and trade (Verkerk & Pyka, 2021). These models can effectively evaluate the impacts of these policies on various factors, including GDP, income creation, land-use change, greenhouse gas (GHG) emissions, and more. CGE models simulate how markets react to changes in macroeconomic policy (e.g. the introduction of subsidies, price incentives), and the availability of labor, capital, and natural resources, and assess the resulting impacts on the production and consumption of specific goods and services (Solomon, Simane, & Zaitchik, 2021). In CGE models, the production of goods and services in each sector is determined by primary factors like labor, capital, and natural resources, as well as intermediate factors obtained from other sectors. The total demand for output in each sector includes demand from other sectors, consumers, and investors. Technologies are represented by production functions that capture the relationship between input factors and output in each sector. Consumer demand is described by the relationship between the consumption of goods and services and overall welfare.

Policy entry point 3: value chain analysis

Partial equilibrium models provide detailed analysis of specific agricultural sub-sectors, examining supply and demand, price formation, interdependencies between inputs and outputs, policy effects on supply and producer income, and more. These models follow a neo-classical approach, where supply and demand reach equilibrium and producers and consumers strive to maximize profits and product utility (Kotevska, Dimitrievski, & Erjavec, 2013). Partial equilibrium models, such as IMPACT or CAPRI, primarily concentrate on a singular sector or a limited group of sectors (MATS, 2022). Particularly within the agricultural market framework, these models operate under the assumption that the market functions as an isolated system, disregarding its interconnections with the broader economy. Nonetheless, it is possible to introduce modifications to model parameters and exogenous variables, thereby integrating the effects of the wider economy or the global market on the agricultural system. Partial models provide intricate insights into specific products, offering a level of detail that may not be achievable through CGE models.

Policy entry point 4: food, energy and water nexus

A key aspect of agricultural production systems is the interconnectedness of environmental, biological, and socio-economic resources (Kragt, et al., 2016). Therefore, when conducting applied agricultural systems research, it is essential to carefully examine the connections between the quality and quantity of natural resources, such as soils, water, habitat quality, plant and animal physiology, as well as farm production costs and profits. The System Dynamics modelling framework finds extensive application in research related to the management of agricultural land, soil, and water resources (United Nations, 2022). It also plays a crucial role in examining the resilience of food systems in the face of intricate and nonlinear feedback systems. By integrating dynamic systems modelling with spatial models, such as employing generic differential equations within a Geographic Information System (GIS) for a specific ecosystem type in a landscape, it becomes possible to capture the diverse evolution of each pixel within the landscape due to variations in initial conditions or management regimes. This systems approach allows for the incorporation of non-linear dynamic processes, feedback mechanisms, and control strategies, enabling the study of complex ecosystem dynamics, including the identification of thresholds in ecosystem responses.

Land degradation, soil erosion, and desertification

Soil erosion control services refer to the ecosystem's contributions, specifically the stabilizing impact of vegetation, which mitigates soil and sediment loss while supporting agricultural activities (United Nations, 2022). This service is critical for land productivity, as indicated in relation to *rural economic development, food security and nutrition*, policy entry point 1 on crop production, and is occasionally referred to as soil erosion prevention or sediment control. Vegetation plays a crucial role in securing sediment, creating a stable base of nutrient-rich soil that promotes productivity in forestry and agriculture.

Erosion negatively affects soil productivity and contributes to desertification in vulnerable regions (Panagos & Katsoyiannis, 2019). Given the existing climate change and more frequent water crises, policy measures are required to prevent and mitigate the consequences of soil erosion in degraded areas.

Policy entry point 1: identification of areas vulnerable to soil erosion

There are two approaches to sediment retention modelling: the first involves utilizing globally accessible data sets and pre-existing ecosystem service models (such as InVEST, ARIES, ESTIMAP, LUCI/Nature Braid), which require minimal user input. The second approach utilizes national data sets with certain modifications and includes in-stream sediment measurements for validation purposes (United Nations, 2022).

The first approach, using models like InVEST and LUCI/Nature Braid, utilizes freely available tools and involves inputting raster data sets of climate, soil, elevation, land use, and land cover, along with look-up tables for crop management and support practice factors (United Nations, 2022). These models have the advantage of quantifying the connectivity of each pixel to streams, allowing for the calculation of the sediment likely to leave a given pixel rather than just potential erosion. ARIES currently incorporates the RUSLE (Revised Universal Soil Loss Equation) to estimate sediment retention in its global models.

The second approach, employing models such as LUCI/Nature Braid, requires customization and in stream sediment measurements for validation. LUCI/Nature Braid traditionally provided estimates of sediment erosion based on the Compound Topographic Index. However, new supplementary algorithms now allow for models based on the RUSLE, which provides annual estimates of retained soil. While LUCI/Nature Braid is parameterized with global datasets, it is more detailed for specific regions like the UK, New Zealand, the Philippines, and other Asia-Pacific locations. For national applications, LUCI/Nature Braid necessitates inputs such as soil type, land cover, precipitation, and evapotranspiration. Careful choices must also be made to accurately calculate factors like soil erosion from rainfall.

Policy entry point 2: identification of areas suitable for reforestation and land restoration

Additionally, the Soil and Water Assessment Tool (SWAT) is a commonly employed watershed model utilized to forecast the effects of land management on soil erosion and water quality (United Nations, 2022). It is a modelling tool that operates at the scale of small watersheds to river basins (SWAT, 2023). It is utilized to simulate both the quantity and quality of surface and groundwater, as well as predict the environmental consequences of land use, land management practices, and climate change. SWAT finds extensive application in evaluating soil erosion prevention, non-point source pollution control, and regional management within watersheds. SWAT operates as a semi-distributed model, meaning that outcomes are aggregated at the sub-watershed level instead of being distributed across a raster surface. Consequently, additional adjustments may be necessary to adapt SWAT results for SEEA EA accounts.

Implementing SWAT necessitates a substantial amount of data and empirical parameters for its development and calibration.

Freshwater quality and quantity

When conducting water demand and supply modelling, it is beneficial to model different economic activities separately. Ideally, national water-use databases should provide a comprehensive overview of water usage across different regions and over time in a consistent manner. Agriculture is frequently one of the major water consumers. To model agricultural water use, coefficients that represent water requirements for different types of crops (based on crop type and climate) could be used. In order to model irrigation specifically, there is a variety of water models available, ranging from basic water balance and precipitation models to advanced integrated models for water resource planning that incorporate spatial explicitness (United Nations, 2022).

Policy entry point 1: estimating crop water requirements for optimal food production planning

CROPWAT, developed by the Land and Water Development Division of FAO, is a decision support tool used to calculate crop water requirements and irrigation needs based on soil, climate, and crop data. It aids in developing irrigation schedules under different management conditions and determining the necessary water supply for varying crop patterns. CROPWAT also assists in evaluating farmers' irrigation practices and estimating crop performance under both rain-fed and irrigated conditions.

