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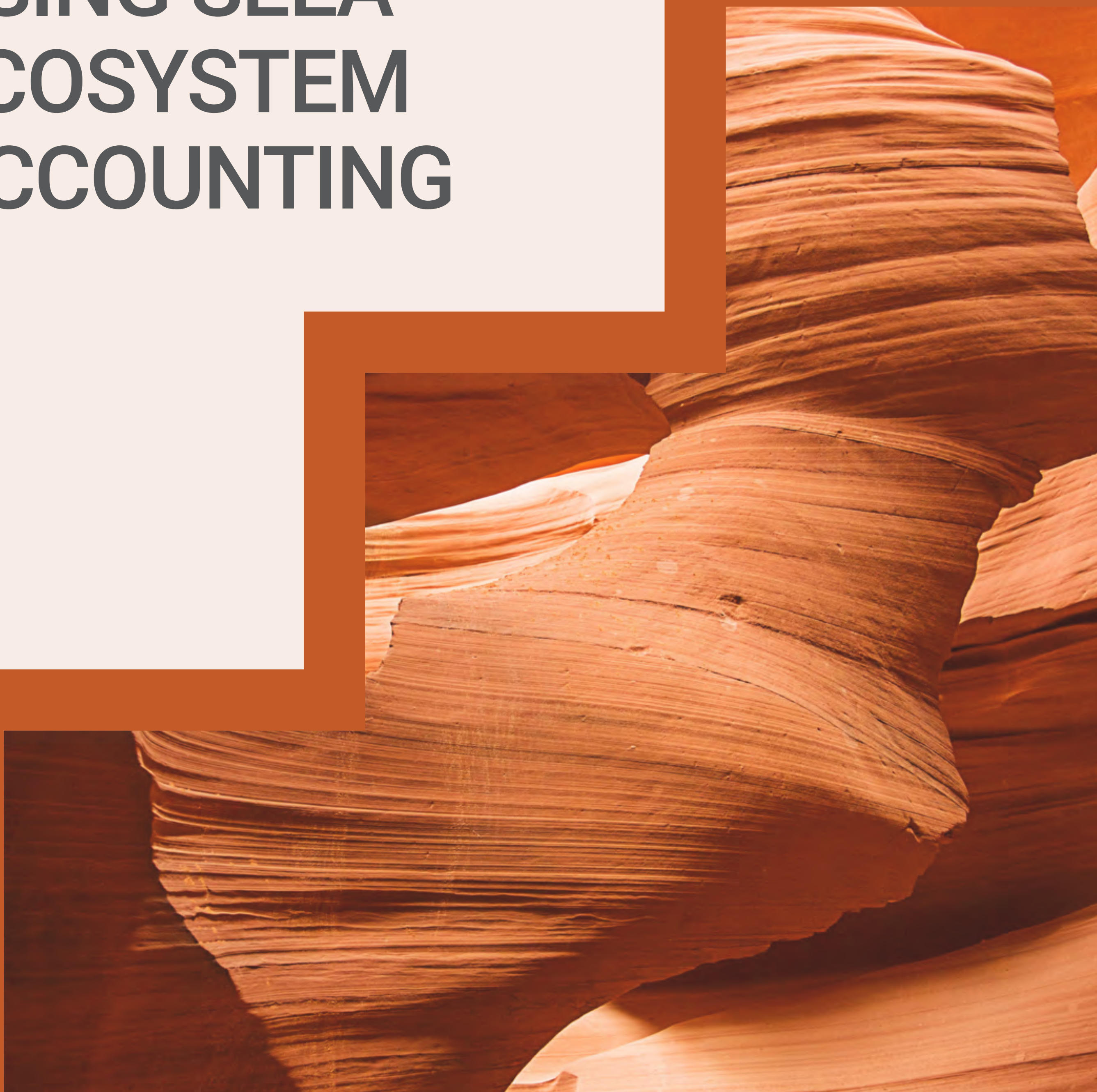
POLICY SCENARIO ANALYSIS USING SEEA ECOSYSTEM ACCOUNTING



Reference and Licensing

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Abbreviations and Acronyms

ABM	Agent Based Modelling
AIM	Asian Pacific Integrated Model
AIRES	Artificial Intelligence for Ecosystem Services
ASF	Atmospheric Stabilization Framework Model
BAPPPENAS	Ministry of National Development Planning of the Republic of Indonesia
BAU	Business-As-Usual scenario
CBA	Cost-benefit analysis
CBD	Convention on Biological Diversity
CEA	Cost-Effectiveness Analysis
CGE	Computable General Equilibrium
CLD	Causal Loop Diagram
CLUE	Conversion of Land use and its Effects
CRA	Environmental Reserve Quotas
DEM	Digital Elevation Model
DSCR	Debt Service Coverage Ratio
DTL	Dawna Tenasserim Landscape
EDPRS II	Economic Development and Poverty Reduction Strategy
EDR	Groups of Municipalities
EEA	Experimental Ecosystem Accounts
ES	Ecosystem Services
ESAV	Ecosystem Service Assessment and Valuation
FC	Forest Code
FOCI	Flexible Ocean and Climate Infrastructure
GE	Green Economy scenario
GEF	Global Environment Facility
GEM	Green Economy Model
GEO	Global Environment Outlook
GHG	Greenhouse Gas
GIS	Geographic Information System
GLO	Global Land Outlook
GMEP	Glastir Monitoring and Evaluation Programme
Gt C	Gigatons of Carbon
HoB	Heart of Borneo

HUMUS	Hydrologic Unit Model for the United States
IA	Impact Assessment
IAM	Integrated Assessment Models
IEA	International Energy Agency
IEEM	Integrated Economic-Environmental Modelling
Ifs	Integrated Futures
I-GEM	Indonesia Green Economy Model
IIASA	International Institute of Applied Systems Analysis
IISD	Institute for Sustainable Development
IMAGE	Integrated Model to Assess the Greenhouse Effect
IMF	International Monetary Fund
InVEST	Integrated Valuation of Environmental Services and Trade Offs
I-O	Input-Output
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change
IPS-Road	Integrated Planning for Sustainability – Road Infrastructure
IRR	Internal Rate of Return
JK-GEM	Province of Jakarta Green Economy Model
KPI	Key Performance Indicators
KT-GEM	Province of Kalteng Green Economy Model
LCA	Life Cycle Analysis
LCDI	Low Carbon Development Initiative for Indonesia
LEAP	Long-range Energy Alternatives Planning System
LR	Legal Reserve
LUCI	Land Utilisation Capability Indicator
LULC	Land-Use and Land-Cover
LULUCF	Land Use, Land-Use Change and Forestry
MAES	Mapping and Assessment of Ecosystems and their Services
MARIA	Multiregional Approach for Resource and Industry Allocation
MCA	Multi Criteria Analysis
MDGs	Millennium Development Goals
MESSAGE	Model for Energy Supply Strategy Alternatives and their General Environmental Impact
MIMES	Multi-scale Integrated Model of Ecosystem Services
MiniCAM	Mini Climate Assessment Model
MSA	Mean Species Abundance

NCE	New Climate Economy
NDC	Nationally Determined Contribution
NPV	Net Present Value
P4P	Payment for Performance
Pas	Protected Areas
PES	Payment for Ecosystem Services
PNLL	Pacific Northwest National Laboratory
PPP	Public Private Partnership
PRMS	Precipitation-Runoff Modelling System
RE	Reference scenario
REDD	Reducing Emissions from Deforestation and forest Degradation
RIVM	National Institute for Public Health and Environmental Hygiene
RPJMN	National Medium Term Development Plan
SAGCOT	Southern Agriculture Growth Corridor of Tanzania
SAGEM	South-Africa Green Economy Model
SAM	Social Accounting Matrix
SaS	Story and Simulation
SAVi	Sustainable Asset Valuation tool
SD	System Dynamics
SDGs	Sustainable Development Goals
SEEA	System of Environmental and Economic Accounts
SEI	Stockholm Environment Institute
SNA	System of National Accounts
SPP	Sustainable Public Procurement
SRES	Special Report on Emissions Scenarios
SST	Sea Surface Temperature
STPs	Sewage Treatment Plants
SWAT	Soil and Water Assessment Tool
T21	Threshold 21 or iSDG model

TEEB	The Economics of Ecosystems and Biodiversity
UKERC	UK Energy Research Centre
UNCCD	United Nations Convention to Combat Desertification
UNFCCC	United Nations Framework Convention on Climate Change
UPA	Units of Agricultural Production
WAVES	Wealth Accounting and the Valuation of Ecosystem Services
WEAP	Water Evaluation and Planning

1 Introduction

1.1. Objectives of the report

The increasing interconnectedness between the natural environment, human societies and their economies implies new challenges and opportunities for policymakers. The interdependent nature of the 17 Sustainable Development Goals and underlying indicators of the 2030 Agenda for Sustainable Development embodies the need for a systemic approach to tackle the challenges that are currently facing humanity. Attaining one goal at the expense of another is neither desirable nor sustainable: ending hunger by over-fishing that threatens life at sea is not a durable solution. Progress on one goal can contribute to another: for example, poverty can only be eliminated (SDG 1) through decent work and economic growth (SDG 8). Failure on one goal will lead to negative progress on another: accelerated climate change will exacerbate desertification, land degradation and biodiversity loss, thus harming life on land.

To adequately take account of such complexities, policymakers require new sources of data, based on coherent statistical frameworks that can be transformed into decision-relevant information through the application of innovative, sophisticated modelling techniques. This report focuses on how one such statistical framework – the System of Environmental-Economic Accounting Ecosystem Accounting (SEEA EA) – can be deployed in the application of scenario analysis to support policymaking. The objective of the report is to improve the effectiveness of decisions for sustainable development by highlighting how use of the ecosystem accounts of the SEEA EA in scenario analysis models can provide policymakers with a better understanding of the interconnections existing between society, economy and the environment, and hence lead to better decisions.

Ecosystem accounts are by nature backward-looking: they describe the state of affairs at some point in the past, which may be relevant for a whole range of policies. Policymaking is, by contrast, forward-looking: it seeks to influence future states of affairs based on decisions taken today. The challenge, then, is how to marry the two. The report focuses on the use of backward-looking data in forward-looking policy scenario analysis that allows policymakers to assess the possible impacts of their choices. The utility of such an approach is demonstrated by the work carried out by The Economics of Ecosystems and Biodiversity (TEEB) in various countries and policy areas.

This report shows how such types of analyses can be informed or improved by applying ecosystem accounts in different types of models and modelling approaches. In order to achieve this goal, this report provides: an overview of core concepts and dimensions in scenario design (Section 2); a technical review of state-of-the-art methods and simulation models for scenario analysis (Section 3) and policy-relevant content to create an explicit link between the use of models and policymaking, based on successful examples (Section 4). As a result, this report connects methods for the creation of scenarios (ie. forward-looking assessments, created with simulation models) to policy processes and the key indicators required to make informed decisions. In doing so, it describes what types of analysis are possible when using the ecosystem accounts and the TEEB approach, and reviews what types of policy questions can be answered when using these accounts in conjunction with simulation models.

This report emphasises the growing opportunity for the SEEA EA and the TEEB approach to support policy analysis and hence sustainable development. More specifically, the SEEA EA provides improved data – due to its standardized approach to data collection, interpretation and use – that allows more reliable quantification of the interlinkages between society, the economy and the environment. Thus, policy formulation can be informed by: (1) use of SEEA EA data in scenario analysis to expand the scope of the analysis; (2) better interpretation of the results of simulation models that are currently used; (3) improvement and expansion of simulation models by using SEEA EA data. With the availability of these data, and improved understanding of ecosystem services and their valuation, the TEEB approach can be implemented more effectively, recognizing, demonstrating and capturing the value of nature for improved decision-making.

1.2. Outline of the report

The report starts with an introduction to the SEEA EA and TEEB, and an overview of applicable scenario and forecasting methods (Section 2). In addition to describing the goals of SEEA EA and TEEB, Section 2 explains why these two initiatives are relevant for policy analysis, especially in the context of forecasting exercises.

Section 3 introduces various models that are frequently used for the creation of projections on policy outcomes. Section 3 also provides indications on how SEEA EA can support the improvement of model structure, creation of stronger outcomes and better interpretation of such outcomes, and how the TEEB approach supports the recognition and demonstration of the value that is provided by nature, also through modelling exercises.

Section 4 provides an overview of the main policy domains and the type of policy questions that can be answered by scenario analysis. It further explains how SEEA EA and TEEB can improve policy effectiveness, by informing policy formulation and assessment (ex-ante) as well as monitoring and evaluation (ex-post). This section is largely based on case studies.

Section 5 summarizes findings.

1.3. Reader's guide

This report is written with three main audiences in mind: (i) government officials who are in charge of policy formulation and evaluation, (ii) officers in statistical offices that develop SEEA EA accounts, and (iii) modellers, working in various sectors and domains.

The primary audience is represented by government officials working on technical policy assessments that are involved in the creation of sectoral and national development plans. Examples include officers in charge of policy analysis within a ministry or being part of an inter-ministerial task force or working group. Their tasks include developing policy assessments in-house, as well as procuring quantitative policy assessments carried out by outside experts. The most relevant content for this audience can be found in Section 2 and 4, which respectively provide an overview of the approach used and on policy questions that could benefit from scenario analysis using the accounts. For information about what type of analysis can be created by integrating SEEA EA concepts and data in the many simulation models described in this report, see Section 3.

The goal of this report for officers in statistical offices is to provide explanations and examples of policy application in order to better understand how the data they produce can be used in scenarios exercises aimed at informing policy formulation and evaluation. This is primarily addressed in Section 3 from a technical perspective, and the policy relevance of this work is presented in Section 4.

For modellers, this report provides information that could be useful to explore how their existing models can be expanded, as well as how the interpretation of the results of their work can be improved when using SEEA EA data. Details on models can be found in Section 3, including an assessment of how the use of SEEA EA can strengthen various sectoral and integrated models. Section 4 presents how the use of SEEA EA can increase the policy relevance and uptake of forecasting exercises.

2 Policy scenario analysis and forecasting

The policymaking process includes five broad steps (UNEP, 2009) (Figure 1): (1) issue identification (or agenda setting); (2) policy formulation (including identification of intervention options and their assessment); (3) decision-making (or policy adoption); (4) policy implementation; and (5) monitoring and evaluation.

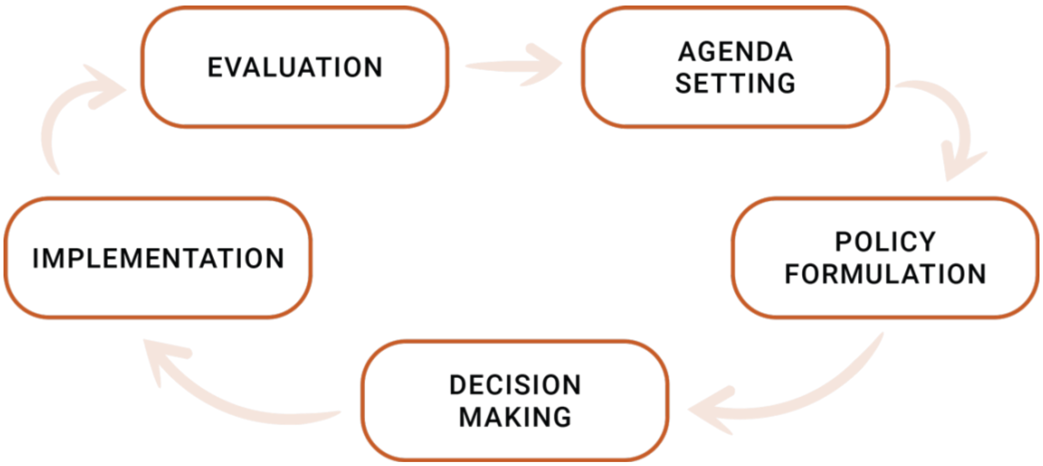

Figure 1: *Graphical representation of the policymaking cycle based on (UNEP, 2009)*

Scenarios are primarily used to inform the issue identification, policy formulation and evaluation steps. In *agenda setting*, scenarios identify the possible emergence of problems or opportunities, as well as upcoming trends and dynamics that inform the development agenda. For example, scenarios are used to forecast wastewater generation and water pollution, and the possible emergence of health impacts. In *policy formulation,* simulation models are used to identify targets for selected indicators, and assess the effectiveness of various intervention options in reaching these targets. For example, emission reduction targets have been used to estimate required investments and policy interventions for climate change mitigation. *Decision-making* and *implementation* are operational steps that do not rely directly on the scenarios. In *monitoring and evaluation,* scenarios can be generated to monitor either the performance of the sector or the issue analysed and then from there assess the effectiveness of the policies implemented.

The use of SEEA EA can inform the policy making cycle by (Figure 2):

(i) Providing consistent and coherent input data for simulation models;

(ii) Improving the interpretation and contextualization of scenario and forecasting exercises, by broadening the scope of the analysis to capture more explicitly the interconnections that exist among society, economy and the environment;

(iii) Providing data for the calculation of new indicators to track progress against policy objectives; and

(iv) Providing spatially disaggregated results that allow for spatially targeted policymaking, such as land-use planning.

