Summary for Research Institutions
TEEB AgriFood India Implementation
Information on Modelling Tools

An eco-agri-food system is a dynamic and complex system. Multiple dimensions of the eco-agri-food system present complex analytical and policy challenges. Efforts to alter one aspect of the system (e.g., reducing environmental pressures) can produce impacts elsewhere (e.g., affecting employment, investments and earnings). This can also mean that interventions of any kind can produce significant unexpected feedback and side effects. For instance, encouragement of high-efficiency irrigation can directly reduce the water use per area and the total water use of a given system. However, this can lead to other changes, such as, crops that were previously unprofitable or agronomically unfeasible may become lucrative, increasing the share of water-intensive crops in the overall cropping system, and increasing the average water use per area. Thus, policies that seem reasonable in one sector or for providing a solution to one problem can cause unintended adverse effects on other sectors, or over a longer time horizon or larger spatial scale.

A systems approach to thinking is important to improve evaluation and impact assessment before policies or technologies are put in place. An analytical framework capable of integrating subsystems and showing connections between them can improve our understanding of the consequences of choices in quantitative and qualitative terms, across the whole ecogram- food system. TEEB AgriFood studies, in general, use scenario assessments that compare baseline scenarios with alternative policy scenarios to assess the systems impact of policies. Scenario assessments can help simplify and understand the complexity of the eco-agri-food system and evaluate the short vs. longer-term advantages and disadvantages of the analysed interventions.

Scenario analysis is done using models. Models help planners decide how to manage the land and draw long-term plans for development, including the location of different activities and their impact on land, ecosystems and people. Figure 1 explains six steps in scenario development and for proposing a theory of change in a TEEB AgriFood study.

Several modelling techniques can be used to carry out such systemic analysis. Experience in geospatial analysis, biophysical modelling, and valuation, are used in the development and use of scenarios with various modelling tools/ approaches. Figure 2 summarizes the key skills required to undertake a TEEB AgriFood study.

There is a large and growing literature on the use of modelling tools/approaches to analyse specific geographical contexts. This documents presents a summary of models presented in the TEEB For Agriculture & Food Scientific and Economic Foundations Report. The list of models reviewed in the report is not exhaustive and only serves to provide an indication of the kind of modelling tools that can be used for undertaking TEEB AgriFood studies at the national level.