Policy entry point 2: identification of areas suitable for improved water management

The Soil and Water Assessment Tool (SWAT) is a modelling tool specifically designed for large and complex watersheds. Its purpose is to quantify the impact of land management practices on water supply. Operating on a daily time step over extended periods, SWAT predicts the effects of land management on water, sediment, and agricultural yields. It is particularly valuable for simulating water and nutrient cycles in agricultural landscapes at the basin scale, assessing the environmental efficiency of best management practices, and evaluating alternative management policies. Nonetheless, substantial data inputs are required for running the SWAT model effectively. Ideally, four years' worth of daily streamflow data from multiple stations within a watershed are necessary for model calibration.

The Precipitation-Runoff Modelling System (PRMS) is a physically-based modelling system that assesses how land-use changes and the climate crisis impact watershed characteristics and hydrological responses. PRMS utilizes distributed parameters and watershed partitioning to account for spatial variations in rainfall within the watershed. It models the hydrological system based on physical laws or empirical relations, calculating separate water and energy balances for small units within the analyzed watershed and aggregating them to derive area-based weighted total responses.

Policy entry point 3: water allocation across competing uses

Water stored, transported, and used for agriculture can compete with or compliment other sectors, such as energy generation, tourism and recreation, and wildlife conservation. As freshwater management challenges become more prevalent, the allocation of scarce water resources among agricultural, municipal, and environmental needs necessitates the comprehensive integration of supply, demand, water quality, and ecological factors (WEAP, 2023). The Water Evaluation and Planning system, known as WEAP, seeks to address these complexities by providing a practical and reliable tool for integrated water resources planning. This tool, developed by the Stockholm Environment Institute, takes an integrated approach to water resource planning (United Nations, 2022). By considering water supply, demand, quality, and ecological aspects, WEAP addresses the challenges associated with freshwater management. Its GIS-based interface allows users to overlay elements onto existing GIS maps, enabling exploration of the potential impacts of changing assumptions. WEAP incorporates models for rainfall-runoff, infiltration, evapotranspiration, crop requirements and yields, surface and groundwater interaction, and in-stream water quality.

Policy entry point 4: climate resilience, including in urban environments

The InVEST software package includes various models for estimating Seasonal Water Yield, Water Purification, Sediment Retention, Reservoir Hydropower Production, Urban Stormwater Retention, and Urban Flood Risk Mitigation. These models rely on GIS map layers. By comparing existing land use/land cover (LULC) images to hypothetical future LULC data layers, these models spatially demonstrate how changes in LULC can affect the provision of these ecosystem services. InVEST offers a low-data requirement tool, that support the assessment of the impact of landscape management on seasonal water demand and supply (Hamel, et al., 2020).

4. A step-by-step approach to policy formulation and evaluation

This section provides a step-by-step approach for the creation of a systemic policy assessment. Seven steps, summarized as PROCESS are proposed: identify the **P**olicy question, **R**ecruit a multi-disciplinary team, **O**utline scenarios and shape the analysis, **C**onfirm relevant indicators, **E**valuate the results of the analysis with suitable methods and models, **S**hare and interpret results and **S**tart implementing (Figure 11).

These steps are broadly aligned with the implementation phases of the TEEB AgriFood framework, which includes the frame (phase 1), describe & scope (phase 2), measure & value (phase 3), and take action (phase 4). This guidance document focuses on the use of forecasting methods and models within phase 3, on measurement and economic valuation (Figure 12). On the other hand, in order to select, customize and use simulation models effectively, it is important to integrate the modelling assessment in all implementation phases. For this reason, the 7 steps provided cover phase 1 (step 1), phase 2 (step 2), phase 3 (steps 3-6) and phase 4 (step 7).

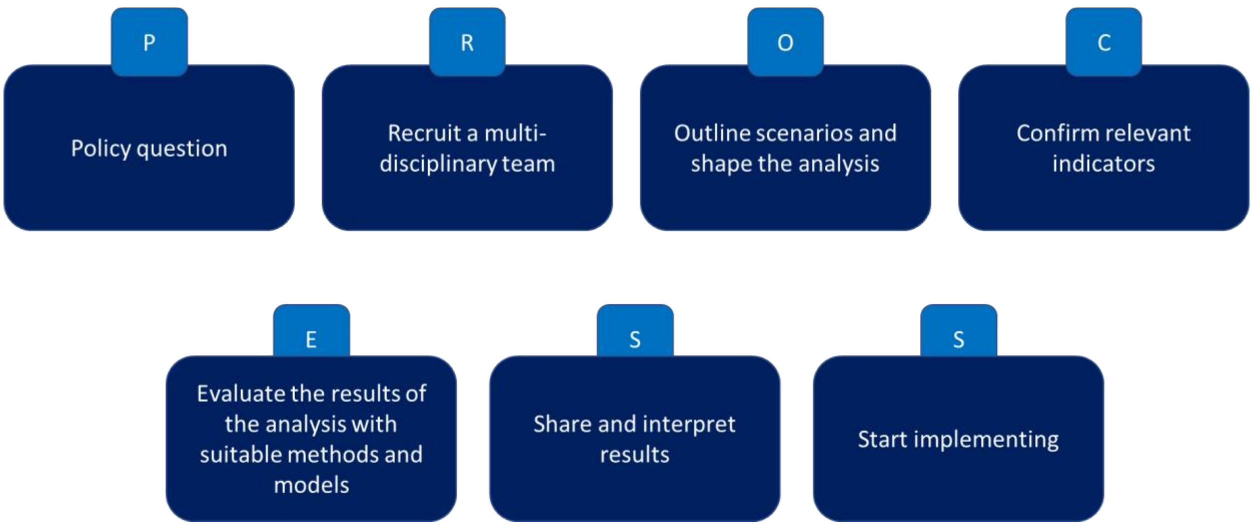

Figure 11: The seven implementation steps of the TEEBAgriFood policy formulation and evluation process.

Two case studies are used to present the implementation of these steps "in action". These are TEEBAgriFood assessments carried out in Indonesia and Thailand, respectively with focus on the impact and dependence of cocoa agroforestry production, processing, distribution, and consumption activities on supporting ecosystems and their services (Indonesia) and on the transition from conventional rice farming to organic rice farming (Thailand).