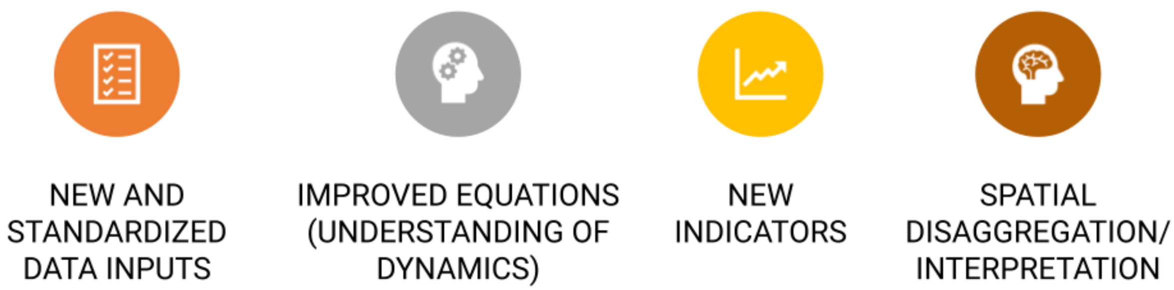

Figure 2: *Contribution of SEEA EA to simulation models and policymaking (Report authors)*

There are different entry points for the use of SEEA EA in scenario and forecasting exercises, both originating from the institutionalization of the accounts and emerging from the need of specific policy assessments, on demand. A "*data push*" approach, driven by the availability of new information, and a "*policy pull*" case, where the use of SEEA EA data is requested to carry out a comprehensive policy assessment, are both important (Figure 3). In this regard, the TEEB approach and the SEEA EA can be seen as complementary initiatives that can enhance more informed policymaking.

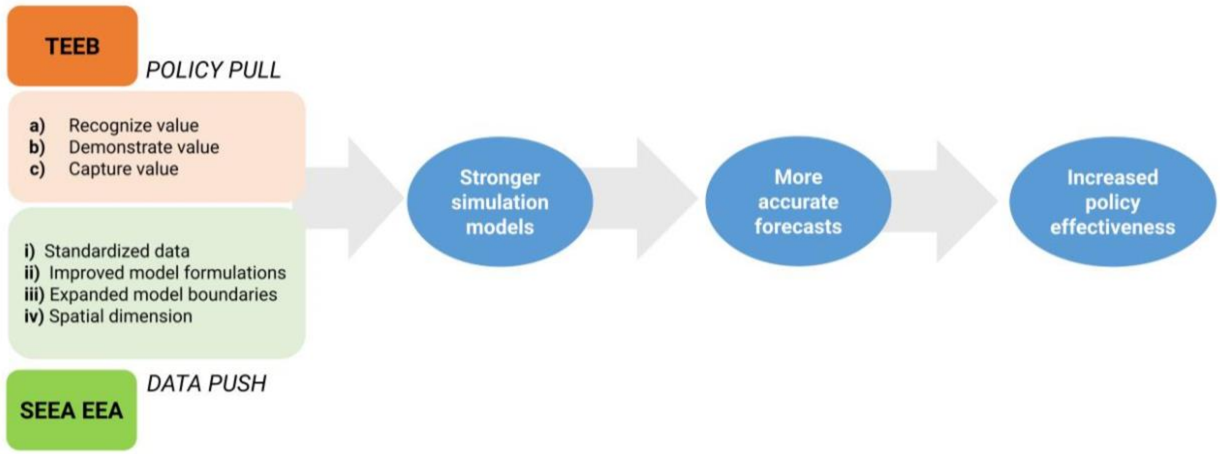

Figure 3: *The contribution of SEEA EA and TEEB to policy scenario analysis through (a) the improvement of simulation models, (b) the creation of stronger forecasts and (c) increased policy effectiveness. (Report authors)*

2.1. Scenarios and forecasting methods

To decide between alternate courses of action, policymaking makes use of a wide inputs, including: the logical and scientific evidence base obtained by international research fora; the review of surveys that gauge the opinion of citizens; newspaper articles that present current and upcoming issues and opportunities; statistics explaining past performance; and forecasts that explore the emergence of new threats and opportunities.

This report refers to (a) *scenarios* which are "representations of possible futures for one or more components of a system … including alternative policy or management options" (IPBES, 2016) (b) *simulations* as quantified scenarios, generated with (c) *simulation models*, which are simplified representations of reality that use mathematical formulations to generate projections. Such projections can be used for both backcasting (eg. what policy mix is required to reach a stated objective) and forecasting (eg. how close to the objective would a given policy mix deliver).

The creation and quantification of scenarios with mathematical simulation models allows for the creation of quantitative estimates for various scenarios (eg. of implementing or not implementing a proposed policy) that can be used to inform the policymaking process. This is *policy scenario analysis* ie. an exercise that aims at informing decision-making and makes use of scenarios to assess the outcomes and effectiveness of various policy intervention options.

Specifically, policy scenario analysis:

- Starts with the identification of an issue, or the determination of the development agenda.
- Assesses policy interventions for all scenarios, and compares performance against a baseline or reference scenario.
- Supports the estimation of the outcomes (both desirable and undesirable, foreseeable and emerging) of planned interventions, increasing the general readiness to tackle emerging trends.
- Sheds light on uncertainty, estimating the effectiveness of public intervention under various underlying possible futures.
- Results in the creation of strategies that combine several interventions options, both to create new opportunities and minimize the emergence of trade-offs.

Both the private and public sector have used policy scenario analysis over the last few decades to manage risk and develop robust strategic plans in the face of an uncertain future.

The various types of scenario that can be used in policy scenario analysis are usefully classified by IPBES (IPBES, 2016) (Figure 4) into (a) exploratory scenarios, (b) target-seeking scenarios, (c) policy-screening scenarios and (d) retrospective policy evaluation. This characterization is consistent with the potential for scenarios to inform policymaking primarily in the agenda setting and design phase, and for monitoring and evaluation after implementation.

Exploratory scenarios are generally used to forecast trends, both of action and inaction, and primarily support the issue identification or agenda setting steps of the policymaking cycle. For example population growth projections can be used to estimate (or 'explore') expected land-cover changes, investigating trends in agricultural expansion or urbanization. Such an exercise would help identify land constraints (requiring new land-use planning exercises and zoning) or changes to water availability and water quality, as well as what level of investment would be required to provide the desired level of public services for a growing population in a specific landscape (eg. roads, power distribution, wastewater management, hospitals and schools).

Target-seeking and policy-screening scenarios are collectively known as *intervention scenarios* because they include modelling of the impact of policy interventions. Policy-screening scenarios tend to analyse the likely impact of a discrete policy choice. In optimization and econometrics models, the policy is seen as a "shock" to the system and the model forecasts how the system reacts to the introduction of such shock (such as the introduction of a carbon tax). Target-seeking scenarios instead often comprise the simulation of a variety of policy options, as part of a strategy or policy package intended to meet a certain target (eg. the unemployment rate). These scenarios estimate what mix of polices would be needed to achieve the target.

Retrospective policy evaluation is an ex-post assessment carried out after policy implementation used to compare expectations to real, observed developments. For instance, a policy implemented in 2012 could be evaluated by comparing the simulated results of policy implementation with actual data from 2012 to 2018.

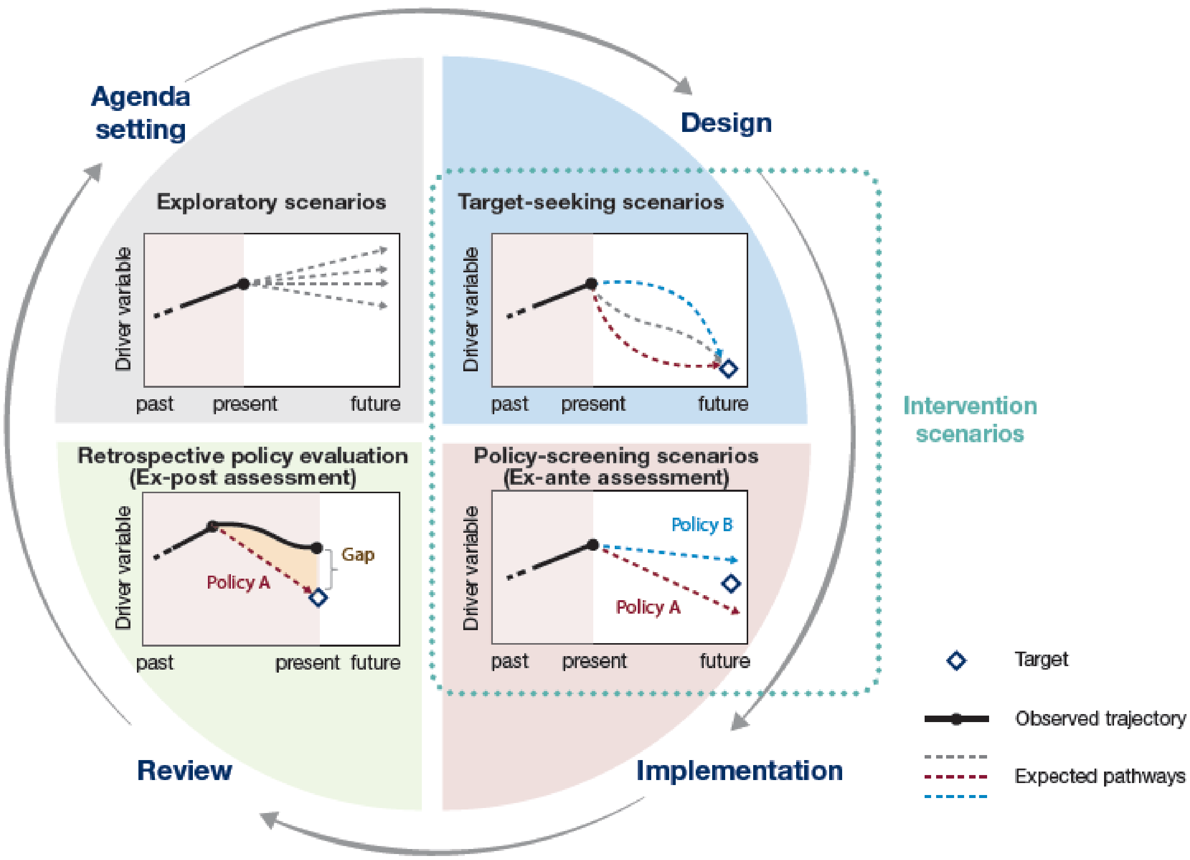

Figure 4: *Roles played by different types of scenarios (referred to as "simulations" in this report when these scenarios are quantified) corresponding to the major phases of the policy cycle (IPBES, 2016).*

To complement the characterization presented above, it is worth mentioning that there are two main types of scenarios:

- **Baseline scenarios**: elaborated to define the trends to assess performance against (eg. population, food demand trends). This is also known as business-as-usual, because it considers the likely future path without the implementation of policies under consideration.
- **Policy scenarios**: generated to determine how the performance of a system is affected by a proposed policy change (eg. investment in irrigation infrastructure).

The use of SEEA EA and TEEB promote scenarios exercises that create innovative thinking about possible future paths of the systems, improve multi-stakeholder and cross-sectoral risk management and support monitoring and evaluation. Figure 5 compares two traditional approaches (supply-led and demand-led) with a more innovative approach of scenario and model co-creation. SEEA EA and TEEB use the latter, more innovative approach, considering model and scenario co-creation and employing a variety of data and data sources for knowledge integration.

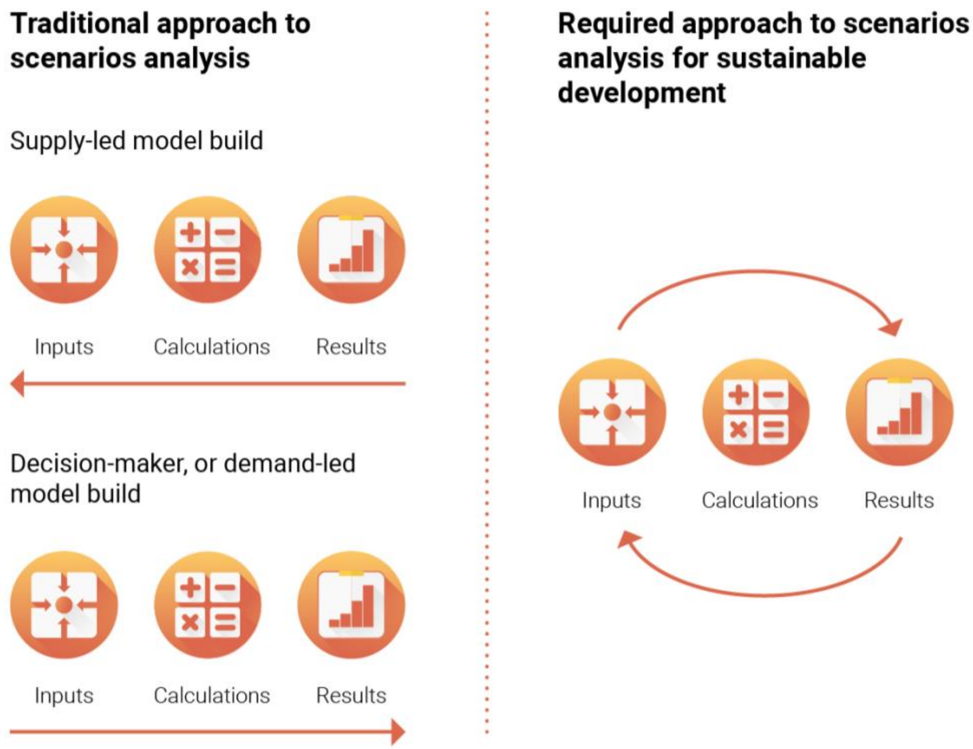

***Figure 5**: Three possible sequences of scenario and model building (IISD, 2019a)*

2.2. Global scenario exercises: examples

Scenarios are frequently developed to explore how the future may unfold, and anticipate risks and opportunities. Qualitative scenarios are generated to conceptualize future paths and goals, such as in the case of the five Shared Socioeconomic Pathways (SSPs), which represent socioeconomic global changes up to 2100 and are used to derive and quantify greenhouse gas emissions scenarios (Riahi et al., 2017). Other global and national quantitative scenarios are generated for economic growth (IMF, 2018), climate (IPCC, 2000) and its drivers (IPCC, 2019a; IPCC, 2019b), energy (IEA, 2018), biodiversity (UN Environment, 2019) and more (Table 1).

Table 1: *Summary of the scenario exercises presented (Report authors)*

Source	Time horizon	No of scenarios presented	Region/Global	Data available for download?
IMF (IMF, 2018)	**2024**	1	Country	Yes
World Energy Outlook (IEA, 2019)	**2040**	4	Global & Regional	Yes, at a fee
Global Environment Outlook (GEO) (UN Environment, 2019)	**2050**	Many, see Annex 1-1 of GEO-6	Global	No
IPCC (IPCC, 2000)	**2100**	Many (ensemble)	Global and regional	Yes
UNCCD GLO (PBL, 2017; UNCCD, 2017)	**2050**	4	Global and regional	No
IPBES (IPBES, 2019)	**2050**	Many (ensemble)	Global and regional	Yes, via the Land Use Harmonization (LUH2) project

The analysis and projections contained in the World Economic Outlook[1], issued by the International Monetary Fund (IMF), provide 1) the expected economic development of regions and countries if currently observed trends continue and 2) highlight opportunities and challenges for economic development.

The World Energy Outlook[2] published by the International Energy Agency (IEA) contains different scenarios describing the consequences of various energy development trajectories. It outlines the potential impacts of global energy trends on energy demand and supply, air emissions and energy access.

The Global Environment Outlook (GEO), published by UN Environment, provides information about the current state of the environment and plausible development trajectories for action and inaction (UN Environment, 2019). The GEO addresses key environmental issues such as water use and supply balances, resource consumption the bleaching of coral reefs, melting of Artic ice and the frequency of major loss-related natural events. Further, by providing information about policy effectiveness and potential future trends, the GEO provides guidance to policymakers, as well as other decision makers, for policy formulation and evaluation (Figure 6).

[1] See: https://www.imf.org/en/Publications/WEO
[2] See: https://www.iea.org/topics/world-energy-outlook

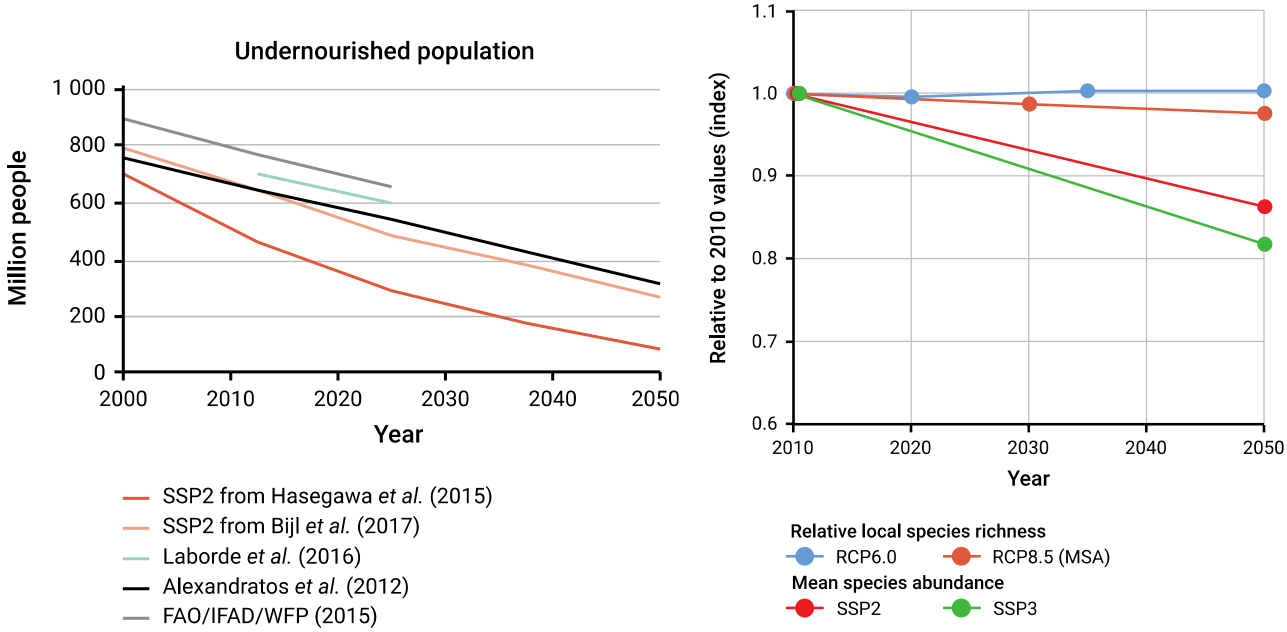

Figure 6: *Future projections of global undernourished population (left) and future projections of relative local species richness for a range of climate stabilization scenarios and Mean Species Abundance (MSA) for SSP2 (Shared Socioeconomic Pathway 2: Middle of the Road) and SSP3 (Shared Socioeconomic Pathway 3: Regional Rivalry, A Rocky Road) land-use (right) (UN Environment, 2019).*

The publications of the Intergovernmental Panel on Climate Change (IPCC) contain a variety of climate projections with a long-term time horizon (up to 2100) (IPCC, 2018),A description of expected impacts on precipitation, temperature and extremes like heavy rainfall and hot- and cold days is provided for each of the scenario to raise awareness about the potential impacts of climate change (Figure 7).