Figure 1: TEEB Six-Step Approach

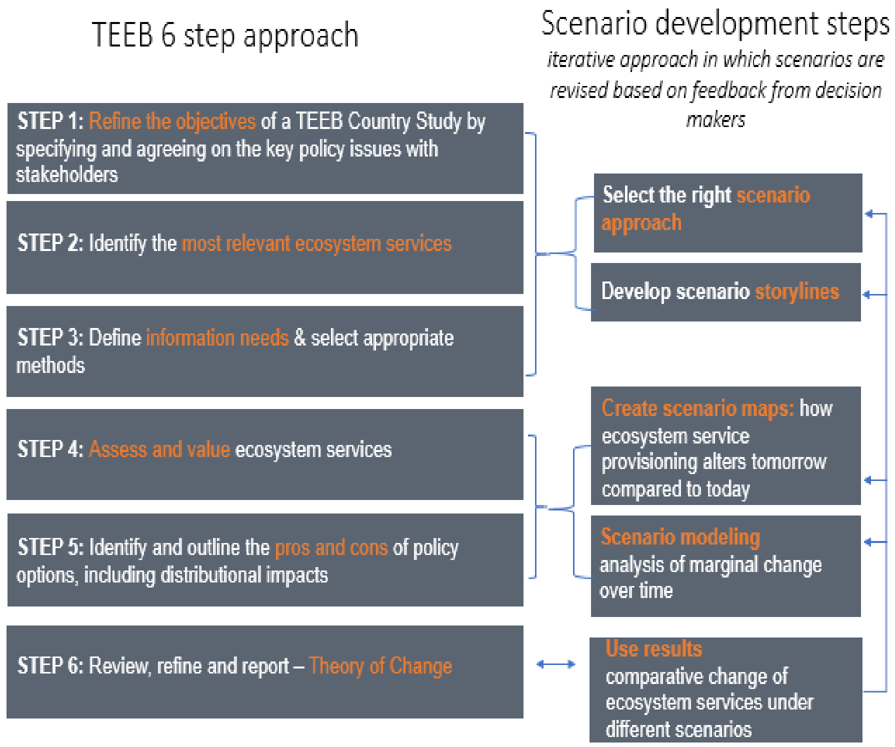

Figure 2: Key requirements for TEEB AgriFood Study Implementation

1.Scenario Assement

2. Biophysical Modelling & Geospatial Analysis

3. Valuation of Ecosystem Services

4. Measurement of impacts on produced, human and social capital

Biophysical Models

Biophysical models help planners decide how to manage the land and draw long-term plans for development, including the location of different activities and their impact on land, ecosystems and people. Such models can be a key input into the valuation of ecosystem services related to agriculture and, in the case of land use models, spatial data are sometimes used as an input for the estimation and economic valuation of present and future ecosystem services. Products are often highly visual (e.g., maps, graphs, diagrams, and charts) but considerations of social and economic variables are in most cases qualitative.

CROPWAT is a decision support tool developed by the Land and Water Development Division of FAO. It facilitates the calculation of crop water requirements and irrigation requirements based on soil, climate and crop data. Concerning its application, CROPWAT informs the development of irrigation schedules for different management conditions and the calculation of required water supply for varying crop patterns. An example of the application of CROPWAT in Africa is done by Bouraima (2015) in Benin, where they estimated the crop reference and actual evapotranspiration, and the irrigation water requirement of Oryza sativa in the sub-basin of Niger River of West Africa[1].

Soil and Water Assessment Tool (SWAT) is a river basin scale model developed to quantify the impact of land management practices in large, complex watersheds. SWAT is a continuous time model that operates on a daily time step at basin scale. SWAT was developed to predict the impact of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying soils, land use and management conditions over long periods. It can be used to simulate at the basin scale water and nutrients cycle in landscapes whose dominant land use is agriculture. It can also help in assessing the environmental efficiency of best management practices and alternative management policies.

Integrated Valuation of Environmental Services and Trade Offs (InVEST) is a family of models developed by the Natural Capital Project that quantifies and maps environmental services and supports their economic valuation. InVEST is designed to help local, regional and national decision-makers incorporate ecosystem services into a range of policy and planning contexts for terrestrial, freshwater and marine ecosystems, including spatial planning, strategic environmental assessments and environmental impact assessments.

Artificial Intelligence for Ecosystem Services (ARIES) is a web-based model that assists rapid ecosystem service assessment and valuation (ESAV). ARIES helps users discover, understand, and quantify environmental assets and the factors influencing their values, for specific geographic areas and based on user needs and priorities. ARIES encodes relevant ecological and socioeconomic knowledge to map ecosystem service provision, use, and benefit flows.

Multi-scale Integrated Models of Ecosystem Services (MIMES) is a model developed by the University of Vermont's Gund Institute for Ecological Economics. MIMES uses a systems approach (in that it considers entire ecological systems, but not social and economic dynamics) to model changes in ecosystem services across a spatially explicit environment. The model quantifies the effects of land and sea use change on ecosystem services and can be run at global, regional, and local levels.

Marxan and Land Change Modeler are land use models, and are used to plot out optimal physical placement of economic activities, human settlements and other land uses. Practically, through the identification of trends (e.g. for population) and/or the use of assumptions for future land use change (e.g. land use per person), these models generate future land cover maps that optimize placement in space (e.g. with population being located close to urban centres or to infrastructure, or with agriculture land being in located in the most productive areas depending on soil types and water availability, or with the minimization of forest loss, and hence decline in carbon sequestration capacity and biodiversity loss). These models allow users to modify a specific set of parameters (e.g. hectares of land cover by type, or their determinants, such as population growth), but often do not include consideration to what the assumed/forecasted land use change means for socioeconomic effects or monetary valuation of loss/gain in natural capital assets.

There are several advantages of using biophysical models. First, they allow to estimate, and fully consider, the characteristics of a landscape, region or country and its carrying capacity. Second, the use of spatially explicit datasets and the generation of maps, allows visualization of past and future trends, and better estimates of the value of the ecosystem services that may be gained or lost. However, there are limitations in using them such as the lack of social and economic dimensions to the analysis, for which spatial data are generally less available and thus impact can only be inferred and not estimated directly. Furthermore, the analysis of land use changes and the resulting need for inputs to production (e.g., water) does not normally include the analysis of endogenous

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[1] Bouraima (2015) https://ijabe.org/index.php/ijabe/article/view/1290

feedback loops, rendering the analysis comparatively static. In other words, the analysis does not consider that the expansion of agricultural land may lead to an increase in population, which may result in water consumption being higher than expected, and hence affect irrigation requirements and land productivity. As a result, the use of biophysical and spatially explicit models is primarily for scenario analysis rather than for supporting policy formulation and evaluation, where the anticipation of side effects is crucial. Finally, many of the parameters of the models are unknown and educated guesses have to be made about their values. This often makes the results they generate lacking in empirical data, a factor that highlights the strength of these models in policy formulation (where possible targets are set), rather than in policy assessment (where specific provisions are identified, and where a more in-depth assessment of local dynamics is required).