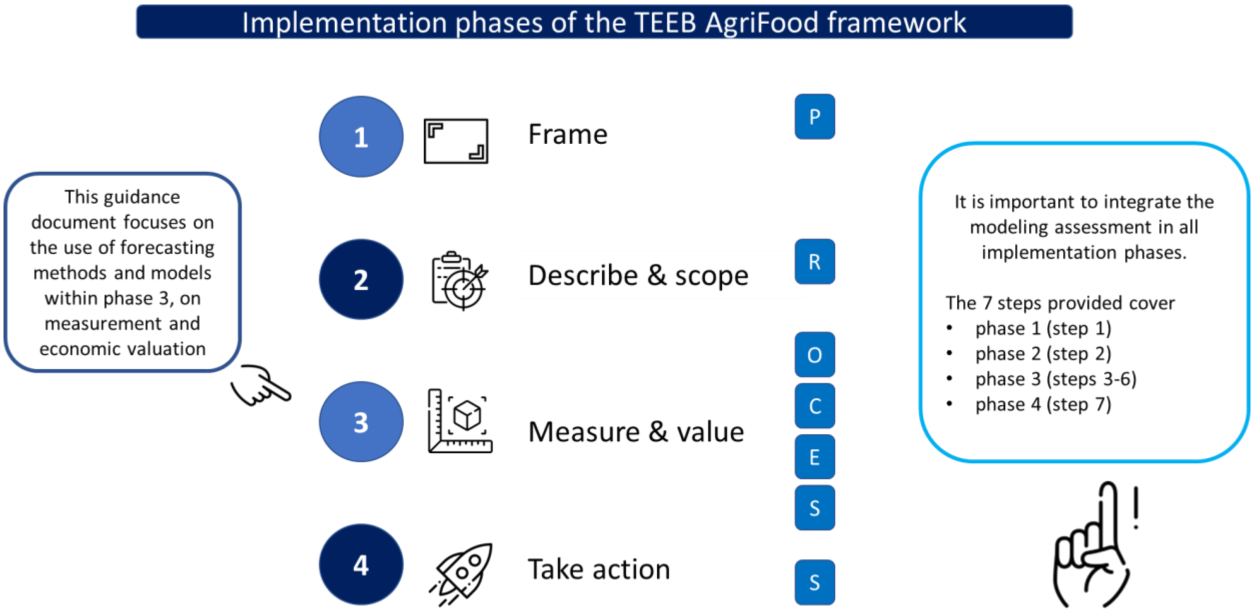

Figure 12: Alignment between the implementation steps of the TEEBAgriFood Framework and the TEEBAgriFood policy formulation and evaluation assessment, with scenario analysis and forecasting tools.

4.1. Identify the policy question

The first step is to identify the policy question that needs to be addressed. This question should be formulated in a way that makes it clear what the policy aims to achieve and what the specific problem or issue is that the policy seeks to address. This involves clearly defining the issue, understanding its causes and effects, identifying some measurable indicators of the issue, and determining what the policy goals or targets are, also via the use of measurable indicators.

The policy question can emerge from a variety of sources. It may arise from a problem or challenge that needs to be addressed, such as underperformance in the economy, conflict in society, or degradation of the environment. Alternatively, the policy question may arise from a missed opportunity that decision-makers want to realize.

Regardless of the policy driver, the policy question should be clearly defined and well-understood in order to guide the policy analysis process. A well-defined policy question will help ensure that the analysis is focused and relevant, and that the resulting policy recommendations are actionable and effective. It also supports the identification of relevant indicators, both reflectivng causes and effects of the problem, and the co-benefits of action.

A steering committee composed of members who have a stake in food systems or who would be impacted positively or negatively by food system changes can support the identification of the policy question and relevant indicators, using a participatory and multi-stakeholder approach. The steering committee would then ensure that the research and modelling work carried in the steps presented next, answer the policy question.

Case study Indonesia

The TEEB case study for Indonesia focuses on the impact and dependence of cocoa agroforestry production, processing, distribution, and consumption activities on supporting ecosystems and their services in North Luwu Regency, South Sulawesi, which encompass nearly 7,843 km^2 dryland area. It assesses the extent to which current, monoculture production practices cause negative environmental impacts, and how more sustainable practices can result in a better balance between ecosystems and economic activity, making cocoa production ultimately more resilient and economically viable from a societal perspective.

The cocoa agroforestry system relies heavily on ecosystem services that are not fully captured in the market, and their dependency and impacts in monetary terms can be measured using economic valuation tools, which also make them comparable to other valued indicators.

Agriculture relies on ecosystem services as inputs and provides many ecosystem services as well. The stages involved in cocoa production, from land clearing and preparation to harvesting, product preparation for the consumer market, consumption, and final waste disposal, generate several economic impacts, such as income for producers, wages for employees, tax revenues to the government, or subsidies from the government, and the possibility of importing inputs and exporting outputs. Some of these impacts are captured through market transactions or financial resources exchanged between agents in society, while others are not. For example, water flow regulation, carbon storage, soil biodiversity and soil nutrient loss through erosion, N and P runoff, and other ecosystem services and impacts are easily ignored because they are not directly observed in markets, despite the fact that they indirectly impact the economy and human wellbeing.,

Case study Thailand

Rice farming accounts for half of Thailand's cultivated land and provides a complex livelihood system that connects trees, crops, and livestock. However, the intensification of rice production over the last four decades has caused significant environmental impacts. The climate crisis poses serious threats to the future of rice cultivation in Thailand, with changes in rainfall patterns and increasing temperatures impacting rice output in key areas.

To address these challenges, a TEEBAgriFood case study aims to assess whether the transition from conventional rice farming to organic rice farming would enhance society's net benefits. The analysis focuses on the potential reduction in health costs, reduction in greenhouse gas emissions (GHG), improvement in biodiversity, and increase in farmer income associated with the adoption of organic rice farming practices in the Northeast of Thailand. This assessment can inform decision-makers and stakeholders about the potential trade-offs and benefits of transitioning to organic rice farming practices as part of an overall shift towards sustainable agriculture.

Specifically, the conventional cultivation of rice in Thailand results in several negative externalities, including greenhouse gas emissions, adverse impacts on farmers' and public health, loss of biodiversity, and high cultivation costs due to the use of chemical inputs. The government provides funds to rice farmers to alleviate financial hardship facing this critical agricultural sector each year. In the main, public support to the rice sector has not been conditional on the adoption of sustainable agricultural practices. The One Million Rai Organic Rice promotion project was introduced to provide a temporary cost subsidy to farmers switching to organic production. As outlined below, the study assessed various scenarios involving achievement of enhanced, accelerated and ambitious area targets of this programme over time.

The assessment has yielded several outputs. These include the identification and evaluation of policies that incentivize farmers to adopt sustainable organic practices, improved knowledge and skills of farmers to increase productivity in organic rice cultivation, consumer recognition of the positive value of organic rice and willingness to pay a premium price for it, and easier and more accessible organic rice market channels for the public.

4.2. Recruit a multi-disciplinary team

A multi-disciplinary team should be recruited to undertake the policy assessment. This team should comprise experts in the relevant fields, including those with expertise in ecology, agriculture, economics, and policy analysis.

A multi-disciplinary team is an essential component of the policy analysis process for several reasons. Firstly, if the assessment is cross-sectorial and multi-dimensional, it requires expertise from various sectors and policy domains. Bringing together experts from different fields will help ensure that the analysis is comprehensive, well-informed, and takes into account different perspectives.

Secondly, a multi-disciplinary team enables an internal validation of the method, data, and models used, and of the recommendations that emerge from the analysis. Involving experts from different fields allows for a critical evaluation of the assumptions within a sector as well as across thematic areas of relevance. This can help to identify potential biases or weaknesses in the analysis and strengthen its validity and reliability.