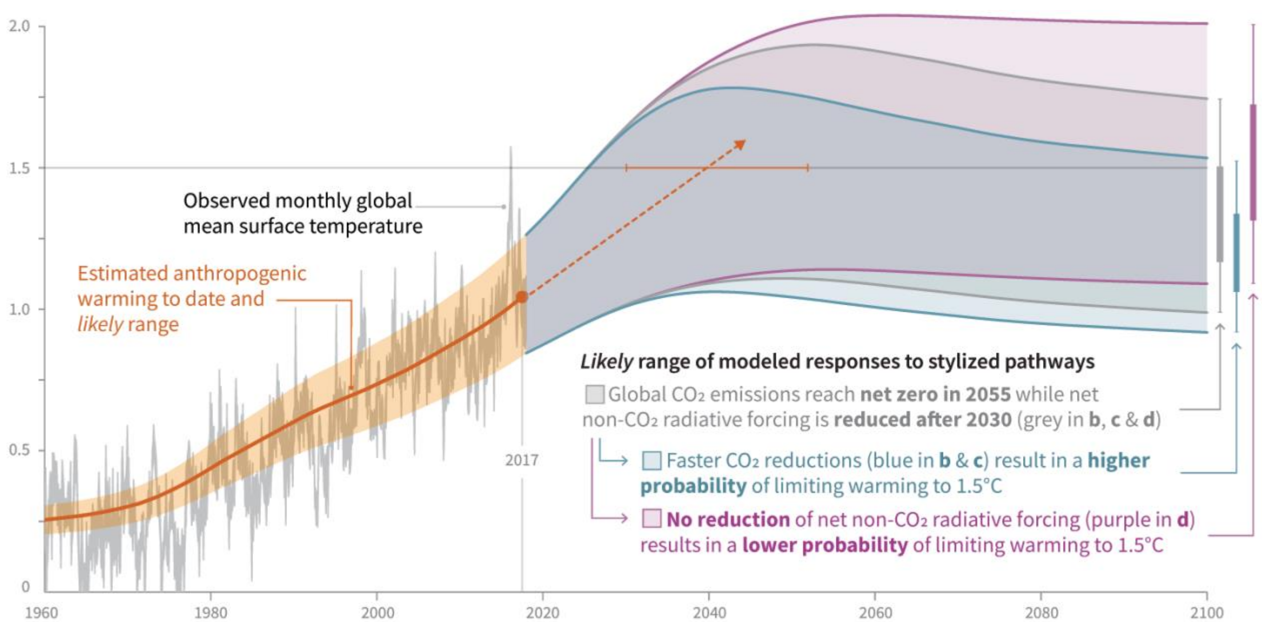

Figure 7: *Observed Global temperature change and modelled responses to stylized anthropogenic emission and forcing pathways (IPCC, 2018).*

In addition to climate scenarios, the IPCC also addresses issues with strong linkages to air emissions, such as for example land use (IPCC, 2019a) or ocean carbon sequestration (IPCC, 2019b) (Figure 8).

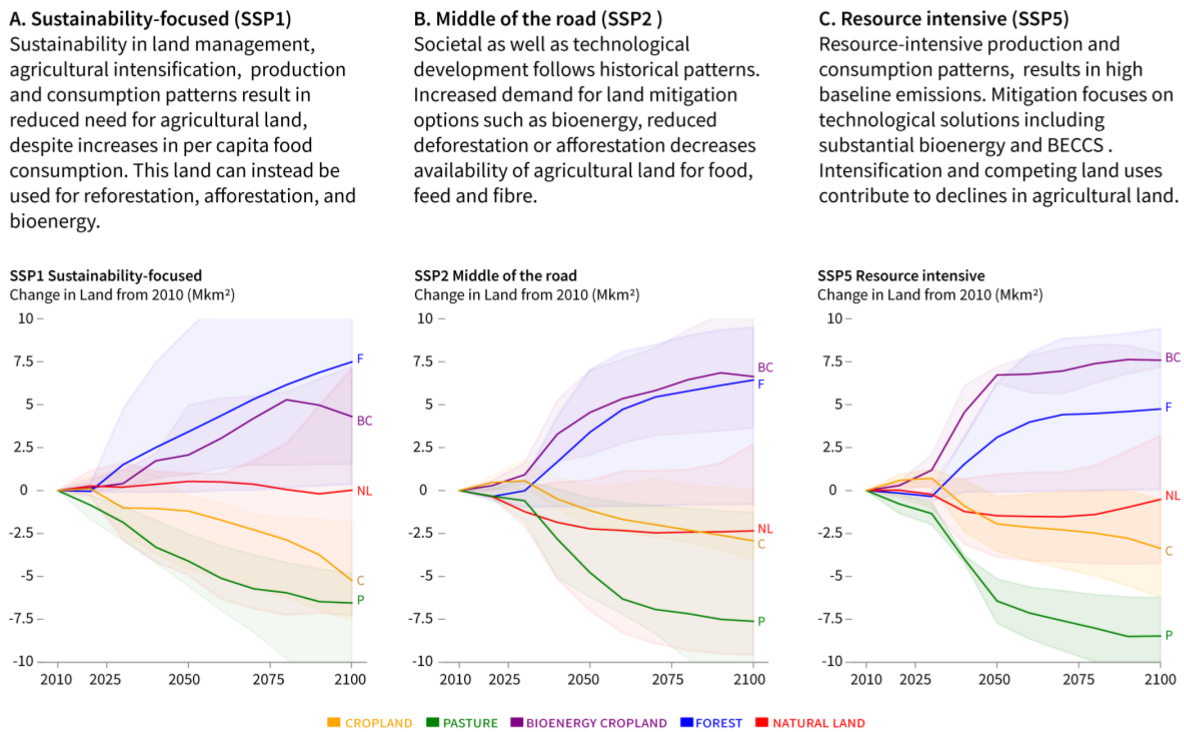

Figure 8: *Pathways linking socioeconomic development, mitigation responses and land (IPCC, 2019a)*

The Global Land Outlook[3] (GLO), published by the United Nations Convention to Combat Desertification (UNCCD), provides an assessment of how future needs for land-based goods and services can be satisfied sustainably. Land-use projections included in the GLO are based on scenario analyses conducted by the PBL Netherlands Environmental Assessment Agency (PBL, 2017) (Figure 9).

[3] See: https://www.unccd.int/actions/global-land-outlook-glo

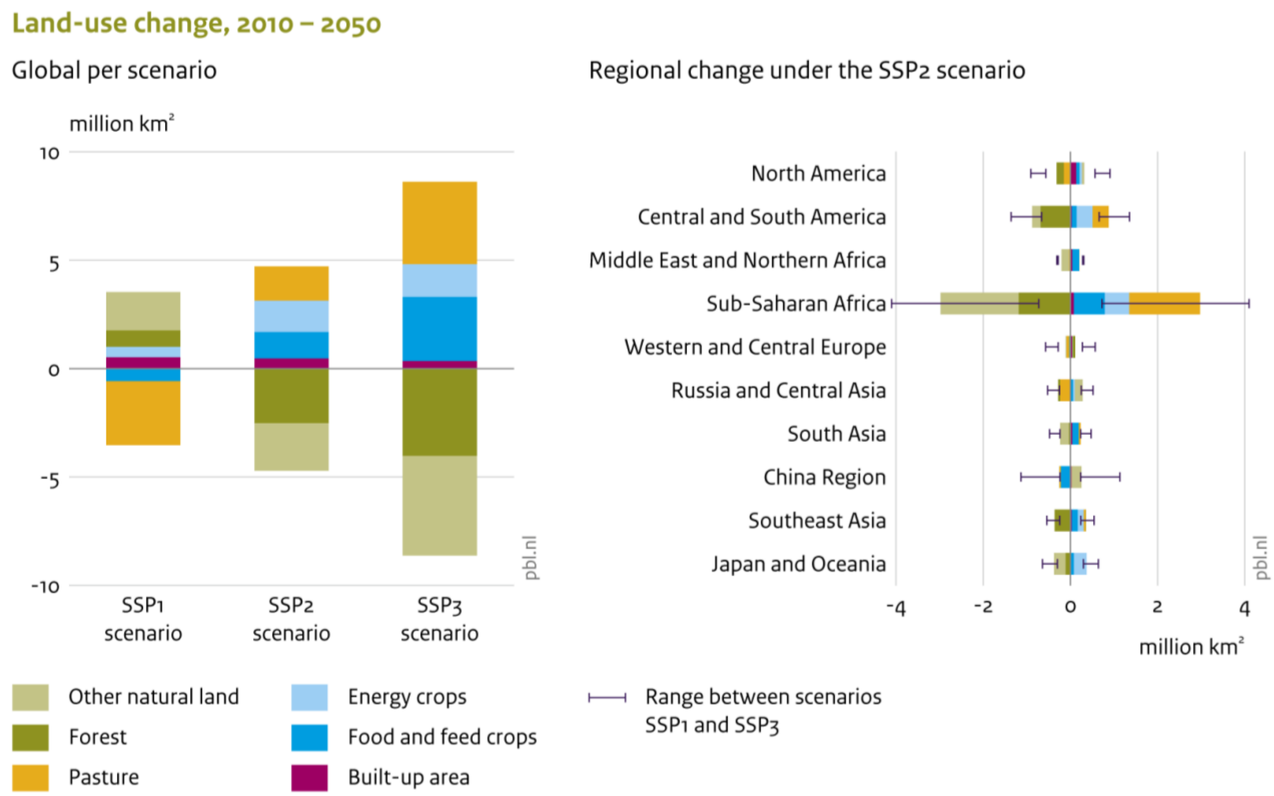

Figure 9: *Projected land-use change in the SSP1-3 scenario (PBL, 2017)*

The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) aims at providing policymakers, the private sector and civil society with credible and independent up-to-date assessments of available knowledge for improve decision-making (IPBES, 2019). The 2019 IPBES report assesses the status and trends (up to 2050) of the natural world and the social implications of observed trends, building on the narrative of the SSP scenarios (Figure 10A and 10B).

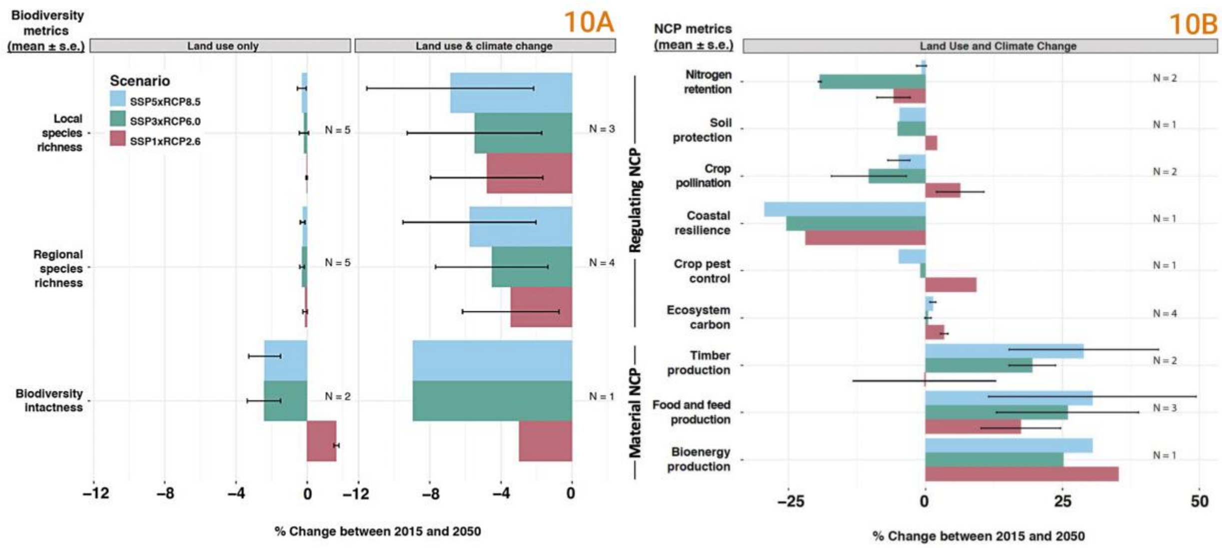

Figure 10A and 10B: *Projected change in species richness and biodiversity intactness (A) nature's contribution to people (B) between 2015 and 2050 (IPBES, 2019)*

2.3. Scenario modelling at the country level: who and how

Scenario modelling is a common exercise at the country level, both to set the development agenda and to formulate and assess policies. For example, scenarios for the Millennium Development Goals (MDGs) and the Sustainable Development Goals (SDGs) are an example of scenarios applied at the national level. Scenarios can be more narrowly focused on particular regions (eg. provinces or landscapes), specific domains (eg. economic performance, unemployment and deforestation) and/or specific sectors (eg. industry, water, energy).

The creation of a vision for the development of the economy and society at the national level can be considered a scenario exercise. This is often a quantitative assessment, with the identification of specific targets for sectoral performance and the creation of sectoral strategies. This exercise involves various ministries and requires the integration of data from various fields. The custodians of such modelling exercises are often the Ministry of Planning or the Prime Minister's Office, or departments tasked with the assessment of national performance (eg. through the harmonization of policies and investments across sectors).

Scenarios at the sectoral level are most commonly found in relation to economic planning (eg. for the estimation of the impact of fiscal policies) and for infrastructure planning (eg. electricity supply), specifically in the context of medium-term development plans. These plans are more detailed than the strategic priorities included in the vision, and often result in the estimation of the investment required to implement desired intervention options, and in an assessment of the likely outcomes (primarily economic) of such investments. The custodians of these scenario-modelling exercises are line ministries, with the economic analysis being communicated to the Ministry of Finance or Treasury to determine what investments to prioritize in relation to national development targets. For instance, electricity supply models can be used to assess the best technologies to use to match future demand, or to determine the extent to which renewable energy could complement conventional thermal generation, or to estimate changes in generation costs when subsidies are introduced/removed.

There are also decisions that require a sub-national (even landscape) assessment, and make use of models that are spatially explicit. This is the case of water and transport infrastructure, land- use planning and zoning.

Finally, scenario modelling can be used on an ongoing basis to analyse the outcome of specific policies or policy packages (eg. in relation to the preparation of the annual budget at the Ministry of Finance). In this respect, although there are important differences from country to country, it can be said that technical expertise to create, modify and run simulation models can be more frequently found in those ministries that use these models often (eg. Ministry of Finance in relation to CGE models, and Ministry of Energy in relation to energy demand and supply models). In areas where models are not used often, eg. due to the lack of data or to the nature of the investments (eg. if infrastructure has a long lifetime and hence modelling exercises can be regarded as "one off") it is more common to find reliance on external expertise, from universities and/or experts/consultants. This is also the case when highly specific knowledge is required for running models and where funding constraints make it impossible to hire modellers.

2.4. The SEEA

The System of Environmental-Economic Accounting (SEEA) is a framework that integrates economic and environmental data to provide a more comprehensive and multipurpose view of the interrelationships between the economy and the environment and the stocks and changes in stocks of environmental assets, as they bring benefits to humanity. It contains the internationally agreed standard of concepts, definitions, classifications, accounting rules and tables for producing internationally comparable statistics and accounts. The SEEA framework follows a similar accounting structure as the System of National Accounts (SNA). The framework uses concepts, definitions and classifications consistent with the SNA in order to facilitate the integration of environmental and economic statistics. The SEEA is a multipurpose system that generates a wide range of statistics, accounts and indicators with many different potential analytical applications. It is a flexible system that can be adapted to countries' priorities and policy needs while at the same time providing a common framework, concepts, terms and definitions.

The SEEA consists of three parts:

- The SEEA Central Framework (2012) was adopted by the UN Statistical Commission as the first international standard for environmental-economic accounting in 2012.
- The SEEA Ecosystem Accounting offers a synthesis of current knowledge in ecosystem accounting.
- The SEEA Applications and Extensions illustrates to compilers and users of SEEA Central Framework based accounts how the information can be used in decision-making, policy review and formulation, analysis and research

Ecosystem accounting has been created to provide a coherent and comprehensive view of ecosystems at a given point in time (eg. every year in the last decade and up to the current year). The SEEA Ecosystem Accounting identifies indicators that categorize and organize ecosystems, including their ecosystem extent, condition and services provided. SEEA EA complements the SEEA Central Framework, which measures the environment and its relationship with the economy by covering three main areas: environmental flows, stocks of environmental assets and economic activity related to the environment. The focus of the report is on SEEA EA but, as presented in the next sections, simulation models can include both SEEA Central Framework and SEEA EA data. In addition, certain assessments require both standards, such as in the case of green economy/green growth, circular economy, low carbon development and climate adaptation.

Ecosystem accounting takes a spatial approach and ecosystem assets are delineated as spatial areas containing a combination of biotic and abiotic components and other characteristics that function together. These ecosystem assets provide ecosystem services, which are the contributions and benefits of ecosystems to economic and other human activity.