Biophysical models require several types of data, often spatially explicit. Examples include data on land cover and on physical flows, both regarding inputs and outputs to production or other natural processes. For instance, in the context of water-related studies, data are required to estimate the supply of water (e.g., precipitation, evapotranspiration, percolation) and its consumption (e.g., land cover by type and by crop, specific daily or monthly water requirements by crop, population and resulting water consumption for sanitation). Estimating ecosystem services requires additional information, depending on the assessment. Examples include maps on soil and vegetation types, multipliers for carbon sequestration, by land cover and vegetation type. The availability of data for biophysical models is improving, especially from international databases (e.g., Group on Earth Observations, EXIOBASE11). On the other hand, issues often arise in relation to the (low) resolution of maps and the validation of data on the ground (required to ensure the accuracy of the data extracted from the map). As a result, local validation is required, or customization of the model should be performed to better capture the local context.

Partial Equilibrium Models

Partial Equilibrium (PE) models can be conceptualized as the interaction of supply and demand in a single market. PE models are a family of models that over a single sector, generally at a high level of detail when compared to economy-wide models (e.g., CGE models). They range from single-sector single-company, or up to country models or single-sector multi-country models. PE models typically use a "bottom-up" approach, placing emphasis on specific policy interventions (e.g., fiscal policies) or technology adoption. In both cases, PE models estimate the impact of such interventions on demand and production in a given sector.

Partial equilibrium models generally require detailed information on a given sector, including: i) economic accounting for revenues and costs of production, ii) knowledge of production inputs (e.g. employment and labour cost, energy consumption and related expenditure, capital and material inputs and required investment), iii) information on key determinants of demand and supply (e.g. the responsiveness of demand to price changes) and iv) knowledge of the cost of interventions (e.g. technology investments) and their effectiveness. In the case of ecoagri- food system models, information for the estimation of revenues would be required on agriculture land, yield and prices, and concerning costs on infrastructure (e.g., mechanization and irrigation), labour, water and other inputs (e.g., energy, fertilizers and pesticides). When considering the value chain, additional data could be required on transport costs and the capacity to process food, including the revenues and costs (and their main determinants) of food processing. Given their high degree of customization, PE models, when data are available, can include a high degree of detail for the sector analysed.

The advantage of PE models, which represent a piecemeal approach (in that these models focus only on part of the whole eco-agro-food process) is that the model can be highly customized and that the analysis is comparatively transparent, being tractable and relatively easy to carry out. In fact, detail can be added more easily than with macroeconomic (e.g., CGE) models. Further, data requirements are normally not extensive, and the model can be structured according to the availability of data. Conversely, the estimation of economic impacts across the whole value chain can be complex, spanning across several economic activities and disciplines of research, and data are not easy to obtain, interpret and use. As a result, if the item of interest is a particular activity (e.g., farm-related non-point pollution) it may be reasonable to focus on that component only.

The main limitation of PE models regards its sectoral and primarily economic focus. For instance, a technological breakthrough that lowers the cost of sugar production from cane may increase production and result in land clearance and other environmental impacts, which would be analysed as part of that process. But the lower costs of sugar production would also lower the costs of sugar as an input in the ecoagri- food process, making high sugar products cheaper and increasing problems of obesity and type II diabetes. This would normally not be considered in a partial equilibrium analysis that focuses on sugar production. This is because a PE analysis does not consider feedback effects, from the macro to the sectoral level. Similarly, given their limitation in addressing system-wide dynamics, PE models are not the best option to assess social equity concerns. While these models allow for the estimation of aggregate employment and income-related impacts, they generally fail to describe detailed distributional impacts of policy interventions and investments.

Computable General Equilibrium (CGE) Models

A general equilibrium approach models supply and demand across all sectors in an economy. Analysis is typically conducted using computable general equilibrium (CGE) models. CGE models are a standard tool of analysis and are widely used to analyse the aggregate welfare and distributional impacts of policies whose effects may be transmitted through multiple markets, or contain menus of different tax, subsidy, quota or transfer instruments.