Thirdly, a multi-disciplinary team can create shared ownership for the project, analysis, and policy recommendations. By involving participants from different fields, they can feel that they have contributed to the process and that their expertise has been valued. This can help to build consensus and support for the policy recommendations, which is essential for their effective implementation.

Case study Indonesia

In order to fully understand the trade-offs between economic, environmental, and social considerations, it is important to consider the range of stakeholders in the assessment of cocoa's impacts on the environment and well-being. In the Indonesia cocoa sector these stakeholders include cocoa farmers, processors, traders, consumers, government officials, and representatives from civil society organizations.

Each of these stakeholders has a different perspective and interest in the cocoa production, processing, and consumption system. For example, cocoa farmers may be primarily concerned with maximizing their yield and income, while consumers may be more interested in the taste and quality of the chocolate products they buy. Government officials may have a broader interest in promoting sustainable development and protecting natural resources, while civil society organizations may be focused on ensuring that the rights and livelihoods of local communities are respected.

By involving these different stakeholders in the assessment process, it is possible to better understand the full range of impacts and trade-offs associated with cocoa production and consumption. For example, farmers may provide valuable insights into the practical challenges and opportunities of adopting more sustainable farming practices, while civil society organizations may highlight the social and environmental risks associated with certain production methods. Consumers may be able to provide feedback on the desirability and acceptability of different product attributes, while government officials can help to identify policy interventions that could support more sustainable cocoa production and consumption. Again, a diverse project steering committee should help determine which stakeholder impacts are relevant and material to the policy objectives and the policy question that a TEEBAgriFood analysis will evaluate.

Case study Thailand

The project engaged various stakeholders throughout its lifecycle, from conceptualization to the presentation of final results. The study area and purpose were first identified in the project's Inception Workshop, which received contributions from multiple stakeholders. The project Steering Committee, chaired by the Office of Natural Resources and Environment Policy and Planning (ONEP) of the Ministry of Environment and Natural Resources (MoNRE), further refined these inputs. Committee members were drawn from the Department of National Parks, Wildlife and Plant Conservation, Department of Environmental Quality Promotion (MoNRE), Department of Agriculture, Department of Agriculture Extension, Rice Department, National Bureau of Agricultural Commodity and Food Standards, Royal Forest Department, Department of Fisheries, and the Department of Livestock Development, from the Ministry of Agriculture and Cooperatives (MOAC), as well as the National Economic and Social Development Board (NESDC). The modeling team was also multi-discplinary, with experts performing thematic assessments in the following areas: socio-economic dynamics, human health, ecosystem services, water availability and quality, soil quality,biology, animal biodiversity, and GHG modelling. It is worth noting that, in a follow up study, the range of stakeholders was further expanded, adding also the Ministry of Finance, Commerce and Public Health.

4.3. Outline scenarios and shape the analysis

The next step is to outline the different scenarios that need to be considered in the policy assessment. These scenarios should cover a range of possible policy inputs, and underlying conditions, and be used to then evaluate model-based quantitative outcomes. As described in Text Box 1, this involves gathering data about the policy target (e.g. area or indicator affected) the policy instrument (e.g. a mandate or an incentive), and the ambition over time (e.g. will there be progressively increasing action, or stronger action in the short term versus the medium term). Some backround research will need conducted to gather this information, and identifyany assumptions required by simulation models for the creation of simulations.

The formulation of scenarios is a crucial step in the policy analysis process, for two main reasons. Firstly, scenario formulation allows for the identification of the level of ambition required for interventions (including investment and potential behavioural change), taking into account the policy goal.

Secondly, scenario formulation helps to identify the roles of different economic actors, both in terms of the effort required for implementation and the benefits that can be accrued from implementation. By understanding the potential roles of different actors, policymakers can design interventions that are more likely to be effective and sustainable, for one or the other stakeholder group. This can help to ensure that interventions are designed to maximize impact while minimizing unintended consequences.

Case study Indonesia

The assessment compares the potential costs and benefits of a Business as Usual (BAU) scenario assuming monoculture to a simple agroforestry (SAF) and a complex agroforestry (CAF) scenario. Although many studies have shown that the latter outperforms the former, this study aims to identify the best farm-level practices that can achieve cocoa agroforestry that is both economically viable and environmentally desirable in the Indonesian context. This implies that cocoa production and environmental impacts resulting from farm management changes are well balanced, generating profits for farmers and societal value generation for the government and population. For the implementation of the CAF scenario, two policy interventions are considered: (a) Providing seedlings for the agroforestry system and GAP training & extension and (b) Certification and Eco-labelling.

The analytical framework for this study involves a 5-step process to comprehensively analyze the impacts of cocoa monoculture and agroforestry on the environment and people's well-being over a period of 30 years. First, a thorough inventory of all possible ecosystem services provided by cacao monoculture and agroforestry is conducted to identify the full suite of meaningful ecosystem services in the study context. Second, a short list of key services is prepared through expert consultation, local stakeholder engagement, and literature reviews. Third, the ecosystem services are quantified and forecasted, under different scenarios. Fourth, economic valuation techniques are applied to assess the economic value of each ecosystem service. Finally, the study extrapolates the results and examines trade-offs among various ecosystem services and stakeholders.

The study's main objective is to quantify the impacts and outcomes of cocoa agroforestry relative to cocoa monoculture and other land cover types, and evaluate the potential consequences of cacao agroforestry expansion scenarios. To achieve this goal, a set of dynamic simulation models is applied to evaluate a range of indicators within current cocoa growing areas and areas suitable for growing cocoa between 2021 and 2050. By following this analytical framework, the study aims to provide a comprehensive understanding of the impacts of cacao production on the environment, the economy, and society, involving multiple stakeholders.

Case study Thailand

The TEEBAgriFood assessment conducted in Thailand aimed to assess the various costs and benefits associated with rice production, in order to identify strategies for promoting long-term sustainability in the management and production of rice landscapes. To this end, a scenario analysis was conducted to illustrate the potential synergies and trade-offs that may arise as organic rice production practices in Thailand are expanded over the period 2019-2035. The key questions addressed by this assessment were:

- What is the value that rice production provides to nature, people, and society under different production practices?
- What are the often-overlooked impacts and dependencies that rice food systems have on nature, people, and society?
- What are the costs and benefits of different policy interventions aimed at increasing organic rice production and consumption, including initiatives like the “One Million Rai” Organic Rice Development project and the Parliamentary targets for Sustainable Agriculture Development by 2030?

Through these questions, the research sought to uncover the hidden benefits and costs that exist throughout the rice value chain, as well as the connections between rice production and the health of both farmers and consumers.

The TEEBAgriFood assessment in Thailand developed four scenarios to assess the potential impacts of government policies, including the One Million Rai Organic Rice promotion policy, and Parliamentary targets for sustainable agriculture by 2030. The analysis modelled impacts over a period of 17 years, from 2019 to 2035, divided into short-term (2019-2025), medium-term (2019-2030), and long-term (2019-2035) timeframes.