The SEEA EA prescribes the development of five connected core accounts, representing the extent and condition of ecosystems, the supply and use of ecosystem services (physical and monetary) and the monetary ecosystem asset (see Figure 11).

1. **Ecosystem extent account:** This account serves as a common starting point for ecosystem accounting. It organizes information on the extent of different ecosystem types within a country in terms of area.
    - The extent account organizes data on the extent or area of different ecosystem types. Data from extent accounts can support the derivation of indicators of

deforestation, desertification, urbanization and other forms of land-use driven change and thus provide a common basis for discussion among stakeholders of the changing composition of ecosystem types within a country. Compilation of these accounts is also relevant in determining the appropriate set of ecosystem types that will underpin the structure of other accounts

2. **Ecosystem condition account:** This account organizes the relevant data on selected ecosystem characteristics, and the distance to a reference condition, in order to provide insight into the ecological integrity of ecosystems.

    - The characteristics of ecosystem condition are: physical state characteristics (eg. soil structure, water availability), chemical state characteristics (eg. soil nutrient levels, water quality, air pollutant concentration), compositional state characteristics (eg. presence/abundances of key species, species diversity), structural state characteristics (eg. total biomass, canopy coverage, mass density), functional state characteristics (primary productivity, disturbance frequency) and landscape and seascape characteristics (eg. landscape diversity, connectivity, fragmentation).

3. **Ecosystem services flows accounts – physical terms:** The supply of final ecosystem services by ecosystem assets and the use of those services by economic units, including households, enterprises and government, constitute one of the central features of ecosystem accounting. This account records the flows of final ecosystem services both supplied by ecosystem assets and also used by economic units during an accounting period. It also allows for the recording of intermediate service flows between ecosystem assets.

    - Various ecosystem services are considered among provisioning services, regulating and maintenance services and cultural services.

    - Quantitatively, supply of ecosystem services equals use. Thus, the assumption is that all supplied services are also used in the economy.

4. **Ecosystem services flow account – monetary terms:** Estimates of ecosystem services in monetary terms are based on estimating prices for individual ecosystem services and multiplying by the physical quantities recorded in the ecosystem services flow account in physical terms.

5. **Ecosystem monetary asset account:** Asset accounts are designed to record information on stocks and changes in stocks (additions and reductions) of assets. The ecosystem monetary asset account records this information in monetary terms for ecosystem assets based on the monetary valuation of ecosystem services and applying the net present value

approach to obtain opening and closing values in monetary terms for ecosystem assets at the beginning and end of each accounting period.

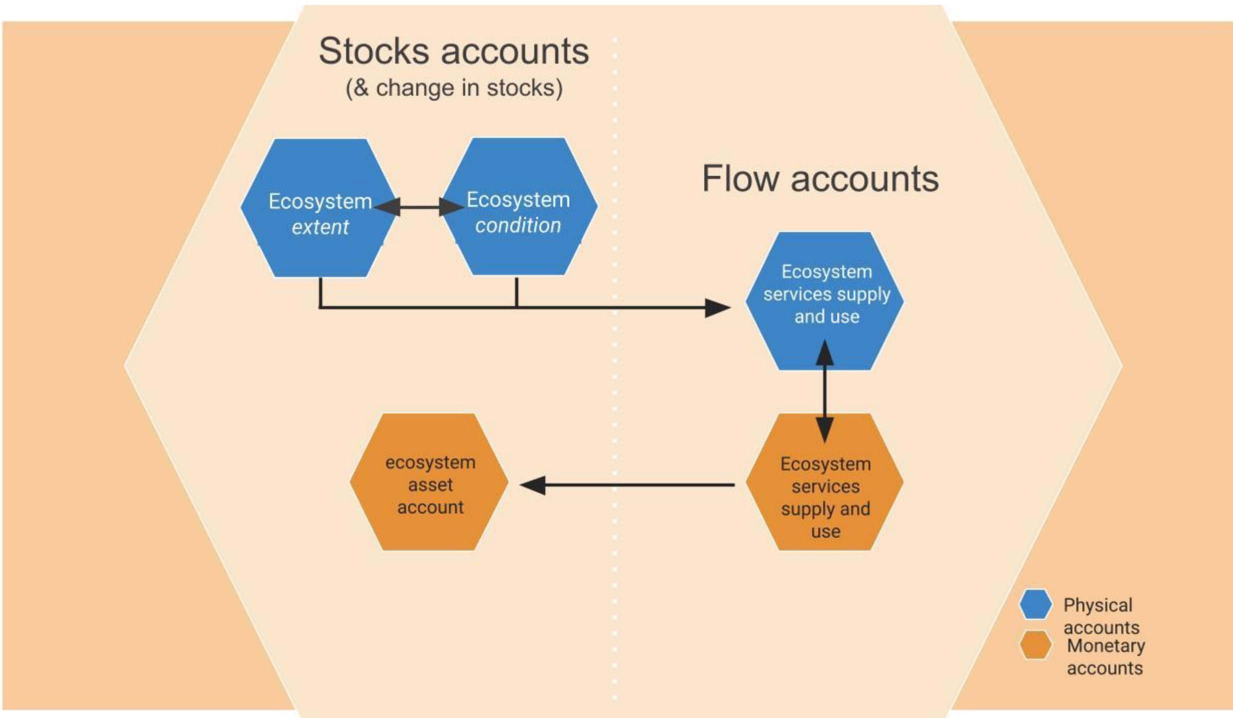

Figure 11: *Connections between ecosystem accounts, as presented in SEEA EA (United Nations, 2012)*

2.5. The TEEB approach

The Economics of Ecosystems and Biodiversity (TEEB) is a global initiative focused on "making nature's values visible**".** Its principal objective is to mainstream the values of biodiversity and ecosystem services into decision-making at all levels. As a result, TEEB takes a forward-looking approach to inform policy formulation and assessment.

There are several other initiatives that support countries in the mainstreaming of the values of ecosystems services within policymaking. Each of these initiatives uses its own entry point to inform policymaking, method and tools. Examples include Wealth Accounting and the Valuation of Ecosystem Services (WAVES)[4] facilitated by the World Bank, the Intergovernmental Science-Policy

[4] See: https://www.wavespartnership.org/

Platform on Biodiversity and Ecosystem Services (IPBES)[5], the EU working Group on Mapping and Assessment of Ecosystems and their Services (MAES)[6] and The New Climate Economy (NCE)[7], a project of the Global Commission on the Economy and Climate. The availability and use of SEEA EA data can support the effort of all these initiatives, increasing their effectiveness in informing agenda setting, policy formulation and evaluation and supporting the implementation of the TEEB approach.

TEEB, whose approach is analysed is more depth in this report, uses a structured approach to valuation that helps decision makers *recognize* the wide range of benefits provided by ecosystems and biodiversity, *demonstrate* their values in economic terms and, where appropriate, suggest how to *capture* those values in decision-making:

1. **Recognizing value** in ecosystems, landscapes, species and other aspects of biodiversity is a feature of all human societies and communities and is sometimes sufficient to ensure conservation and sustainable use. With emphasis on impact, TEEB utilizes policy relevance as entry point.
2. **Demonstrating value** in economic terms is often useful for policymakers and others such as business in reaching decisions that consider the full costs and benefits of an ecosystem rather than just those costs or values that enter the markets in the form of private goods.
3. **Capturing value** involves the introduction of mechanisms that incorporate the values of ecosystems into decision-making through incentives and price signals. This can include payments for ecosystem services, reforming environmentally harmful subsidies or introducing tax breaks for conservation.

The TEEB Approach highlights the importance of engaging with policymakers and identifying policy relevance, which is necessary to bridge the gap between the availability of data and scenarios and their use in policymaking. It starts with recognizing the value of ecosystems in the context of a planning process aimed towards achieving development objectives. Such objectives include health, gender equality, social equality, and jobs, all of which are intrinsic considerations to mobilise the equitable and sustainable use of ecosystems and their associated products, and their valuation. In this respect, using a coherent set of data organized in ecosystem accounts can facilitate the uptake, use and correct implementation of the TEEB approach. At the same time, if TEEB is successful in highlighting the relevance and validity of ecosystem accounts through policy assessments, the

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[5] See: https://www.ipbes.net/
[6] See: https://ec.europa.eu/environment/nature/knowledge/ecosystem_assessment/index_en.htm
[7] See: https://newclimateeconomy.net/

institutionalization of the SEEA EA is likely to be more efficient and effective. There is therefore a mutually reinforcing relationship between SEEA EA and TEEB.

In summary, TEEB promotes the use of, and creates, multi-stakeholder platforms for decision makers in the public and private sector as well as experts (eg. economists working on public policy or project finance). These are the key potential users of SEEA EA data, but the language of accounting with these audiences may resonate less than language which is in the form of economic analysis. This is where scenario analysis can establish a connection between SEEA EA and TEEB, when integrated assessments are performed, and therefore bridge the gap across disciplines.

2.6. The relevance of SEEA EA and TEEB for policy analysis

Both the SEEA EA - by providing a standardized approach, consistent and coherent data - and the TEEB approach - by targeting policy relevance and the involvement of local stakeholders in policy analysis - can support the use of accounts, further development of modelling approaches and creation of new models, all with the ultimate goal of informing policy decisions. This can happen through the:

- Creation of new knowledge about ecosystems and how their extent and quality leads to ecosystem services that benefit communities and human well-being. This allows for the incorporation of ecosystems in social and economic assessments.
- Creation of coherent and harmonized accounts, allowing for the development of new models that can make use of such a data framework (eg. Computable General Equilibrium (CGE) models that are employed to carry out macroeconomic policy analysis use the System of National Accounts (SNA) as main data input and new economic and integrated models can use the SEEA EA).
- Promotion of the use of a systemic (closed-loop) approach, closing the loop between models that assess (a) the impact of human activity on ecosystem and (b) models that determine the extent to which ecosystems influence human health and human activity.
- Design of new integrated or coupled models (Figure 13):
    - Improving the analysis performed with sectoral models, by introducing physical indicators on ecosystem extent, condition, services and hence generating a higher degree of realism.

    - Generating knowledge on how existing models could be connected with one another to better represent the relations between society, economy and environment.
    - Providing information for the creation of new integrated models.
- Use of simulations, extending the analysis provided by SEEA, by forecasting or back-casting scenarios.
- Making explicit the importance of site-specific drivers of change, system responses and impacts, with the use of a spatially-explicit analysis that allows to determine the value of ecosystem services based on the location where these are used (ie. more explicitly assess demand and supply).

There are several contributions provided to policymaking by the use of ecosystem accounts. These include:

- Integrating knowledge across disciplines and bringing experts and decision makers together, given the comprehensive nature of the ecosystem accounts.
- Bringing the social, economic and environmental dimensions of development to the same table, with the same unit of measure when possible and thereby revealing patterns and challenges in other systems of knowledge. Examples of the wider environmental data integration may include: indigenous and traditional knowledge; geospatial information on people and environment; and the disaggregated information and data on the environment and women, the poor, and other vulnerable groups (UN Environment, 2019).
- Highlighting the importance of stocks and flows, representing the history of the system analysed, to identify how the state of a system leads to its performance:
    - Estimating stocks and flows, and the quality of stocks (eg. to represent the contribution of extent and condition account in the determination of ecosystem services).
    - Showing the existence of different types of stocks (eg. renewable and non-renewable).
- Representing time in an explicit manner to forecast short, medium and longer term outcomes:
    - Complementing existing forecasts on the speed of change of social and economic indicators with environmental indicators.
    - Showing possible “worse before better” situations.

    - Estimating the impact of accumulation over time, leading to new dynamics and the crossing of important thresholds for sustainability.

- Supporting the assessment of impacts (i) across sectors, (ii) across economic actors, (iii) across dimensions of development, (iv) over time and (v) in space.

By taking a systems thinking approach, all of the above result in the enhanced potential to identify and anticipate the emergence of synergies as well as side effects (eg. trade-offs that may emerge when the gains achieved by transforming natural capital into productive assets are the cause of losses associated with a reduction in ecosystem service flows from natural capital). This helps to inform the decision-making process for the maximization of societal value (or value for money from a societal perspective) that takes into account social, economic and environmental indicators.

It should be noted that while the SEEA EA provide a framework to present data in biophysical and monetary terms, the implications for this data for policymaking must be viewed through the lens of social relationships and their reflection in human-environment interactions. While environmental problems and solutions typically manifest in physical landscapes and ecosystems, the state of the environment can only be explained by examining social, cultural and economic systems and arrangements. Those structures are gendered and as such it is critical to consider the implications of policy measures for the interactions between society and the environment, including the gender dimension (UNEP, 2019).

3 Models, scenarios and accounts to inform policy scenario analysis

Section 3 provides an introduction to simulation models, and offers an overview of scenario creation and forecasting models. This overview includes an introduction to the specific model, examples of its applications, and potential areas of improvement (for the model and the resulting analysis) when SEEA EA and TEEB are actively used.

3.1. Simulation Models

In this section, various simulation models are discussed. Models are simplifications of reality, used in this context to forecast various scenarios and assess the outcomes of policies and investments on a variety of social, economic and environmental indicators. The models presented represent a small subset of all the models that are currently available; however, models chosen are intended to be representative of the modelling work being carried out to inform policy for sustainable development. The examples presented provide insights into how either new models could be adopted, or existing ones could be improved with the availability of SEEA EA. The strength of the SEEA is that it provides knowledge and data to connect the environment with society and the economy, with a spatially explicit approach. This is the kind of information that is needed to connect domains of research and integrate many of the models that are currently being used in isolation.

In this respect, the possible outcomes emerging from the use of SEEA EA are: (1) models could use SEEA EA as data input, (2) models could be improved, (3) expanded or (4) equipped with spatial features.

The simulation models are described based on the following elements:

a) **Sectors**: sector refers to sectors of the economy (eg. primary, secondary and tertiary sector, or output of particular industries in the SNA), as well as energy, water and infrastructure. A sectoral perspective allows analysis of a system's overall performance as well as of its constituent parts. The performance of any sector is impacted directly or indirectly by the resources and services that ecosystems provide.

b) **Economic actors**: the success of policy interventions is often related to the extent to which it supports a given economic actor. On the other hand, it is important to consider all economic actors, including households, the private and public sector. This is to ensure that an intervention generates positive outcomes for the whole of society or, if negative outcomes are likely to emerge for certain economic actors, complementary measures are identified. The assessment of outcomes across economic actors has to consider ecosystems. This is because certain groups of the population and certain businesses rely on natural resources and on ecosystem services and ecosystem goods more than others. As a result, certain policy interventions may generate benefits for some economic actors while creating challenges, as side effects emerge, for other actors.

c) **Dimensions of development**: sustainable development has three pillars: society, economy and the environment. It is critical that all pillars are treated as part of the same system in order to avoid that advances for one do not lead to challenges for others. The environment, if represented by ecosystem extent, condition and ecosystem services - in addition to the stocks and flows of natural resources that are used for human activities - can support the integration of environmental consideration in socioeconomic assessments.

d) **Time**: certain parts of a system change and adapt quickly, while others take more time to adjust to new conditions. The outcomes of decision-making, including policies and investments, as well as behavioural change, have to be assessed for the short, medium and longer term. Longer-term impacts are particularly important to natural capital, since ecosystems form equilibria over many years and since long-run equilibria (eg. the global climate) have been often overlooked in the search for quick, short term gains.

e) **Space**: the emergence of various trends, such as rural to urban migration, sea level rise and floods due to climatic changes, uneven availability of natural resources at the country level, have highlighted that the location of policy impacts is important. Location is even more critical when estimating ecological outcomes, such as for the provision of ecosystem services and their economic valuation and for the assessment of the vulnerability (or efficiency) of infrastructure.

3.2. Typology of simulation models

Simulation models can be categorized in many ways. The following grouping is used for this report:

- *Scenario creation models (qualitative)*: eg. system maps, tree diagrams, dynamic pathways;
- *Scenario forecasting models (quantitative)*: economy (general and partial equilibrium models), infrastructure (systems engineering models), land use (spatially explicit models), green economy (systems models);

- *Complementary approaches used to inform and/or evaluate scenarios* represent different ways to organize and present the results of modelling exercises for different audiences, such as the case of Cost-benefit analysis (CBA) or Multi Criteria Analysis (MCA), impact assessment, or lifecycle analysis.

Table 3: Overview of the data requirements, scenarios generated and potential use of SEEA accounts for the models analysed present a summary of the characteristics of the models analysed, as well as an overview of the contribution that SEEA EA can provide to model creation/customization and the interpretation of model results. In the following sections this is grouped into four main categories: new and standardized data inputs, improved equations (improved understanding of dynamics), new indicators (extended model boundaries), spatial disaggregation/interpretation.