CGE models utilize input-output tables, which can also be utilized as standalone models for more static analysis, and which represent inputs and outputs of several economic activities (e.g., the amount of labour, energy and material input required to produce a unit of production output). Equations are estimated that explain the relationship between inputs and outputs of a given process, or sector (e.g., how much energy is required for a unit of output, given the use of a specific technology in the production process). In other words, the model uses productivity multipliers that serve for the calculation of the output values given a specific set and quantity of inputs, or it estimates the required inputs for a given value of output.

While being most often primarily focused on economic flows, CGE models have in several cases been extended to include environmental impacts of production and consumption on water, land and air. As a result, these models can assess the impacts of changes such as climate or trade liberalisation on outputs and prices across all sectors as well as on the incomes of different groups in society. There are numerous applications focusing on the agricultural sector that use such models, for instance, the effect of climate change and water scarcity on crops and livestock, as well as on the income of poor groups in society. See for example the MAGNET model of the European Commission, which has been used to assess the impacts of agriculture, land-use and biofuel policies on the global economy[2].

CGE models optimize utility for economic actors to solve simultaneously for the set of prices and the allocation of goods and factors that support general equilibrium. CGE models assume that the demand and supply for a product and service always match, through the identification of a price that satisfies both consumers and producers. As opposed to partial equilibrium models, CGEs are ‘top-down’, meaning that variables such as food production are determined by parameterised equations (e.g., balancing demand and supply through prices), rather than considering individual technologies. The underlying assumption is that if there is demand (e.g., through consumption), there will be production as well. Bottom up models estimate instead what production level is feasible and at what costs, depending on the technology available and utilized. CGE models require a large amount of detailed data on across all economic sectors, including factors of production and international trade. Traditional data inputs for CGE models are the Social Accounting Matrices (SAMs), and the System of National Accounts (SNA).

The main advantages of CGE models include the estimation of direct and indirect impacts of policy interventions and investments, and the use of an economy-wide approach. As a result, interdependences across sectors, and countries, are taken into account. The variables included in CGE models are, among others, sectoral consumption and production, wages, household income and inflation, as well as trade.

Nowadays, several agricultural sector analysis involving taxes or subsidies or changes in trade regimes make use of CGE models. Consequently, CGE models are being used very often to assess equity impacts, especially in terms

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[2] Boulanger, P., Dudu, H., Ferrari, E., Himics, M. and M’barek, R. (2016). Cumulative economic impact of future trade agreements on EU agriculture. European Commission. https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/cumulative-economic-impact-future-trade-agreements-eu-agriculture

of income distribution across income classes and employment groups. On the other hand, CGE models do not generally support the assessment of non-monetary dimensions of equity, such as access to services and resources. CGE models are useful in examining the relationship between climate change and agriculture, where increases in temperature and precipitation are expected to lower yields for some crops by significant amounts.

CGEs have significant limitations. First the modelling is complex and depends on a number of parameters whose values are uncertain. This emerges for instance when data are not available, but also when the underlying input output tables and the Social Accounting Matrix, which are often generated every five or ten years, are outdated (e.g., when policy analysis is required for the period 2018- 2025, but the underlying data are from the year 2012). Hence the results have a high level of uncertainty. Second, the level of detail of CGE models is often not adequate to support the analysis of sectoral dynamics in detail. Third, CGE models often suffer from the lack of supplyside constraints (especially physical ones), in that they assume that extra output can be achieved and that scarcity is not a concern. In reality the boundaries of the analysis should be expanded to account not only for the availability of labour and capital, but for natural resources as well. Practically, CGE models lack the explicit representation of biophysical stocks and flows and rely on underlying assumptions on equilibrium and the maximization of welfare that may not represent reality.

System Dynamics (SD) Models

Systems Thinking (ST) is a methodology for “seeing systems” and assessing policy outcomes across sectors and actors, as well as over time. ST can help to assess how different variables in a system interact with each other to shape trends (historical and future).

While Systems Thinking is qualitative, System Dynamics is a quantitative methodology. In fact, it aims to define causal relations, feedback loops, delays and non-linearity to represent the complex nature of systems. It does so by running differential equations over time (i.e., representing time explicitly, with days and months). In contrast to CGE and PE models, System Dynamics models do not optimize the system (i.e., they do not estimate the best possible setup of the system to reach a stated goal). Instead, these are causal-descriptive models used to run “what if” simulations. Created by Jay W. Forrester in the late 1950s, System Dynamics (SD) allows a modeler to integrate social, economic and environmental indicators in a single framework of analysis.