- The first scenario, Business as Usual (BAU), assumed no new policies or interventions to support the expansion of organic rice cultivation. The organic rice area in the Northeast region was projected to increase to 173,027 hectares by 2025 and remain constant until 2035.
- The second scenario (S2) assumed that the One Million Rai Organic Rice Program would continue every five years. The total organic rice area in the Northeast was projected to increase to 320,000 hectares by 2025, 480,000 hectares by 2030, and 640,000 hectares by 2035.
- The third scenario (S3) assumed that additional policies would be implemented alongside the One Million Rai Organic Rice Program to support the expansion of organic rice cultivation. The total organic rice area in the Northeast region was projected to expand to 800,000 hectares by 2025, 1,600,000 hectares by 2030, and 2,400,000 hectares by 2035.
- The fourth scenario (S4) assumed a "transformation towards sustainability," where the organic rice area in the Northeast would expand to 829,000 hectares by 2025 and 5,120,000 hectares by 2030. This scenario assumed that about 87 per cent of rice fields in the region would be converted to organic by 2030 and remain constant until 2035.

4.4. Confirm relevant indicators

Once scenarios have been formulated and the policy ambition has been identified, it becomes easier to identify relevant indicators for the analysis. Indicators are important because they provide a way to measure progress towards policy goals and objectives. By selecting appropriate indicators, policymakers can ensure that they can track the effectiveness of interventions and adjust their approach as necessary. Similarly, in the context of modelling assessment, the identification of relevant indicators supports the selection of simulation models, which can then generate forecasts that can be used to assess whether, over time, expectations of policy impact are being matched in reality. Answering three questions can help identify the appropriate indicators to measure: i) What specific information do policy makers need in order to choose between policy options? ii) Are these priority indicators likely to differ between the scenarios? iii) What non-market impacts that policy makers may have overlooked (ecosystem services, externalities or residuals) which are likely to differ between the scenarios should be included in the policy decision?

As indicated in *Table 1*, biophysical, social and economic indicators are all important for understanding the outcomes of policy implementation.

Case study Indonesia

In assessing cocoa production in Indonesia, various indicators are relevant. These include total costs, broken down into investment, operational costs, and government expenditures (such as upfront agroforestry costs, agricultural extension services, and redirected subsidies). Additionally, cocoa agroforestry systems provide a range of ecosystem services, including provisioning services like food supply (cocoa, fruits, and other food crops), regulation services such as erosion prevention, soil biodiversity and nutrient retention, climate regulation, and regulation of water flows, as well as biodiversity habitat services.

The development of a causal loop diagram was instrumental in the identification of indicators, data gaps and their relevance. Data were collected to measure the stocks of natural capital and flows of ecosystem services in accordance with the TEEB AgriFood framework. Several ecosystem services were analyzed, including provisioning services such as food (cacao, fruits), raw materials (timber, non-timber products), water flow regulation, climate regulation/carbon storage, and soil biodiversity. Other indicators assessed potential ecosystem disservices and valuation approaches, including potential reductions in cacao provisioning and competition for nutrients and water.

These indicators help assess the impact of cocoa production practices and their dependencies on ecosystems. However, questions of equity in food production, promotion of health practices through awareness and education, and the contribution of economic activity and natural capital to the Sustainable Development Goals (SDGs) must also be considered, extending the analysis to the societal outcomes of production.

Case study Thailand

The TEEBAgriFood assessment of rice production in Thailand analyzed several indicators, divided into different categories such as Product (total rice area in hectares), Method and Practices (hectares of conventional rice practice and organic practice), Stock (natural, human, produced and social capital) and Flows (Ecosystem service inputs, Purchased inputs, Residuals Outputs), Outcomes (Natural capital, Human capital, Produced capital, Social capital) and follow the TEEB AgriFood framework.

To provide examples of the specific indicators analyzed, concerning stocks, the following indicators were considered: for human capital, the number of farmers practicing conventional and organic rice farming, as well as their characteristics, and the number of domestic consumers were taken into account. Produced capital was analyzed through changes in yield and income from rice production as well as access to relevant production infrastructure such as farm machinery and community rice mills. Social capital was analyzed by the number of formal farmers cooperatives and groups, as well as the number of members.

Outcomes were also analyzed for each type of capital. Natural capital was analyzed through the amount of crop production per area, as well as ecosystem service provisioning. For Human capital, the value of statistical life (VSL) was considered, in relation to the risk of exposure to pesticides and particulate matter PM2.5 and PM10. Produced capital was analyzed by the amount of profit generated from growing organic rice. Social capital was analyzed through the number of family members who migrated to work outside the community during the dry season and the subjective well-being of farmers, among others.

4.5. Evaluate the results of the analysis with suitable methods and models

Once the scenarios and indicators have been confirmed, the next step is to select, parameterise and customize simulation models, generate forecasts and evaluate the results of the analysis. As indicated earlier, the use of a systemic approach offers the possibility to utilize various types of indicators for policy analysis, including biophysical indicators, model variables that represent socio-economic dynamics, as well as an aggregation of the economic and financial performance of the policy in a CBA and CEA. This is an important step, as it highlights the monetary relevance of of both tangible and intangible impacts of policy implementation. Natural capital is an example: an economic valuation of ecosystem goods and services can shed light on the value of nature, and make explicit the importance of supporting ecosystem integrity, both for present and future income generation. When data scarcity is an issue, Multi-Criteria Analysis (MCA) should be considered. MCA is an approach that allows to integrate quantitative and qualitative indicators in the analysis of policies and investments. This allows to avoid excluding important indicators from the analysis, especially synergies and trade-offs, when data are scarce.

Ultimately, the selection of a method or model will depend on the specific research question and indicators of sustainability required. On the other hand, the analysis of results has to consider all key dimensions of the problem (e.g., the four capitals included in the TEEB AgriFood framework). The availability of a comprehensive set of methods and results also supports sharing the results with a diverse audience, as a starting point with the multi-disciplinary team involved in the modelling exercise, for review and cross-validation.

Case study Indonesia

This assessment utilized a comprehensive suite of models, beginning with the assessment of the potential adoption of agroforestry in cocoa production through a spatially explicit approach. Projection of a future land cover under different scenarios (via TerrSET, a GIS land cover prediction tool) facilitated the estimation of ecosystem service provisioning. The adoption of different production practices and enhanced ecosystem service provisioning were then evaluated to determine their impacts on the value chain and human capital before assessing macroeconomic impacts.

To inform decision-making on land management and develop long-term plans for development, including the placement of different activities and their effects on land, ecosystems, and people, biophysical models were initially employed. Such models are a critical input for the valuation of ecosystem services linked to agriculture. This study employed various models, including Spatial Planning Tools and Ecosystem Services Models such as The Soil & Water Assessment Tool (SWAT), and Soil Analysis, to measure indicators related to natural capital.