__Table 2:__ Overview of the characteristics of the models analysed (Report authors)

Model type	Sector/thematic area	Actors	Dimensions of development	Method for solving equations	Time	Space (maps)
Qualitative	Both thematic and cross sectoral	Public, private, households	Social, economic, environmental, governance	N/A	Not explicitly included	Not explicitly included
Quantitative						
Land-use (spatial planning) models	Land, agriculture	Generally, not specified (but may include considerations on land tenure and production, and so public and private sector)	Primarily environmental. May include economic (eg. agriculture production) and social considerations (eg. land tenure)	Optimization	Snapshot, forecasts outcomes for a given point in time	Explicitly represented
Ecosystem services models	Land, water, air, biodiversity and more	Generally, not specified	Primarily environmental. May include economic (eg. infrastructure damage from floods) and social considerations (eg. population at risk of water scarcity)	Simulation	Snapshot, forecasts outcomes for a given point in time	Explicitly represented
Macroeconometric models	Economy (various sectors), often connected with energy consumption	Economic flows for public and private sector, households, banks and rest of the world	Economic	Econometrics	Continuous time (year on year projections)	Not explicitly included
CGE models	Economy (various sectors, national and international trade)	Economic flows for public and private sector, households, banks and rest of the world	Economic	Optimization	Snapshot (1 year or 5 year intervals)	Not explicitly included

Model type	Sector/thematic area	Actors	Dimensions of development	Method for solving equations	Time	Space (maps)
Energy models	Energy supply, emissions	Private sector (producers) for power generation	Economic (investment required, price of electricity), environmental (emissions)	Optimization	Snapshot (1 year or 5 year intervals)	Not explicitly included, may be considered for sub-national electricity dispatch models
Water models	Water demand and supply, land use	Generally, not specified (but may include considerations on demand for farmers and supply from reservoirs or built infrastructure)	Primarily environmental. May include economic (eg. access to water for food production) and social considerations (eg. access to water for sanitation or nutrition)	Simulation	Continuous time (daily, weekly or monthly projections)	Explicitly represented
Infrastructure models	Energy supply, buildings, roads, water supply and treatment, waste management, natural infrastructure	Generally focused on private sector (contracted entity), but may extend to operators (eg. government) and recipients of infrastructure benefits (society, households and private sector)	Primarily economic. May include environmental (eg. deforestation, emissions) and social considerations (eg. access to services, side effects of construction)	Optimization	Continuous time (monthly, quarterly or annual projections)	Not explicitly included for national assessments, explicitly represented for project-level analysis
Nested models	Various sectors (primarily, energy-economy, economy-land)	Economic flows for public and private sector, households, banks and rest of the world, sectoral dynamics for specific economic actors	Social, economic, environmental	Optimization, simulation	Depending on the methods used: snapshot (optimization) or continuous time (monthly or annual projections)	Not explicitly included for most national models, explicitly represented for some subsectors (eg. water, land use and agriculture production)
Integrated models	Various sectors	Economic flows for public and private sector, households, banks and rest of the world, sectoral	Social, economic, environmental	Optimization, econometrics, simulation	Continuous (or semi-continuous) time (monthly or annual projections)	Not explicitly included for most national models, explicitly represented for some subsectors (eg. water,

Model type	Sector/thematic area	Actors	Dimensions of development	Method for solving equations	Time	Space (maps)
		dynamics for specific economic actors				land use and agriculture production)

Table 3: Overview of the data requirements, scenarios generated and potential use of SEEA accounts for the models analysed (Report authors)

Model example	Potential link with SEEA account	Data requirement	Types of scenarios?
Land-use models			
Marxan **(Game & Grantham, 2008)**	Extent, condition and ES accounts	Species name, or ES, or habitat for optimization/ conservation, landscape data, spatial concentration of conservation parameter, intended budget/cost data	Optimization of conservation for species or ES maintenance
(Dyna-)CLUE **(Verburg & Overmars, 2009)**	Extent account	Land demand (for expansion) and land supply (used for conversion), location suitability, conversion elasticity, land conversion rules	Impacts of large scale processes on local land-use dynamics, land conversion trajectories based on the pre-defined land conversion rules
TerrSet Land Change Modeler	Extent account	Land-cover map and driving factor layers, with the following formatting requirements (consistent spatial extents, references systems, pixel resolution, identical legend categories, a background value of zero)	Future land use and land cover, impacts of REDD and climate change mitigation strategies
Ecosystem services models			
InVEST **(Natural Capital Project, 2019b)**	Extent, condition and ES accounts	Depending on the InVEST model used, land use and land cover, digital elevation model, precipitation and	Provision of ecosystem services (several, full list available at https://naturalcapitalproject.stanford.edu/software/invest),

Model example	Potential link with SEEA account	Data requirement	Types of scenarios?
		evapotranspiration, carbon pools, suitability and management factors	habitat quality and rarity, scenic quality, power generation (hydropower, wind, wave)
ARIES (modelling platform)	Extent, condition and ES accounts	Land use and land cover, digital elevation model, precipitation and evapotranspiration, carbon pools, suitability and management factors (Ecosystems Knowledge Network, 2019)	Carbon storage and sequestration, open space proximity, aesthetic viewsheds, flood regulation, sediment regulation, water supply, recreation, nutrient regulation (Bagstad et al., 2011)
MIMES (modelling platform) **(Boumans et al., 2015)**	Extent, condition and ES accounts	Population; economic data (eg. GDP); impact functions; precipitation; land use; best management practices	Impacts of land-use change on ES provisioning, policy impacts on ES provisioning (eg. fisheries (Boumans et al., 2015))
LUCI **(LUCI Tools , 2019)**	Extent, condition and ES accounts	Land use and land cover; digital elevation model; soil information	Agriculture production; erosion risk and sediment delivery; carbon sequestration; flood mitigation; habitat provision; water quality
Macroeconomic models			
IEEM **(Banerjee et al., 2016a; Banerjee et al., 2016b; Banerjee O. , 2019)**	SEEA CF, extent, condition and ES accounts	System of National Accounts (SNA) and Social Accounting Matrix (SAM), land cover and land use, resource consumption	Impacts of policies on GDP, employment, income, environmental resources, wealth and environmental quality
E3ME **(Cambridge Econometrics, 2019)**	SEEA CF, extent, condition and ES accounts	Population; economic productivity data (eg. GDP, capital, labour); System of National Accounts (SNA); Social Accounting Matrix (SAM); input-output relationships for materials; prices of goods and services; energy demand; emission intensity	Impact of policies on GDP; material consumption; energy demand; CO2 emissions
OECD ENV-Linkages (Burniaux & Chateau, 2010; Burniaux et al., 2013)	SEEA CF, extent, condition and ES accounts	Population; economic productivity data (eg. GDP, capital, labour); System of National Accounts (SNA); Social Accounting Matrix (SAM); input-output relationships for materials; prices of goods	Impact of policies on GDP; material consumption; energy demand; land use and CO2 emissions

Model example	Potential link with SEEA account	Data requirement	Types of scenarios?
		and services; trade data; energy demand; emission intensity	
Energy models			
MARKAL and TIMES **(Loulou et al., 2004)**	SEEA CF, extent and ES accounts	Demand for energy services, technology data (eg. efficiency, cost); cost of primary energy supply, emission factors by fuel/technology	Impact of different energy management strategies on energy system cost; capacity utilization; energy balance; emissions
LEAP **(SEI, 2019a)**	SEEA CF, extent and ES accounts	Population and macroeconomic data (or demand for energy services); technology data (eg. efficiency, cost); cost of primary energy supply, emission factors by fuel/technology	Impact of different energy management strategies on energy system cost; capacity utilization; energy balance; emissions
Water models			
SWAT **(Texas University, 2015)**	SEEA CF, extent, condition, and ES accounts	Stream flow data; precipitation; land use; soil type	Impacts of land-use change on water flow and erosion
CROPWAT **(FAO, 2019)**	SEEA CF, extent, condition, and ES accounts	Precipitation; evapotranspiration; soil type; temperature; water requirements by crop	Crop water demand and irrigation requirements
WEAP **(SEI, 2016; SEI, 2019b)**	SEEA CF, extent, condition, and ES accounts	Geographic boundaries and GIS inputs (optional); time horizon; rivers and groundwater aquifers; water flow data; water demand by consuming entity; demand priority and variation; demand-supply relationships	Rainfall; runoff and infiltration; evapotranspiration; crop requirements and yields; surface/groundwater interaction; in-stream, water quality
PRMS **(USGS, 2019)**	SEEA CF, extent, condition, and ES accounts	Precipitation; temperature; solar radiation; soil type	Evaporation; transpiration; runoff; infiltration; interflow; water budget

Model example	Potential link with SEEA account	Data requirement	Types of scenarios?
Infrastructure models			
Project finance	Extent, condition and ES accounts	Capital and O&M cost; cost of financing; interest rate; discount rate;	Net Present Value (NPV); Internal Rate of Return (IRR); Debt Service Coverage Ratio (DSCR)
SAVi **(IISD, 2018a; Bassi et al., 2019)**	Extent, condition and ES accounts	Capital and O&M cost; cost of financing; interest rate; discount rate; land use; energy and material consumption; precipitation; temperature; climate impacts to infrastructure performance	Net Present Value (NPV); Internal Rate of Return (IRR); Debt Service Coverage Ratio (DSCR); cost-benefit analysis including land use; water and material use; air and water pollution and related health costs; land-use impacts; energy use; employment

Model example	Potential link with SEEA account	Data requirement	Types of scenarios?
Nested or coupled models			
De Survey IAM **(Van Helden et al., 2009)**	SEEA CF, extent, condition, and ES accounts	Climate projections; population scenarios; scenarios for macro-economic variables; market prices for crops; policy options (eg. water pricing, subsidies, zoning); management options (eg. grazing, terracing, planting and sowing dates)	Impacts of policy options and external drivers on macroeconomic productivity, land use, crop production, and the availability of natural resources
ISP - Road to Dawei Model **(Bassi et al., 2014)**	Extent, condition, and ES accounts	Land cover; ecosystem services; road project (eg. length, cost, trajectory); population, agriculture production	Impact of road construction on land cover (direct, indirect and induced impacts), agriculture production, employment and income.
Integrated models			
T21, iSDG https://www.millennium-institute.org/	SEEA CF, extent	Population trends; SAM; SNA; energy balance; land-use and land-cover data; land productivity; education and health	Impact of policies on national development, sectoral and country performance, also in relation to the SDGs
GEM **(Bassi, 2015)**	SEEA CF, extent, condition, and ES accounts	Population trends; SAM; SNA; energy balance; land-use and land-cover data; land productivity; precipitation; temperature; relevant ecosystem services and related economic valuation	Impact of policies on social, economic and environmental indicators of performance, including measures of total wealth. Creation of an integrated (or extended) cost-benefit analysis, including the value of nature
Integrated Futures **(Moyer & Bohl, 2018; Bohl et al., 2018)**	SEEA CF, extent, condition, and ES accounts	Land use; water use; food demand; labour; income; government expenditure; demand and supply of goods; prices; investment; resource use; carbon emissions	Assessment of policy impacts on education, GDP; government revenue; Human Development Index; poverty; life expectancy (Bohl et al., 2018)
PoleStar **(PoleStar Project, 2019)**	SEEA CF, extent, condition, and ES accounts	Population; GDP; household and government accounts; land cover and land use; and sectoral data (eg. transport; industry; energy; water, minerals and waste)	Policy impacts on achievement of the SDGs related to climate, poverty, freshwater, and ecosystem pressure (UNDESA, 2013)

3.3. Scenario creation tools (qualitative)

Qualitative models are an important tool to inform decision-making, particularly because of their contribution to the creation of a shared understanding about the drivers of change, dynamics triggered and the resulting performance of a system. On the other hand, while qualitative models make use of data to better understand the drivers of change in a given system, they lack the quantification of impacts, which is an essential step for scenario modelling in the context of policy formulation and assessment. As a result, scenario creation tools are briefly presented and analysed in this report, but not with the same depth dedicated to scenario forecasting tools.

3.3.1 Decision tree diagrams

Decision trees are widely used to illustrate the logical steps of the decision-making process necessary to attain goals or outcomes. A typical decision tree is composed of three main elements: (1) decision nodes indicate the question that needs to be answered; (2) chance nodes provide the list of options available; and (3) end nodes indicate the final outcome of following a path from the root node of the tree to that endpoint.

Examples

Decision trees have been used to assess policy decisions for climate mitigation, such as carbon pricing and related complementary interventions (Figure 12) (Klenert et al., 2018). This tree highlights that if acceptability of carbon pricing is high (right branch) traditional tax-related policies could be effective; conversely, if the acceptability of carbon pricing is low (left branch), more innovative policies would be required, based on behavioural and political science.

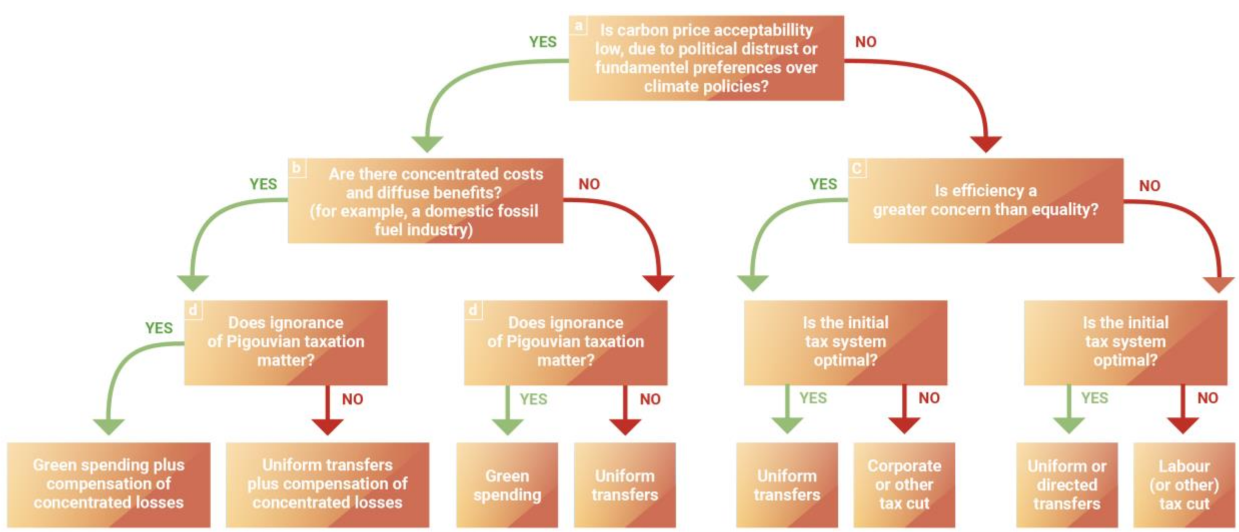

Figure 12: *Decision Tree Diagram for choosing what policy options could be used for mitigating the impacts of carbon pricing (Klenert et al., 2018)*

3.3.2 System maps (eg. Causal Loop Diagrams -CLDs-)

A causal loop diagram (CLD) is a graphical representation of the main variables forming a system and their interconnections. As a map of the system analysed, a CLD facilitates representation and exploration of the complexity of the system, with the use of causal relations and feedback loops (Probst & Bassi, 2014). By highlighting the drivers and impacts of the issue to be addressed and by mapping the causal relations between the key indicators, CLDs support a systemic decision-making process aimed at designing durable solutions.

Examples

Pittock et al (2016) describe the development of CLDs for analysing the interrelationships of hydropower and food supply (Figure 13). The aim of the CLDs is to identify key leverage points for policy interventions and to highlight how those interventions affect the system and change outcomes. The CLDs were developed based on a literature review and case studies to extract and represent the complex dynamics involved in the hydropower-food supply nexus. Figure 3 shows that the introduction of hydropower would generate several dynamics: (a) it would reduce fish and protein supply, leading to the expansion of agriculture land, and related production inputs; (b) it would provide energy supply, leading to more economic activity and energy demand; (c) it would lead to economic growth and energy demand and reduce carbon sequestration, generating further interest for hydropower. Overall, the diagram shows a critical nexus between hydropower, water, biodiversity and agriculture resource use.

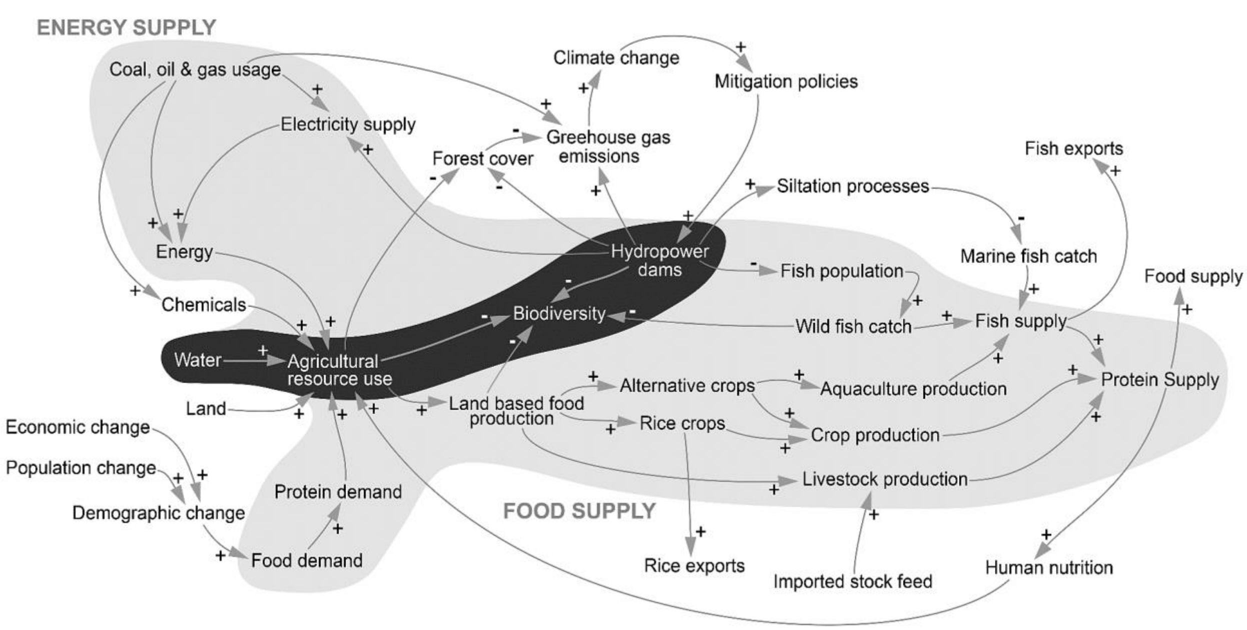

Figure 13: *Consolidated CLD of the Hydropower-Food nexus in the Mekong Basin (Pittock et al., 2016)*

TEEB has assessed the outcomes of implementing the Southern Agriculture Growth Corridor of Tanzania (SAGCOT) in the Kilombero Valley. CLDs were created in collaboration with local stakeholders to better understand local dynamics and create a shared understanding between different stakeholder groups (TEEB, 2018). The CLD then served as blueprint for the development of a quantitative System Dynamics model that was used to simulate a range of scenarios analysing pressures related to the implementation of SAGCOT. Furthermore, the CLD supported the identification of policy entry points where the implementation of sustainable development related interventions would yield the highest benefits.