SD models are based on the assumption that structure drives model behaviour and uses causal relationships to link variables. By way of further explanation, SD models include feedback loops (a series of variables and equations connected in a circular fashion). The feedback loops generate non-linear trends that ultimately determine the trends forecasted. This is what is meant by saying “structure” (i.e., the variables and, more importantly, the feedback loops in the model) determine “behaviour” (i.e., the trends forecasted over time). In all other modelling approaches that are linear (i.e., with no feedback loops), the “behaviour” is primarily driven by the data used (not by the equations, or the structure of the model). SD approaches provide a more explicit representation of the factors driving demand (e.g., population divided by age cohorts, income divided by household group, and prices) and supply (for agriculture production these factors include land productivity as affected by soil, quality, mechanization, labour, production inputs, water availability and weather conditions), merging biophysical and economic indicators as stocks and flows. The complexity of a system is represented using Causal Loop Diagrams (CLD) and models can be customized to analyse the socioeconomic implications of different actions across sectors (social, economic and environmental) and actors (e.g., households, private sector and the government), within and across countries.

SD models typically need data on socioeconomic and environmental variables, depending on the boundaries of the model. Practically, more data across social, economic and environmental indicators are required than in the case of other modelling approaches, but the level of depth and disaggregation of the data is lower than what is normally required by biophysical, partial and general equilibrium models. These data are sourced from multiple disciplines and databases and checked for consistency (or harmonized) for inclusion in the integrated model. Further, it is worth noting that SD models start simulating in the past (e.g., year 2000) and, unlike other methodologies (e.g., econometric modelling), rely on historical data only for the parameterization of the simulation model, not for the creation of forecasts. In other words, while econometric models investigate the correlation among historical time series to determine how future trends may be shaped, correlation factors in SD models are not an input for simulations; instead, these emerge from the simulation of endogenous feedback loops (based on causality) and exogenous parameters.

The main strengths of SD include the ability to estimate strategy and policy impacts for a specific project or policy and for society, and how these impacts unfold dynamically over time. In fact, the simulation of scenarios with quantitative systems models allows decision-makers to evaluate the impact of selected interventions within and across sectors as well as economic actors, using social, economic and environmental performance indicators (both stocks and flows). Second, the simulation of causal descriptive models helps to simplify the complexity of the eco-agri-food system (because it more transparently shows all the relationships existing across modelled variables, and how changes in one variable are reflected in all the others) and can evaluate the short vs. longer term advantages and disadvantages of the analysed interventions. In other words, it reduces complexity. Third, a causal descriptive model can capture new and emerging trends (or patterns of behaviour) emerging from the strengthening (or weakening) of certain feedback loops and help identify potential side effects and additional synergies. This is particularly useful in assessing physical and economic impacts, and how these are interconnected (such as in the case of access to resources and services). In other words, SD models can estimate the strength of a feedback loop and forecast changes that may emerge in the future. For instance, the price of a limited resource may be low when such resource is abundant. As a result, the balancing feedback loop that leads to resource efficiency would be weak (i.e., the resource is so cheap that investments that improve resource efficiency may not be bankable). On the other hand, as consumption increases in the future and the stock of such resource declines, its price would increase. In this situation the balancing feedback loop of resource efficiency would become stronger, because a higher price justifies investments that reduce resource consumption. Practically, SD models can forecast whether feedback loops that were weak in the past may gain strength in the future, and whether feedback loops that were strong in the past may become weak in the future.

There are also limitations to the use of SD models. First, the effectiveness of a CLD and SD model is directly related to the quality of the work and the knowledge that goes into developing them. Two aspects need to be considered: the source of the knowledge embedded in the model, and the skills of the modelling team. On the former, multi-stakeholder perspectives should be incorporated and cross-sectoral knowledge is essential to correctly identify the causes of the problem and design effective interventions. In addition, the selection of relevant variables and the way in which they are mapped (most often in a group model building exercise) is crucial. On the skills of the modelling team, building valid SD models requires extensive experience to develop a sufficiently detailed and representative description of the system (i.e., the dynamic hypothesis). The lack of experience increases the difficulty to correctly identify and estimate the underlying feedback structure of the system.