The spatial analysis for this study involved considering various indicators, including biophysical factors (such as the percentage of areas with gentle topography, the proportion of cacao plantation areas, and cacao planting patterns), social factors (such as education levels and population), economic factors (such as the percentage of non-permanent housing types and the percentage of agricultural lands per region), institutional factors (such as the presence or absence of institutions regulating cacao management), infrastructure factors (such as road accessibility to cocoa market centers), and political factors. This information was used to perform the following tasks: a) analyze historic changes in land cover, b) generate a change transition matrix (in terms of predicted area change), c) develop a cacao suitability map, and d) forecast land cover for a specific time period. To accomplish this, the study utilized time-series land cover data from the last three decades (1990-2020). The land cover prediction was for a thirty-year period, resulting in the creation of land cover maps up to 2050. The land use forecast was modeled using the TerrSet software, developed by Clark University. The Land-use Change Modeler (LCM) in TerrSet (formerly known as IDRISI) software was originally designed to manage biodiversity influences, analyze land use and land cover changes, and forecast future changes.

In regards to ecosystem services models, the Soil and Water Assessment Tools (SWAT) (Arnold, Srinivasan, Muttiah, & Williams, 1998; Hussainzada & Lee, 2022) were utilized to estimate water quantity and quality, nutrient leaching, and erosion and sediment transport. This was especially useful for complex watersheds with spatially and temporally varying features, where monitoring data was limited. The TerrSET software was also used to estimate carbon stock and sequestration. The amount of carbon stored in a land parcel is dependent on the size of four primary carbon sinks: aboveground biomass, belowground biomass, soil organic matter, and dead organic matter. Additionally, soil quality was studied in relation to soil physical properties such as bulk density, porosity, and water retention, as well as soil chemical properties including

C-organic, N-total, P-available, and P-total. Soil biology was also assessed, including soil fauna, total microbial abundance, and total fungi.

The analysis of human capital was conducted using descriptive statistics and labour productivity analysis. The value chain analysis was performed by examining the flow of products and actors involved in the value chain, from the producer level (farmers) to the processor level, in order to identify which actors provide the greatest value-added in the value chain. Since the focus of this research is on cacao beans, the value chain analysis was only conducted up to the processor level and did not include the retail and consumer levels.

Extending the value chain analysis at the macroeconomic level, a Computable General Equilibrium (CGE) model was used to estimate the possible impacts of CAF in South-Sulawesi, across economic sectors. The WAYANG-ORANI model was used, a combination of WAYANG model (Wittwer, 1999) and ORANI-G model (Horridge, 2003). The limitations observed from linking a bottom-up analysis with a macroeconomic model include: (i) the model does not incorporate an environmental module, which means that it was not possible to directly assess the national targets of the Low Carbon Development initiative and COVID green package via net zero target emissions. Furthermore, the results of natural capital and ecosystem service provisioning could not be integrated into the macroeconomic assessment; (ii) This CGE model is comparative static in nature, it has no explicit treatment of time and thus it can only compare one equilibrium state with another, with no information on transitions from one state of the system to the next; (iii) the impacts of CAF are exogenous, and introduced as an assumption in the CGE model. As a result, the CAF assessment using the CGE model is not intended to be a standalone analysis. The results have to be interpreted in relation to the other modelling work performed, especially the estimation of ecosystem service provisioning, which is not captured in the CGE model (only production changes are considered, implying that most benefits of CAF are not captured in the macroeconomic analysis).

Case study Thailand

This study focuses on assessing the potential benefits of organic rice farming in Northeast Thailand. It includes (i) land-use change modelling, including the assessment of the transition potential to organic farming, (ii) resulting ecosystem services modelling (e.g., yield, biodiversity, GHG emissions and soil organic carbon stock), and (iii) human health impact analysis. Further, (iv) CBA was then carried out, via the economic valuation of ecosystem services, to provide an overall assessment of the impact of rice production for farmers and society.

Concerning land-use change modelling, predictive land use (LU) scenario modelling was used to integrate existing and new biophysical and valuation data to provide an assessment of the changes in ecosystem service provisioning as a result of the expansion of the area under organic rice. In the first step of LU modelling, a land-use change model has been processed using IDRISI-TerrSet49 and Land Change Modeller (LCM) for assessment and projection of land cover change. The transition potential model was based on the result of the land use change analysis between the two periods (2015 and 2019). In this model, five explanatory variables were added, including climate data and distance to urban areas and markets. Three climate driver variables were the minimum, the maximum, and the average temperature. The monthly precipitation is the sum to represent the annual value applied in this study. The climate data were derived from the Representative Concentration Pathways (RCP) adopted by the IPCC, specifically, emissions scenario RCP 4.5. This exercise is complementary to the household survey aimed at further understanding socio-economic and cultural factors for a switch from conventional to organic.

Concerning the analysis of communities, biodiversity, and ecosystem services carried out with modelling, biophysical models were used to assess changes in ecosystem service provisioning and changes in capital stocks from organic versus conventional practices, based on the land-use change modelling outcomes under different policy intervention options. The changes in ecosystem services are described quantitatively and aggregated across the study region. In each of the four policy scenarios, the change in ecosystem services was determined, based on the land-use change modelling outputs, localized agronomic data and analysis, supplemented by secondary data on outcomes of different rice practices (agronomic and ecological outcomes at landscape level). The research team collected the biodiversity and environmental-related data in each of the rice cultivation practices assessed in the selected samples of rice fields from 24 study sites in Buriram and Surin province.

To quantify the relationship between rice farming practices, the latent variables of biodiversity and yield/cost of rice farming were identified and modeled using the Bayesian framework. The biodiversity results were then merged with the household survey data to create the model. The parameters for the Bayesian model included the average effect of both rice cultivation practices on biodiversity (β) and the latent average effect of biodiversity on yield/cost ratio (γ) were used as parameters for the model. All of the data variables were rescaled to fit the normal processes of the modelling framework. The model was fitted using Gibbs sampling methods of Markov chain – Monte Carlo in STAN program running on R interface via rSTAN package (Stan Development Team, 2021).

Greenhouse gas emissions and soil organic carbon stock were estimated considering (a) GHG emissions that are generated directly during cultivation, the flooding of the rice fields, as a major source of methane (CH4) gas emissions; (b) GHG emissions from the soil, which is related to soil carbon stocks; (c) GHG emissions from rice straw burning, a common post-harvest field management practice that also generates air pollution. Field burning is prohibited in organic rice practice.

The resulting yield from rain fed systems under conventional and organic practices is estimated using the Denitrification-Decomposition (DNDC) model. Further, health impacts analysis was performed considering the health risks arising from the use and misuse of the agricultural pesticides applied to rice production, as well as the health risks to the broader population associated with air pollution from post-harvest rice straw burning. The Amended Human Capital (AHC) approach was used, based on the concept of labour productivity loss (i.e., morbidity) because of individual absence from work. The Value of a Statistical Life (VSL) analysis is complementary to AHC, and it is better suited to assess mortality impacts. Both methods were used in this analysis.

4.6. Share the results to inform policymaking

After the analysis has been completed, it is important to share the results with policymakers and other stakeholders. This involves presenting the methods, models, related assumptions and results clearly and concisely, highlighting the key findings of relevance to the target audience, and making recommendations for action.