UN Environment has also used CLDs to map the complexity of the eco-agri-food system in their latest TEEB report for agriculture and food (Zhang, 2018). Figure 14 presents the CLD, indicating key variables, causal relations and drivers of dynamics (reinforcing and balancing feedback loops). It highlights several reinforcing loops (eg. demand driving production, production leading to income creation, and income stimulating demand) as well as various balancing loops (eg. the more agriculture land, the more deforestation, the lower biodiversity and land productivity, leading to higher need for agriculture land). Further it shows how human health is central to the realization of a sustainable eco-agri-food system.

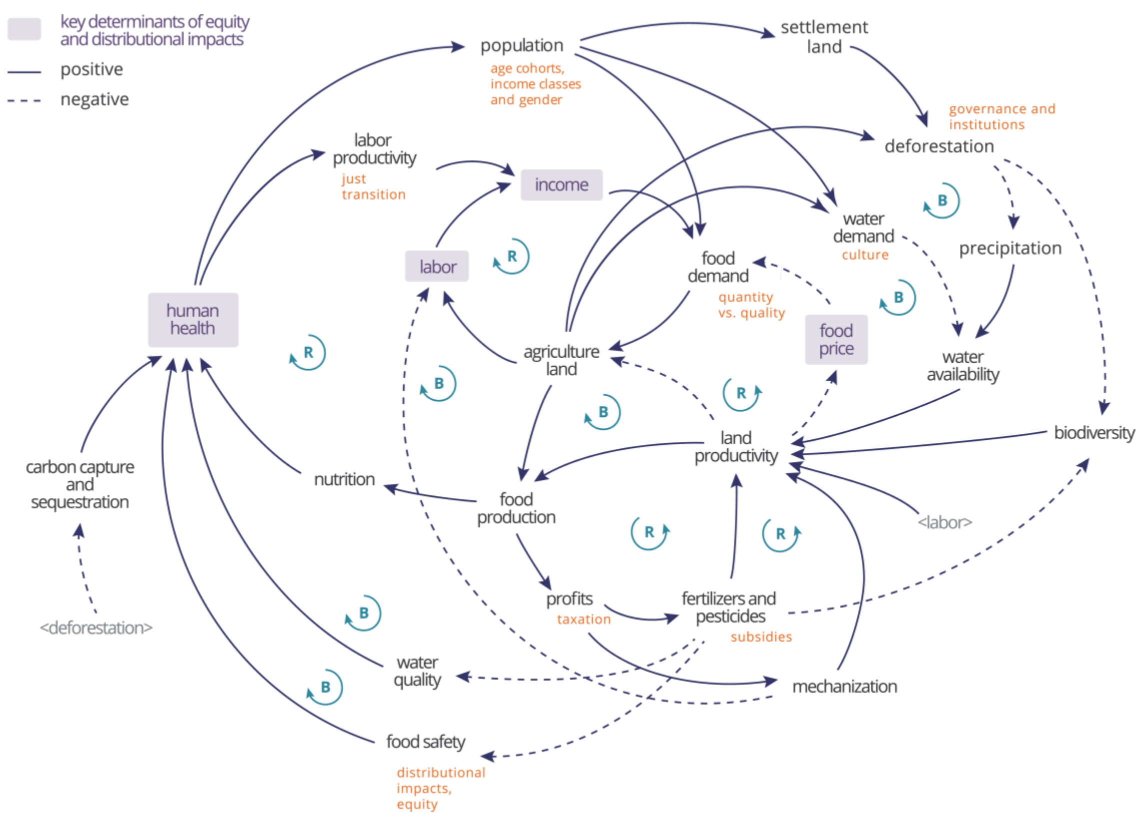

Figure 14: *Causal Loop Diagram of the eco-agri-food system. Source (Zhang, 2018)*

3.3.3 Narratives (eg. Delphi analysis and Story and Simulation -SaS-)

Scenarios are often presented using storylines or narrative descriptions of expectations about the future, formulated in short statements, and often developed via a multi-stakeholder processes.

As an example, the Delphi analysis method entails a group of experts who anonymously reply to questionnaires and subsequently receive feedback in the form of a statistical representation of the "group response," after which the process repeats itself. The goal is to reduce the range of responses and arrive at something closer to expert consensus (Rand Corporation, 2019). The scheme in Figure 15 captures the process of the Delphi analysis to obtaining key performance indicators (KPI), which can be applied to any issue of interest.

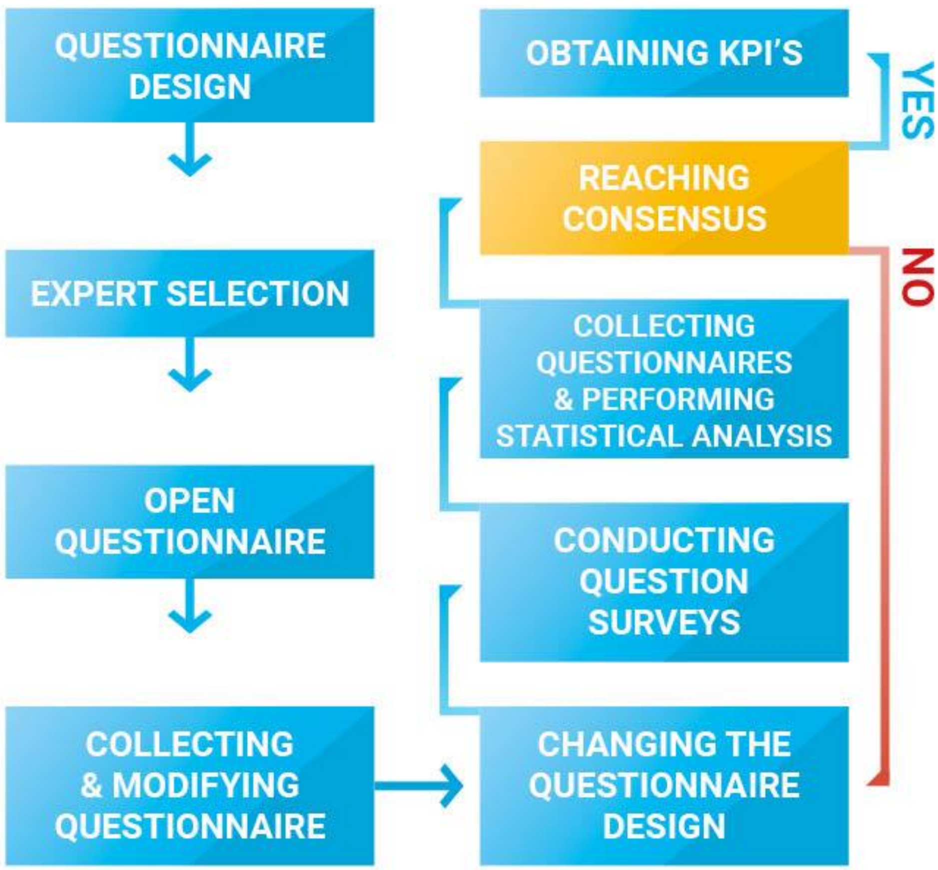

Figure 15: *Schematic representation of the Delphi process (Cheng et al., 2011)*

Story and Simulation (SaS) is a scenario development method that combines qualitative and quantitative approaches (Alcamo, 2001). In the initial phase, scenario storylines are developed through multi-stakeholder discussions. Subsequently, quantitative modelling tools are used to assess the impacts of the scenarios.

Examples

One of the largest Delphi studies conducted to date is the EurEnDel study conducted by the European Commission (European Commission, 2006). With the aim to describe future trends and developments as well as identifying research and development needs in the energy sector, almost 3,000 participants across Europe were interviewed over a period of 30 years (Jørgensen et al., 2004; European Commission, 2006). Over the years, the EurEnDel study generated a multitude of socio-technological perspectives, and contributed to the formulation of scenarios and policy recommendations surrounding the development of Europe's energy sector. During the EurEnDel study, experts were provided with 19 technology statements related to trends observed for energy demand and supply, with a special focus on emerging technologies. Subsequently, they were asked to rank the anticipated impact of these statements in four key areas: wealth creation, environment, quality of life, and security of supply. Figure 16 presents the results of an index-based calculation of the impacts expected by experts for various technologies (Jørgensen, et al., 2004).

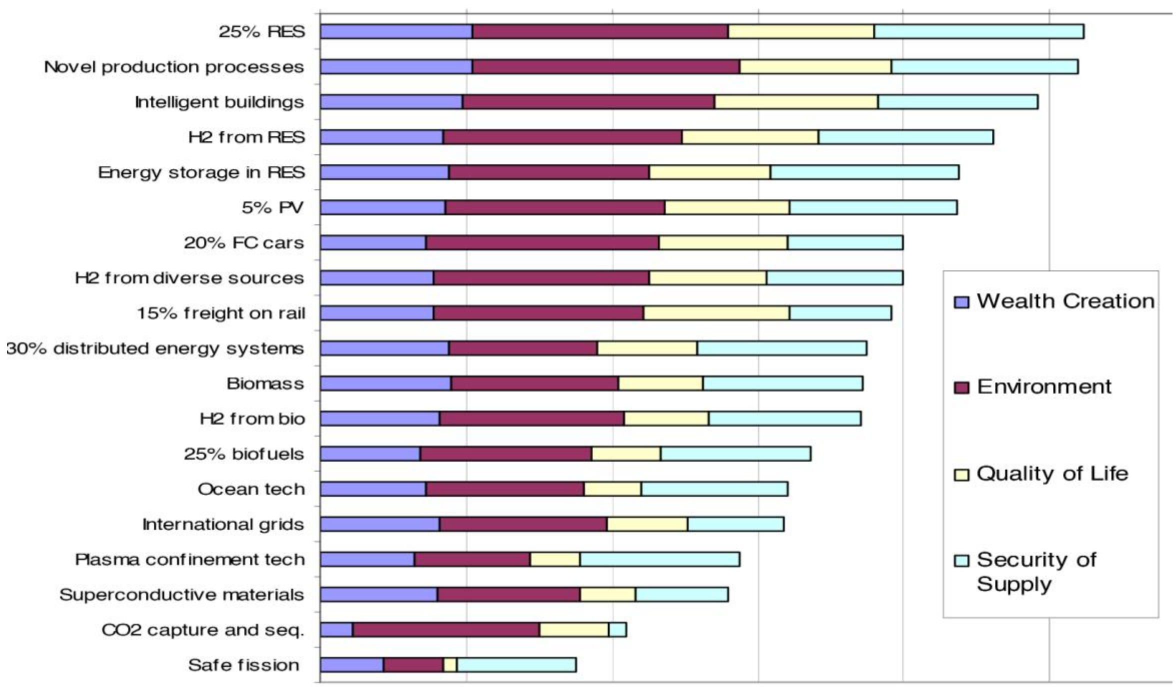

Figure 16: *Average ratings of Delphi statements for four areas of impacts (Jørgensen et al., 2004)*

Houet et al. (2016) developed a SaS based structural framework to enable scenario definition for exploring potential climate impacts in urban areas in the longer term at a fine scale. The authors focus on establishing a structural framework that generates and explores scenarios to identify the most important drivers and then translate them into quantitative inputs to models. For the definition of scenarios, a six step process was followed: **1)** identify sectors, driving forces and assumptions; **2)** combine assumptions to create consistent and contrasted scenarios for each sector; **3)** combine "sectoral scenarios" to create narratives; **4)** translate driving forces to model input data; **5)** build quantitative projections for each output/dataset; and **6)** enrich each narrative using models' simulations.

The approach proposed was applied to the city of Toulouse in south-west France. In a stakeholder workshop, the information generated throughout the six steps was used to develop seven distinct scenarios: a Reactive city; a Thoughtful city; a Dynamic city; a Green city; a Nocuous city; a Passive city; and Business as usual. The scenarios diverged in terms of local trends, land-use scenarios and technological trends.

Potential improvements with SEEA EA

The information generated by SEEA EA can considerably improve the creation of qualitative scenarios. First, it can lead to an improved understanding of the dynamics of the system (eg. linking ecosystem extent and condition to obtain ecosystem services, and better understand how the economic valuation of ecosystem service is obtained). As a result, in the case of CLDs and Delphi Analysis it can support the creation of a shared understanding and improve the accuracy of the analysis. Second, SEEA EA data allow to more explicitly consider indicators that would otherwise be qualitative, including ecosystem condition indicators (eg. species abundance index, a variable that is not of easy interpretation when working with qualitative models) or ecosystem supply and use indicators (eg. crop provisioning, carbon and blue carbon retention, or relevance when determining the cost and benefits of interventions). As a result, and in addition to providing a better understanding of the system, the boundaries of the analysis could be expanded when SEEA EA data are available. This allows to fully integrate the environmental dimension (both at national and sub-national level) in the creation of qualitative scenarios. Third, the availability of SEEA EA data, being spatially explicit, allows for the inclusion of spatial considerations in the creation of scenarios. This allows to touch upon a variety of issues that are often not considered when preparing sectoral or thematic scenarios and policy assessments.

Table 4: *Characteristics of qualitative models, and summary of the potential contribution of SEEA EA (Report authors)*

Model type	Sector/thematic area	Actors	Dimensions of development	Time	Space
Qualitative	Both thematic and cross sectoral	Public, private, households	Social, economic, environmental, governance	Not explicitly included	Not explicitly included
Contribution of SEEA EA: **1** - Improved understanding of dynamics **2** - New indicators (extended model boundaries), examples include indicators of ecosystem condition (eg. species abundance, nutrient concentration, air pollution concentration and habitat quality) to better explain the causes for changes in ecosystem service provisioning, **3** - Spatial disaggregation/interpretation					

3.4. Scenario forecasting with simulation models (quantitative)

Simulation models are presented as (a) thematic, or sectoral models and (b) cross-sectoral, nested or integrated models. It is worth noting that both modelling platforms (eg. *ARIES, MIMES*, but also *GCE*) and models (eg. *IEEM, GEM*) are presented. The former are used to create specific models. There are also a family of models, such as in the case of *InVEST*, that can be used for different purposes. For simplicity, the presentation focuses on the features of the platforms and models, and their applications. More details specifically on biophysical modelling can be found in Guidance on Biophysical Modelling for Ecosystem Accounting – version 2.0. (United Nations 2021).

Thematic models that focus on a single theme or area of analysis (eg. economy, employment, energy, water, land) are generally sectoral and focus exclusively, in the vast majority of cases, on biophysical or economic indicators. Thematic models can be found for assessments related to land use, macroeconomic performance or infrastructure assessments, such as for energy and water.

Cross-sectoral models are also called integrated models. These models consider the interconnections existing across various sectors that include social, economic and environmental indicators and are either built as nested models (ie. linking existing models with one another or as new and customized integrated models.

3.3.4 Land-use models

Spatial planning tools are used to plot out future optimal physical placement of economic activities, human settlements, based on a variety of scenario drivers. On the other hand, this is often without reference to what this means for socioeconomic effects or monetary valuation of loss/gain in natural capital assets. They are often static assessments that do not 'speak to' decision makers outside of land-use/conservation planners, but provide very valuable inputs for the planning of infrastructure, as well as to assess impacts on ecosystems. A few examples are provided below and more exhaustive list of models can be found on ScenarioHub.[8]

Marxan is a suite of tools developed to provide decision support for conservation related planning problems (Marxan, 2019). *Marxan* is spatially explicit and can be applied to various conservation related problems related to natural resource management in terrestrial, freshwater and marine systems. In addition to providing spatially explicit outputs, *Marxan* allows for specifying conservation related objectives and generates a number of solutions that fulfil the predefined requirements, identifies areas that meet targets related to biodiversity for minimal costs and provides information about trade-offs between socioeconomic and environmental development objectives (Marxan, 2019). Figure17 shows how *Marxan* is applied to the analysis of protected areas (PAs) in the context of a study where three models were used sequentially for analysing areas best suited for biodiversity conservation (Choe et al., 2018).

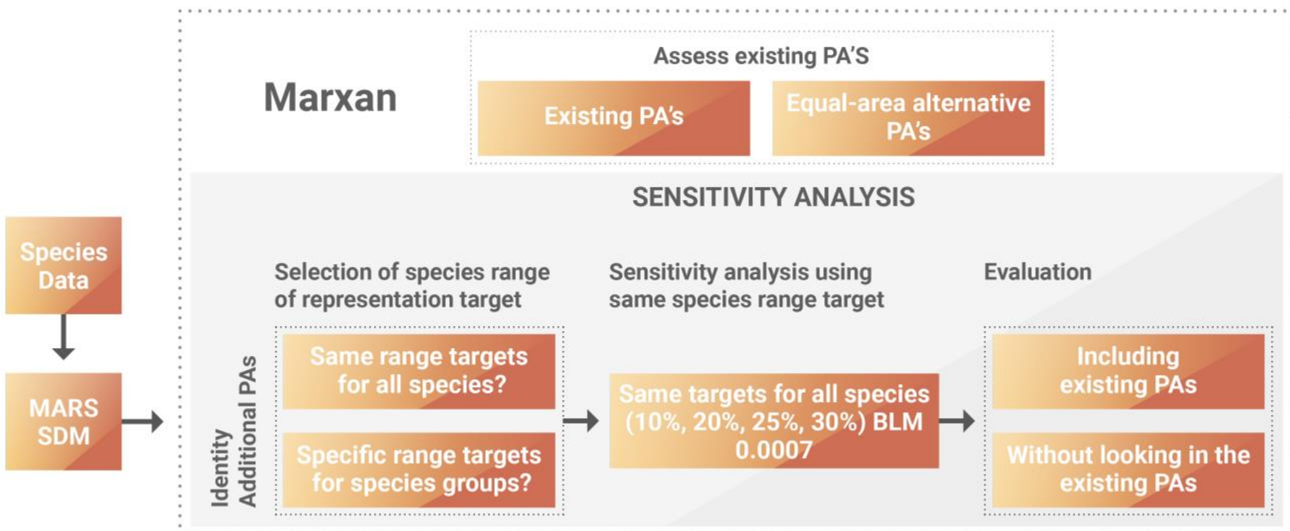

Figure 17: *Study flow diagram; application of Marxan to assessing conservation areas (Choe et al., 2018)*

The Conversion of Land use and its Effects (CLUE) model, a dynamic, spatially explicit land-use and land-cover change model, is among the most frequently used land-use models globally (IVM, 2019). *CLUE* constitutes a flexible and generic land-use modelling framework and allows scale and context specific applications, depending on the requirements of the analysis. An adaptation, the *Dynamic*

[8] ScenarioHub: http://scenariohub.net/tools#5

CLUE, or *Dyna-CLUE*, combines a top-down allocation of land-use changes with a bottom-up determination concerning the land that is used for the implementation of the desired land-use changes ((Verburg & Overmars, 2009).