A second limitation of SD models is the correct identification of boundaries of the system, not an easy task. Errors in identifying the boundaries of the model (i.e., what variables and feedback loops to include/exclude) may lead to biased assessments of policy outcomes, overstating or underestimating some of the impacts across sectors and actors. Third, SD models are highly customized, and are better suited for use in a specific geographical context. In other words, this is not an ideal approach for assessing trade dynamics among several countries; it is an approach better suited to analysing national dynamics, and possibly linkages between two or three countries. It is not well suited to carry out assessments on trade that involve five or more countries. Finally, concerning implementation, the development of a SD model requires a substantial amount of interdisciplinary knowledge. The data needs depend on the level of detail being modelled and increase with every new subsystem that is added. As a result, SD models are generally focused on horizontal integration (i.e., across sectors) rather than vertical integration (i.e., adding sectoral detail). As a result, SD models are weaker than CGE models in the analysis of the distributional impacts of policy intervention, generally including less detail on economic activity, household and income groups.

Integrated Assessment Models

In order to carry out an assessment of the social, economic and environmental impacts of production and consumption in the eco-agri-food system, knowledge integration is required. No single model can address all the needs of various stakeholders, some of which are concerned with macroeconomic trends (e.g., employment creation at the national level) while others are more preoccupied with localized impacts (e.g., nutrition and water quality). The TEEB approach proposes a modelling framework that integrates several modelling approaches. In other words, it makes use of the main strengths of each approach, and by linking them it removes some of their weaknesses.

Mainstream modelling approaches are typically designed to answer a specific policy question, and, in order to excel in one task; these models simplify the complexity of the system. In the context of TEEBAgriFood, this highlights a disconnect between our ‘systemic’ thinking and available models. To ensure that the wider evaluations support the decision-making process for sustainable eco-agri-food systems effectively, emphasis should therefore now be put on the development and use of models that allow for a fuller representation of the complexity of the eco-agrifood system, including the many causes and mechanisms responsible for the emergence of problems as well as for the success (or failure) of proposed solutions.

Considering the various methods and models available to analyse the eco-agri-food system and its parts, several opportunities for using a complementary approach emerge. System Dynamics could be utilized as a knowledge integrator, incorporating the key features of various evaluation methods, and providing a systemic and dynamic view of the problem under consideration and its possible solutions. Practically, a SD model could make use of inputs from biophysical models, and integrate these with those received from economic models, possibly allowing for a spatially explicit analysis. This modelling approach would then complement the analysis carried out with input-output, partial equilibrium and general equilibrium models, providing information on both capital base stocks, flows through the value chain and outcomes. Specifically, this modelling approach can make use of the higher level of detail included in partial equilibrium models as well as of the larger detail on economic activities included in CGE models; coupling these with the explicit spatial representation of biophysical models provides an integrated assessment that includes social and environmental indicators and related dynamics. This analysis would capture feedbacks existing across social, economic and environmental indicators, better assessing policy impacts in highly interconnected and rapidly changing environments.

A high degree of customization is required to create this type of model. This is to account for: i) local circumstances, ii) the tacit and explicit local knowledge, and iii) the identification and understanding of the priorities of local decision makers. Specifically, it is crucial to use local knowledge sources in the identification of causal relations and feedback loops. Further, the analysis must provide information on indicators that decision makers deem important to increase policy impact16.

Conclusion

The eco-agri-food sector is of great economic and social importance. The complexity of the system must be acknowledged; agriculture not only involves the growing of crops and husbandry of livestock but is also part of a configuration in which the activities of production, processing, distribution, consumption and waste disposal are all key components. In the past these linkages have tended to be ignored when formulating and appraising agricultural policies. On the environmental side there is an important link between agriculture and food production and the ecosystems in which such activities are embedded. These ecosystems provide key services to the agri-food system and in turn the way in which the latter works has an effect on the ecosystems. Consequently, it is important to understand these linkages, which requires an appreciation of the different ecosystem services and their relation to food production, as well as the subsequent steps in the agri-food system. A systems approach to thinking that combines modelling tools with geospatial analysis and valuation of ecosystem services is very useful in this regard. This document presented a toolbox for national implementing agencies. Each tool has its strengths and weaknesses and is best suited to specific problems. Modals from this tool box can be used to review the impacts of the functioning of the eco-agri-food sector and to enable policy makers to compare different policies and measures, especially when faced with evidence of inadequate performance of some parts of the system.

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