When sharing model results with a wide group of stakeholders, there are several important factors to consider, including:

- Transparency: Stakeholders need to be able to understand the assumptions, inputs, and outputs of the model. The model should be well-documented and easy to understand.

- Accessibility: The model and its results should be accessible to stakeholders in a format that is easy to understand and use. This may involve presenting results in visual formats such as graphs, charts and maps and providing detailed explanations of how the results were obtained.
- Relevance: Stakeholders need to see the relevance of the model results to their specific concerns and interests. It is important to frame the results in a way that is meaningful to stakeholders and to provide concrete examples of how the results could inform decision-making.
- Engagement: Stakeholders should be engaged in the model development process to ensure that their perspectives and concerns are taken into account. This may involve holding workshops or meetings to gather input and feedback from stakeholders.
- Communication: Effective communication is essential throughout the modelling process, as well as when sharing model results with stakeholders. It is important to use clear and concise language and to avoid technical jargon or terminology that may be unfamiliar to stakeholders.
- Limitations: It is important to be transparent about the limitations of the model and the uncertainty associated with its results. This can help stakeholders to understand the strengths and weaknesses of the analysis and to make informed decisions based on the results.

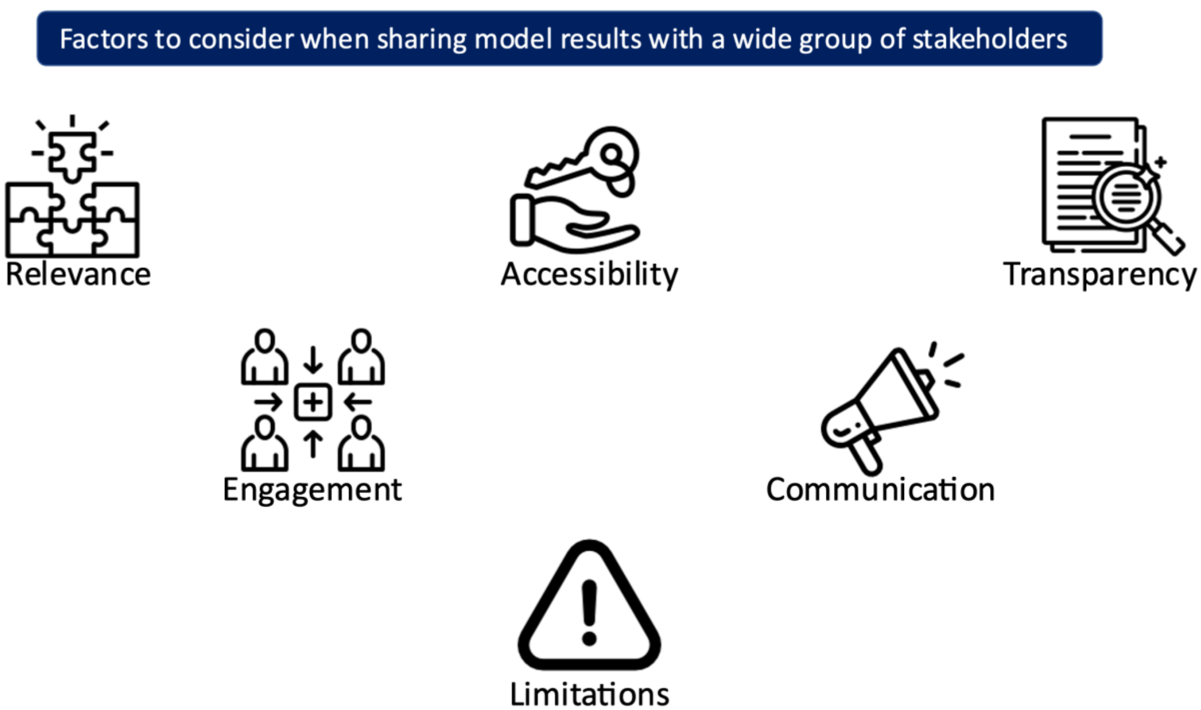

Figure 13: Key factors to consider when sharing model results with a wide group of stakeholders in the context of TEEBAgriFood assessments.

Overall, the key to sharing model results with a wide group of stakeholders is to be transparent, accessible, relevant, engaging, and clear in communication. By considering these factors, stakeholders will be better equipped to understand the results of the model and to use them to inform decision-making.

Case study Indonesia

The analysis produced for the Indonesia case study was shared with decision-makers and other local stakeholders. It includes several key components. First, it provides the results of land use cacao modelling, including typology and suitability. This allows us to identify the best areas for cacao production and make informed decisions about where to allocate resources. Second, it presents the results of biophysical and socio-economic modelling. This helps us to understand the potential impacts of different cocoa agroforestry scenarios on the environment and local communities. Third, it provides an economic valuation of ecosystem services. This helps decision-makers to understand the true value of the natural resources that support cacao production, and to make informed decisions about how to manage those resources. Fourth, it provides a human capital analysis, which helps us to understand the skills and capabilities of local workers and identify areas where training and capacity-building may be needed. Finally, it provides a value chain analysis, which supports the identification of different actors involved in the cacao production process and identifies areas where value can be added.

Overall, the analysis shows that cacao agroforestry provides higher economic values compared to cacao monoculture and cacao intercropping, in terms of both total private and social benefits. However, despite these benefits, the adoption of cacao agroforestry in the field is still very limited. As a result, gaps in agroforestry adoption have to be identified, such as the need for capacity building on Good Agricultural Practices (GAP) and incentives for producing premium quality agroforestry systems. To address these gaps, policy interventions must be considered, including (i) providing seedlings for agroforestry systems and GAP training and extension to stimulate knowledge creation and direct adoption on the side of producers, as well as certification and eco-labeling to stimulate demand and hence incentivize the adoption on the production side also (push and pull strategy realized via the implementation of both policies).

Case study Thailand

In order to achieve the objectives of the Bio, Circular, and Green Economy model in Thailand, which aims for more sustainable growth and environmental responsibility, a transition is necessary towards fully sustainable rice production and landscape management. It is crucial to make visible the connections between nature and rice food systems by quantifying the often-invisible flow of benefits from ecosystems to food systems and human well-being. This involves identifying where, how much, and to whom nature provides benefits, showing the impacts of Business as Usual, and comparing the impacts under alternative agri-environmental policy scenarios for the future.

The estimated outcomes show that if more than 50% of conventional rice areas in Northeast Thailand are transformed into organic rice areas by 2035, health cost reductions due to air pollution and pesticide use will reach $1.9 billion, GHG reductions could be achieved with benefits valued at $8 million, the biodiversity index for insects in the rice cultivation area will increase by at least 100 per cent in 2035 (cultivation practices affect biodiversity, and the expansion of organic rice areas increases agrobiodiversity, especially in insect varieties, at the landscape level, which promotes natural pest control), and the avoided expenditure of organic rice farmers on pesticides is $154 million. These outcomes are expected to provide a compelling case for the adoption of sustainable practices in the rice sector. These results also highlight the need to assess the impact of changes at the landscape level, as farm-level results give an incomplete picture of the full range of impacts, externalities, and dependencies in the system.