The *Land Change Modeler*, which is part of Clark Labs' TerrSet software, is a spatially explicit decision support system that simplifies complexities of land-change analysis. The *Land Change Modeler* allows for rapid analysis of land-cover changes including the simulation of future land change scenarios, establishing empirical relationships to main drivers of change, Reducing Emissions from Deforestation and forest Degradation (REDD) analysis and the assessment of climate change mitigation strategies (Clark Labs, 2019).

The *InVEST Scenario Generator* is also available to create future land-cover maps, allowing users to indicate what land-cover changes can be expected in the future and then allowing to determine how these changes should be processed (eg. based on proximity). It can be used to create alternate futures and given that it can be downloaded with *InVEST*, it allows for the use of its outputs as an input to any *InVEST* model.

Examples

Fajardo et al. (2014) used Marxan for assessing whether Peru's national protected areas satisfy biodiversity conservation needs. Marxan was used, in combination with species distribution modelling and connectivity analysis, to identify additional priority areas for conservation. Specifically, Marxan was applied to determine the most efficient set of areas to be protected to reach stated conservation goals and to be most representative of Peruvian biodiversity. Multiple scenarios were ran to analyse 97,499 planning units of 16km² with data on species occurrence within it, base cost and edge length (Fajardo et al., 2014).

The *Dyna-CLUE* model was applied to the exploration of future European land use and landscapes. Information concerning European land use, specifically abandoned farm lands, was obtained from a global multi-sector model, while the succession of natural vegetation in *Dyna-CLUE* was simulated based on the spatial variation of landscape conditions. The *Dyna-CLUE* model demonstrates that the combination of top-down and bottom-up processes within the same modelling framework better addresses cross-scale interactions in land-use modelling and highlights the importance of cross-scale dynamics for land-use change processes (Verburg & Overmars, 2009). Land use for agriculture production is dependent on trade, as well as, agriculture policies. While, on the one hand, recently abandoned, and not entirely re-naturalized, land may be reconverted rather quickly, arable land, on the other hand, on which natural vegetation has regenerated may be costly or prohibited under nature protection laws, which imposes constraints on potential future land use.

The *TerrSet Land Change Modeler* was applied for mapping future land-use and land-cover (LULC) changes in the area surrounding Laguna de Bay, Philippines. The aim of the study is to inform local decision makers about expected future hydrological impacts of LULC caused by rapid land-cover changes resulting from the ongoing urban sprawl. Publicly available spatial data sets were used to calibrate the *Land Change Modeler* and future LULC change maps were generated until the year 2030 (Iizuka, et al., 2017). TerrSet's *Land Change Modeler* is used by the Global Environment Facility (GEF) for forecasting carbon stocks in protected areas in Kenya. Between 1995 and 2008, GEF implemented 12 protected areas in Kenya for which land cover is monitored using remote sensing. The LCM is used to translate the trends revealed by the land-cover data into future carbon stocks for the years 2020 and 2030. The maps generated and information obtained supports GEF in future policy and programme decisions (DEVELOP, 2016).

Potential structural improvements with SEEA EA

Land-use models, by design, use LULC information for their simulations and use existing land-use stocks as a point of departure for the analysis. The use of the SEEA EA accounts could improve the modelling of constraints related to future land expansion or conservation decisions, depending on the approach used for land conversion (eg. user defined, cellular automata).

There are several ways in which SEEA EA data can improve or enrich model formulations to improve forecasts of LULC with standardized data and a more accurate definition of constraints:

- **Extent**: the availability of maps and classification on land cover, land use and ecosystem extent generated at the national level, already validated by various stakeholders, can increase the accuracy of the analysis (given the likely presence of data for land-cover classes that are relevant at the local level), speed up the modelling process and possibly increase the potential to inform policy.
- **Condition and ecosystem services:** the inclusion of new variables in the model can support the estimation of the impact of LULC changes on existing ecosystems, their condition and hence implications for the provisioning of ecosystem services (eg. indicators on condition and ecosystem services could be used to improve forecasts of land-cover change, including climate regulation services, or water regulation and purification, indicators that are of relevance for a societal assessment rather than for an exclusively economic analysis). This includes deforestation, but also impacts of land management practices and land-use related pressures, which might lead to change in ecosystem condition, ecosystem services and possibly ownership as well. These results can be included in the optimization equation of the model, so that ecosystem condition and ecosystem services can be factors to consider when determining optimal land-cover change.

- **Economic valuation:** the consideration of the economic value of ecosystem services provided by ecosystems would allow for a more nuanced understanding of the value that is provided by intact ecosystems and changes therein caused by human-induced land-use change.

In summary SEEA EA can support the improvement of land-use planning models with:

- New and standardized classification on land and ecosystem extent as well as data inputs, especially for pressures experienced at the national level (eg. ecological hot spots, critical ecosystem corridors and clusters vulnerable to water pollution or land conversion);
- Improved equations (improved understanding of dynamics) for possible land-cover change;
- New indicators (extended model boundaries) and land-cover and/or land-use change matrix, including new potential factors determining the extent to which land use could change.

Interpretation of results

What would emerge if SEEA EA data are used as indicated above?

- Land-use planning models use optimization in the vast majority of cases;
- The results of the model could change if better underlying data (or more aligned with national circumstances) from an integrated statistical framework are available and if ecosystem services are included in the objective function of the model;
- Ecosystem services (through extent and condition) could be directly included (and more often) in land-use decisions, also considering the economic value of such ecosystem services (eg. to preserve nature-based infrastructure).

__Table 5:__ Characteristics of land-use models, and summary of the potential contribution of SEEA EA. (Report authors)

Model type	Sector/thematic area	Actors	Dimensions of development	Time	Space
Land use (spatial planning)	Land, agriculture	Generally not specified (but may include considerations on land tenure and production, and so public and private sector)	Primarily environmental. May include economic (eg. agriculture production) and social considerations (eg. land tenure)	Snapshot, forecasts outcomes for a given point in time	Explicitly represented
Contribution of SEEA EA: **1** - New and standardized data inputs from an integrated statistical framework **2** - Improved equations (improved understanding of dynamics) for possible land cover change **3** - New indicators (extended model boundaries), including new potential factors determining the extent to which land use could change, such as the ecosystem extent matrix.					

3.3.5 Ecosystem service models

Ecosystem service models quantify the services provided by nature, typically based on spatially explicit information. A range of models have been developed to estimate ecosystem services, as well as to support decision makers in assessing the impacts of different development alternatives on ecosystem services. While this report only presents a few examples, there are various reports that provide a more in-depth comparative assessment. Examples include Neugarten et al. (2018) and ValuES (ValuES, 2019). Specifically, Table 6 presents a variety of models (in columns) and the type of outputs they can produce (first set of rows) as well the time, resources and skills required (bottom rows).

__Table 6:__ Types of outputs and requirements of various tools (Neugarten et al., 2018)

Tool	ARIES*	C$N	EST	InVEST	MIMES	PA-BAT	SolVES	TESSA	WW
Type of outputs that can be produced									
Maps of services (GIS based)	✓	✓		✓	✓		✓		✓
Maps of services (participatory mapping)						✓	✓	✓	
Relative or qualitative values	✓	✓	✓	✓	✓	✓	✓	✓	✓
Quantitative (biophysical units)	✓			✓	✓			✓	✓
Monetary value	✓	✓		✓	✓		✓	✓	✓
Designed for scenario comparison (e.g. between land use or policy scenarios)	✓	✓		✓	✓			✓	✓
Time, resources and skills required									
Requires additional paid software licenses					✓		✓		
Requires use of GIS software	✓			✓	✓		✓		
Requires modelling skills	✓				✓				
Requires social science knowledge			✓				✓		
Online training available for modelling tools		✓		✓	✓	N/A	✓	N/A	✓
User support available	✓	✓		✓	✓	✓			✓

The Integrated Valuation of Environmental Services and Trade Offs (InVEST) is used to forecast ecosystem services and value the external costs/benefits of losing/maintaining ecosystems and their services. *InVEST* is a family of models developed by the Natural Capital Project[9] that quantifies and maps the values of environmental services (Natural Capital Project, 2019a). *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.

ARIES is a web-based technology offered to users worldwide to assist 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, based on user needs and priorities (Ecosystems Knowledge Network, 2019). *ARIES* encodes relevant ecological and socioeconomic knowledge to map ES provision, use and benefit flows. This is done through an automated data integration process utilizing an extensive database featuring global-through-local scale GIS data and ecosystem service models at the landscape level.

The *Multi-scale Integrated Model of Ecosystem Services (MIMES*) was developed by scientists at the University of Vermont's Gund Institute for Ecological Economics (AFORDable Futures, 2019). *MIMES* uses a systems approach to model ecosystem dynamics 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. The *MIMES* uses input data from GIS sources, time series, etc. to simulate ecosystem components under different scenarios defined by stakeholder input.

The *Land Utilisation Capability Indicator (LUCI)* is an ecosystem services model for estimating the impact of land-cover changes on the provision of various ecosystem services (LUCI Tools , 2019). It can be applied to different levels of decision-making and allows for the assessment of ES provisioning at multiple scales, using current land-cover and ecosystem service provisioning as inputs. All *LUCI* assessments require a digital elevation model (DEM), land-cover information and soil information. Outputs of the *LUCI* models include agricultural production, erosion risk and sediment delivery, carbon sequestration, flood protection, habitat provision and water quality.

Examples:

Arkema et al. (2019) applied *InVEST* as part of a multi-method study to analyse interactions between socioeconomic and environmental systems in Belize and The Bahamas to inform decision-making and improve coastal planning (Figure 18). Based on multiple rounds of stakeholder consultations, future scenarios were designed and simulated using the *InVEST* Habitat Risk Assessment with the

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[9] See: https://naturalcapitalproject.stanford.edu/

aim to analyse integrated coastal zone management in Belize, and to assess the integration of fisheries management into sustainable development planning in The Bahamas. Results indicate that the application of spatially explicit models, in conjunction with local coastal behaviour, generated a shared understanding of dynamics among the stakeholders involved and increased the granularity of economic analysis. Further, the knowledge generated throughout the process contributed to improving coastal development plans and decisions (ibid). A study on the impact of ecosystem service information on policy design and implementation was conducted, surveying 15 *InVEST* applications listed on the Natural Capital website (Posner et al., 2016). The study found that meaningful engagement with decision makers and the coproduction of knowledge are required for *InVEST* to effectively inform decision-making.

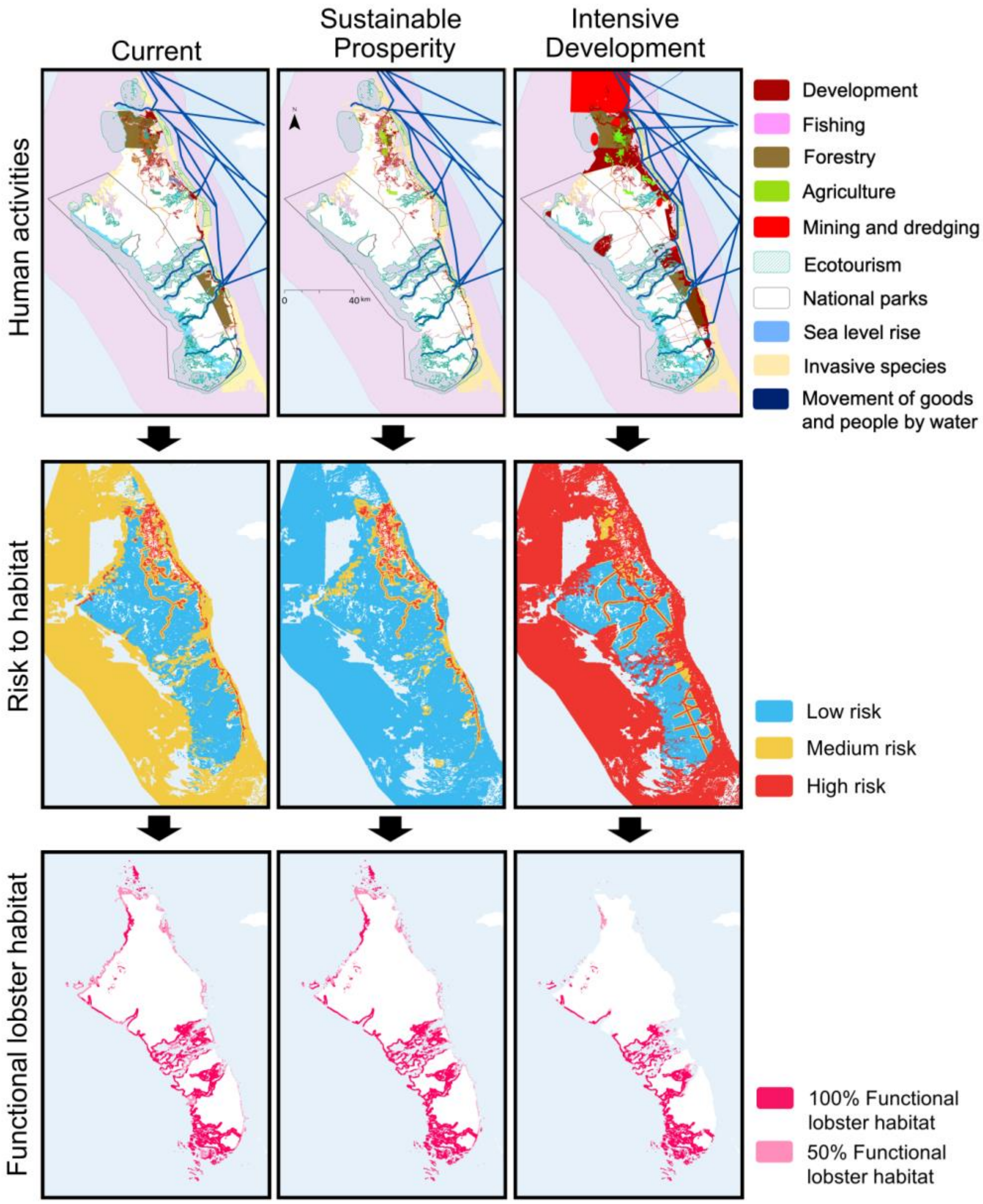

Figure 18: *Human activities (top row), risk to mangrove and seagrass habitat from human activities (middle row), and functional lobster habitat in and around Andros for the current, sustainable prosperity and intensive development scenarios, respectively. The third row maps show functional lobster habitat based on the risk results and nursery habitat classification (Arkema et al., 2019).*

ARIES was applied in Mersey Forest, UK for the assessment of ecosystem services related to a project targeting the reforestation of a post-industrial landscape. The vision of the initiative was to make Merseyside and North Cheshire one of the best places to live, focusing on delivering on key outcomes such as improved health, education, image, job opportunities and many others (Ecosystems Knowledge Network, N.D.). Also, the ecosystem modelling tools, *ARIES* and *SolVES*, were combined in a study conducted by the USA Forest Service (Neugarten et al., 2018). *ARIES* was applied to model four biophysically-based ES across six national forest for the analysis of ecosystem services hotspots. The analysis yielded important implications for forest management if hot/coldspot methods[10] are used. It was found that ecosystem hotspots were more common than coldspots in wilderness areas of National Forests closest to the Colorado Front Range urban corridor, while for two remote national forests in Wyoming, the opposite pattern was found (Neugarten et al., 2018).

Boumans et al. (2015) describe the application of *MIMES* on a global scale, as well as for the Albemarle-Pamlico watershed and the Massachusetts Ocean in the United States, two local examples. Due to its comprehensiveness, the *MIMES* model was found useful for both informing the future research agenda through the identification of data gaps and the assessment of different development strategies and their trade-offs in the case of the Massachusetts Ocean (Boumans et al., 2015).

Trodahl et al. (2017) describe how *LUCI* was applied for estimating nutrient export coefficients in a rural New Zealand landscape. The enhanced spatially representative approach for determining nutrient export coefficients in *LUCI* made the tool well suited for the analysis. The outputs generated by *LUCI* allowed for exploring total nitrogen and total phosphorus loads and concentration in-stream and on land (Trodahl et al., 2017). Also, the *LUCI* tool was integrated into the Glastir Monitoring and Evaluation Programme (GMEP), a comprehensive programme by the Welsh Government for developing alternative scenarios that generate information to inform national and international biodiversity and environmental targets (Emmet et al., 2017).

Potential structural improvements with SEEA EA

Ecosystem services models use, in the vast majority of cases, either proxies or a process-based approach where equations are used to reproduce ecological processes.

The different accounts of the SEEA EA can improve model formulations, both by providing more solid data for proxy-based models and by improving model formulations for process-based models. For example:

- **Extent:** as in the case of land-use planning models, the availability of maps based on a standardized classification on land/ecosystem extent, generated at the national level, already validated by various stakeholders, can increase the accuracy of the analysis (given the likely presence of data for land-cover classes that are relevant at the local level), speed up the modelling process and possibly increase the potential to inform policy.