Concerning outcomes across stakeholders, the expansion of organic rice areas offers benefits to farmers, such as lower production costs and reduced health risks. The Thai population can benefit from higher productivity and lower expenditure associated with improved health outcomes, as well as enhanced biodiversity. The international community can also benefit from the overall reduction in GHG emissions due to the prohibition of straw burning and higher soil organic carbon accumulation. However, there are also potential revenue reductions for farmers, such as a reduction in rice output (although the findings of this study project relatively minor losses in terms of volume output and dollar value), and the investment required for land conversion to organic production should also be considered. This highlights the need to develop policies that can balance the benefits across farmers (investors) and the many beneficiaries of sustainable rice production. A review of the literature shows that the decision of farmers to adopt and/or continue to grow rice organically depends on policy support, particularly during the transitional period (characterized by a small reduction in land productivity), and price incentives to pay back the initial investment in the short term.

4.7. Start implementing, and formulate an implementation strategy

The final step in the policy analysis process is to start implementing the policy and formulate an implementation strategy. This involves identifying the necessary resources, determining a timeline for implementation, and creating a plan for monitoring and evaluating the policy's effectiveness.

Simulation models can provide useful information in this regard. For instance, the investment necessary to implement each policy intervention option is estimated, and different timings can be assumed and simulated in alternative scenarios. As a result, the modelling assessment can provide information on prioritization, affordability, and expected impacts of policy implementation (which can be connected to monitoring and evaluation activities). Furthermore, if the modelling assessment is co-created and uses a multi-stakeholder approach (involving experts, decision-makers, and representatives of the local community), enhanced collaboration and openness to continuous adaptation of the policy can be expected in the implementation phase.

Case study Thailand

The following policy recommendations are from the case study on organic rice production in Thailand:

- While current agriculture subsidy policies have aimed to alleviate farmers' financial difficulties, they do not necessarily incentivize farmers to adopt more sustainable practices. Hence, they do not address the root causes of the financial vulnerability of farmers. To encourage the adoption of organic farming, current subsidies should be restructured to be conditional upon the adoption of sustainable agricultural practices. Programs such as the One Million Rai Program (2017-2021) should be scaled up and improved to achieve this goal.
- Organic rice yields are generally lower than conventional rice yields, but not significantly so. The loss of income due to the slightly lower yield for organic farmers can be offset if farmers can sell their organic rice at a price that is at least 3.5 per cent higher than the price of conventional rice. Further, the benefits generated for society (e.g., considering human health and ecosystems) are much larger than the foregone revenue estimate for farmers. Overall, organic rice production is economically viable, but support is required to make it also financially viable for farmers in the short term.
- Organic rice farming has positive externalities in terms of health and environmental benefits, but these externalities are often not accounted for in the market. The government should minimize market

distortions, internalize externalities and hence turn currently intangible costs into tangible benefits. Organic rice farmers not only receive positive returns from cost reductions and health improvements but also generate positive returns for their local communities and society at large. These benefits should not be overlooked.

- Exporting organic rice to international markets requires various types of certifications, depending on the destination country. In order to reduce the unit, cost of certification for farmers, and improve the financial viability of investments in this area, policies aimed at designing, promoting and implementing standards and labeling for organic rice production should be implemented. This will support the whole rice production sector, rather than requiring actions to be taken by individual farmers.

5. The importance of knowledge integration

The integration of knowledge across scientific disciplines and policy domains is critical for achieving sustainability in agri-food systems. The issues facing the sector are complex and interconnected, and addressing them effectively requires the integration of multiple technical and scientific disciplines and the involvement of several sectors and policy thematic areas. For example, sustainable agriculture involves not only environmental considerations but also economic and social dimensions. To effectively address these issues, it is necessary to draw on knowledge from diverse fields such as agronomy, ecology, economics, sociology, and anthropology, among others. In addition, it is important to engage with stakeholders from different sectors and levels of governance, including farmers, agribusinesses, civil society organizations, researchers, and policymakers. This allows for a more comprehensive understanding of the challenges and opportunities facing the sector, as well as for the co-creation of policies and actions that are tailored to specific contexts and that reflect the diverse perspectives and interests of stakeholders.

The TEEBAgriFood Framework explicitly recognizes the need for interdisciplinary and participatory approaches to understanding and managing the interactions between human and natural systems. The framework emphasizes the importance of engaging stakeholders in the valuation and management of ecosystem services, as well as in the development of policies and actions to promote sustainability. This guidance document argues that the same approach should be followed when developing and using forecasting methods and models, with the goal to inform policy formulation and evaluation.

Integrating knowledge across scientific disciplines and policy domains is critical for several reasons:

- Relevance of content: sustainability is a complex and multifaceted issue that requires a comprehensive understanding of social, economic, environmental and governance drivers of change in the system. Bringing together experts from different fields, together with decision-makers, can lead to enhanced communication and sharing of information, the creation of a shared understanding of the problem, the identification of relevant and multi-faceted indicators, the use of methods and models that capture the complexity of the issue and produce results that are relevant to multiple audiences. This includes the full consideration of externalities in policy analysis. Externalities can be difficult to identify and quantify, especially if undesirable impacts are not visible yet, but are expected to emerge in the future. This makes it challenging to develop effective policies, leaving room for the possible emergence of side effects. By integrating knowledge across scientific disciplines and policy domains, it is possible to identify and quantify externalities more accurately and formulate intervention options that take into account the full range of costs and benefits of scenarios of action and inaction, now and in the future.

- Quality of content: integrating knowledge from different fields can lead to more robust and accurate policy analysis, resulting from methods and models that are interconnected and hence cross-validated for consistency. By using the results of one model as input for others, or by integrating several sectoral modules into a single cross-sectoral model, fewer external assumptions are required. This means that while each sectoral component of the model and analysis can be validated by experts and practitioners working in that sector, the full model can be validated by all experts and practitioners involved in the assessment. This allows to review and validate both individual sectoral modules as well as the interconnections existing across these modules, offering a stronger policy analysis.
- Policy implementation: the implementation of policies, and resulting investments and actions, to enhance the sustainability of the agri-food systems requires input and support from various stakeholders, including policymakers, farmers, industry representatives, and civil society organizations. Integrating knowledge across scientific disciplines and policy domains can help identify and address potential issues emerging in a scenario of inaction, for different stakeholders. It can also support the identification of intervention options that would solve conflicts and trade-offs between different stakeholder groups, resulting in the emergence of synergies. Both qualitative and quantitative modelling exercises can be used to assess the impact of implementing one intervention option at a time (to determine the net impact of a single intervention in, across actors, dimensions of development and over time), as well as to evaluate the outcomes of the implementation of policy packages (including several intervention options). The latter can be designed to realize synergies when implementing several intervention options at the same time, and to maximize the benefits of all stakeholders.

Overall, working in multi-disciplinary teams allows for a diversity of perspectives and knowledge to be brought to the table. Additionally, working in teams can help ensure that the policies and actions developed are acceptable to all stakeholders and have a greater chance of successful implementation.

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