[10] Hot/coldspot methods are derived from geospatial analyses to delineate and identify statistical clustering within data. For example, an ecosystem services hotspot is an area with high provision of ecosystems services; and a coldspot an area of low provision.

- **Condition**: the availability of data on the condition of ecosystems can inform the creation or improvement of mathematical formulations that link extent to ecosystem service provisioning in process-based models. These data can also improve calibration of proxy-based model, and hence improve the estimation of the provisioning of ecosystem services. This information can also be used to support the identification of areas that may require protection or restoration.
- **Ecosystem services**: the availability of data and comprehensive reference list on ecosystem services could improve the accuracy of the forecast of future ecosystem service provisioning (as indicated above, in relation to equations and calibration), as well as provide an opportunity to create new ecosystem service models or merge existing models.
- **Economic valuation**: information on the economic value of ecosystem services can improve the choice of multipliers (in the case of benefit transfer) for the creation of a more solid and standardized economic assessment of natural infrastructure, within a specific landscape. When process-based models are used, economic valuation could be an output of the model, resulting from the estimation of ecosystem service demand and supply.

In summary SEEA EA can support the improvement of ecosystem service models with:

- New and standardized data inputs based on an integrated statistical framework.
- Improved equations in the models (improved understanding of dynamics).
- New indicators (extended model boundaries) with the addition of more ecosystem services.

Interpretation of results

What would emerge if SEEA EA data are used as indicated above?

- Ecosystem service models use, in most cases, simulation. As a result, the main outcomes of the model may not change dramatically, unless model formulations change.
- More accurate results could be obtained from ecosystem service models if better proxies are used or, and more importantly, if process-based formulations can be validated with SEEA EA data and are used more frequently.
- With a stronger estimation of ecosystem services, nested and integrated models could be strengthened, and ecosystem service valuation could become more directly available for all sectoral/thematic and national policy assessments.

Table 7: *Characteristics of ecosystem service models, and summary of the potential contribution of SEEA EA (Report authors)*

Model type	Sector/thematic area	Actors	Dimensions of development	Time	Space
Ecosystem services	Land, water, energy, …	Generally, not specified	Primarily environmental. May include economic (eg. infrastructure damage from floods) and social considerations (eg. population at risk of water scarcity)	Snapshot, forecasts outcomes for a given point in time	Explicitly represented
Contribution of SEEA EA: **1** - New and standardized data inputs based on an integrated statistical framework **2** - Improved equations (improved understanding of dynamics) **3** - New indicators (extended model boundaries) with the addition of more ecosystem services disaggregated by ecosystem type					

3.3.6 Macroeconomic models

Macroeconomic models are used to perform economic assessments at the regional, national and sectoral level. An example of the use of these models is for the estimation of the impact of fiscal policy. Two main approaches are found, based on general equilibrium (optimization) and econometrics.

Computable General Equilibrium (CGE) models (see, for instance, Lofgren and Diaz-Bonilla (2010) are tools used for economic analysis. The World Bank defines CGEs as "completely-specified models of an economy or a region, including all production activities, factors and institutions, including the modelling of all markets and macroeconomic components, such as investment and savings, balance of payments, and government budget" (The World Bank, N.D.). The three conditions of market clearance, zero profit and income balance are employed by CGE models to solve simultaneously for the set of prices and the allocation of goods and factors that support general equilibrium.

Econometric models function by collecting historic data on a range of variables and using economic theory and statistical techniques to determine how a change in one variable is correlated with changes in others. Data on past correlation is then used to project future changes. A macro-econometric model takes this approach with regard to macroeconomic variables. As a result, this type of model is not based on an attempt to theorize how an economy works (despite being nevertheless theory-based), instead it measures how it has evolved based on actual data. Macro-econometric models are top down, and have generally been used to assess similar questions to those evaluated by CGE models and can be applied at the national as well as regional level.

The Integrated Economic-Environmental Modelling (IEEM) platform constitutes a framework for integrating SEEA EA data into CGE models, based on the conceptual framework developed by Banerjee et al. (2016a). The authors illustrate how the integration of the SEEA EA into a CGE model circumvents data reconciliation needs while enhancing analytical power and obviates the need for strong assumptions in reconciling economic-environmental data (Banerjee et al., 2016a). Figure 19 provides an overview of the standard flows considered in CGE models, based on Banerjee (2019).

The *OECD ENV-Linkages* model is a CGE model that projects GHG emissions using economic activity as underlying driver. The model uses economic input-output tables to quantify economic flows across economic sectors. Underlying assumptions of the ENV-Linkages are cost minimization, perfect markets and technologies that provide constant returns to scale (Burniaux and Chateau, 2010; Château et al., 2014). The calibration of the input-output tables in the model is largely based on national statistics and relies on the exogenous definition of certain key parameters such as the government deficit or carbon emissions from Land Use, Land-Use Change and Forestry (LULUCF).[11]

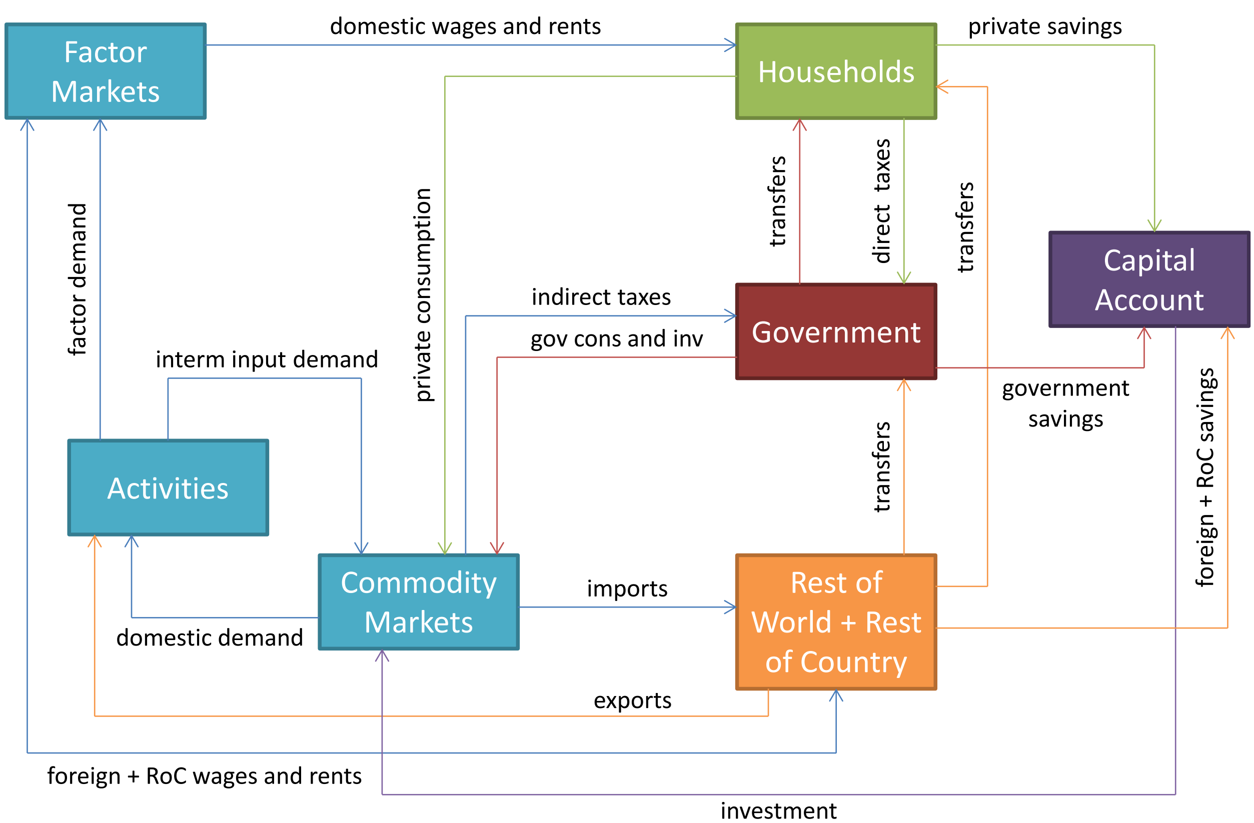

Figure 19: *Standard structure of multi-regional CGE models (Banerjee et al., 2019)*

The *E3ME model* is a computer-based model that is widely used for policy analysis, forecasting and research purposes. It captures the world's economic and energy systems and the environment, and was originally developed as a quantitative tool for policy design and assessments for the European

[11] Refer to https://unfccc.int/topics/land-use/workstreams/land-use--land-use-change-and-forestry-lulucf for further information.

Commission (Cambridge Econometrics, 2019). The *E3ME* model is a macroeconomic model and as such does not focus on optimization, but rather on exploration of uncertainty related to future developments and policy impacts. (Pollitt et al., 2019; Cambridge Econometrics, 2019). An overview of key sectors and indicators in the *E3ME* model is provided in Figure 20.

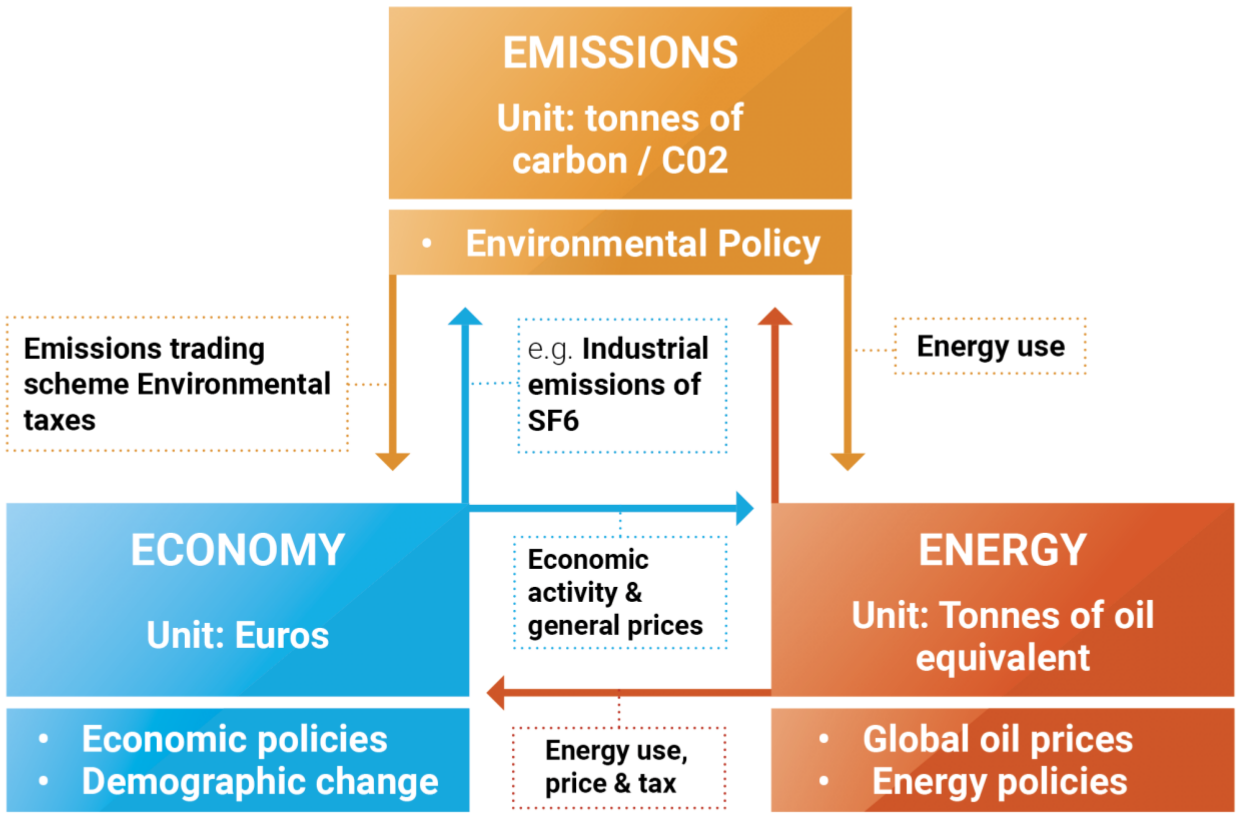

Figure 20: *Overview of the E3ME structure, based on Cambridge Econometrics (2019)*

Examples

The IEEM was operationalized and calibrated using Guatemala's Environmental-Economic Account data with the aim to analyse the country's forest and fuelwood sectors. Several negative health and environmental impacts arise from the inefficient use of fuelwood in households, and the IEEM was used to assess the impacts of the national fuelwood strategy on social, economic and environmental indicators. The analysis focused on both standard macroeconomic indicators (eg. GDP, employment and income) and indicators for assessing policy impacts on natural resources, such as natural resource consumption, wealth and environmental quality, whereby policy assessment related indicators were used to estimate economic growth prospects and future well-being. In addition to analysing the country's fuelwood strategy, the impacts of a reforestation and sustainable forest management strategy (PROBOSQUE) are explored (Banerjee et al., 2016b). Such include the manifold impacts upon the socio-economic considerations of Guatemalan livelihoods in the agricultural frontier resulting from fuelwood scarcity e.g. the increased time allocation for the education of women and children without fuelwood collection, and the reduction of detrimental health effects from open cookstoves particularly for women.

The *ENV-Linkages* model was used to analyse potential designs for carbon markets, considering carbon leakage impacts on competitiveness. The study of different carbon market designs considered a variety of factors such as coverage (eg. countries, type of gases), potential linkages with national trading schemes and the stringency of carbon pricing policies (Château et al., 2014). Furthermore, the model was applied to the analysis of border carbon adjustment policies and their impact on competitiveness (Burniaux et al., 2013). Competitiveness impacts consider both macroeconomic indicators (eg. wealth, sectoral output, exports and imports) and environmental impacts (eg. leaked GHG emissions) (Château et al., 2014). The Center of Policy Studies in Australia used CGE models (ie. TERM CGE, TERM H2O) to investigate issues related to water scarcity, allocation and pricing (Banerjee et al., 2019). The *TERM CGE* model assessed the impact of drought, and its successor, the *TERM-H2O* model, has considerable detail on irrigation and the impact of relative prices on water trade and reallocation (Horridge et al., 2005; Dixon et al., 2011).

The *E3ME* model was applied for assessing macro-level and sectoral impacts of energy efficiency policies in Europe (European Commission, 2017). The study finds that energy efficiency measures area among the most cost-effective options for meeting global emission targets, however that the obtained financial benefits depend on the financing mechanisms deployed. This report provides a comprehensive description of the modelling of energy efficiency in the *E3ME* model, scenario descriptions and results and results of energy efficiency on six impact areas, economy and labour market, health, environmental impacts, social impacts, public impacts and industrial competitiveness (European Commission, 2017).

Potential structural improvements with SEEA EA

One of the main criticisms for economic models is that the estimation of economic performance is disconnected from the state of environment. With information generated by SEEA EA it is possible to more closely couple economic indicators with biophysical ones, allowing economic performance to depend on the availability of natural resources and ecosystem services, and at the same time to affect ecosystem condition and ecosystem services.

There are several ways in which SEEA EA data can improve model formulations, both to improve forecasts related to economic performance and for estimating the impact that economic performance could have on ecosystems, thus creating a feedback loop:

- **Extent**:
  For production – this data can inform the estimation of whether the land resources and

ecosystem assets required to maintain and expand economic production are available. This implies that ecosystem type requirements for different economic activities are estimated and compared with available land (considering all land-cover classes) and potential future land-cover change. In this respect, the use of extent data can indicate whether land and ecosystem type-related constraints may emerge in the future.

For impacts of production - for both CGE and macroeconometric models, the inclusion of new variables on land use and ecosystem extent can support the estimation of the impact of economic production on ecosystem assets, and hence on the condition of ecosystems and provisioning of ecosystem services.

- **Condition**:

  For production – this data can support the estimation of the economic productivity of various ecosystem assets, using biophysical data and increasing the accuracy of projections (eg. for agriculture, forestry or all land-based sectors for instance).

  For impacts of production – new variables could be added to the model that indicate environmental pressures emerging from activities that affect condition but not extent (eg. land management practices, logging practices).

- **Ecosystem services:**

  For production – including ecosystem services in macro models could support the assessment of productivity at the sectoral level. It could shed light on the extent to which regulating services such as water quality, air quality, soil erosion and other ecosystem services can contribute to economic productivity (or conversely, on the extent to which production relies on ecosystem services). This could be introduced through the use of "productivity shocks" in the model, resulting from changing ecosystem service supply. Potential implications for models that estimate trade include the possible generation of scenarios where the decline in ecosystem services leads to changing trade patterns (due to cost increases in certain countries, eg. in the case of water shortage and agriculture production).

- **Economic valuation:**

  For production – this data could inform the extent to which production costs may change in case of declining ecosystem services. This in turn may affect economic growth projections (sectoral and national level) and contribute to more holistic assessments of economic development. In the case of CGE models, this implies that the optimization algorithm would consider an extended set of parameters (ie. the environmental dimension and its impact on production costs). Additional indicators could be considered, for instance the total value-added of final ecosystem services (eg. Gross Ecosystem Product) or total value of ecosystem assets. These are indicators that do not influence the calculation of other, already existing indicators. Instead, these are additional ones that allow to better interpret the economic performance of the area analysed, complementing more conventional indicators (eg. value added by sector, or GDP).

In summary SEEA EA can support the improvement of macroeconomic models with:

- New and standardized data inputs based on an integrated statistical framework.
- Improved equations (improved understanding of dynamics) for the impacts of economic activity on the environment.
- New indicators (extended model boundaries) for the inclusion of the impact of ecosystem services on production (full feedback loop).
- Spatial disaggregation/interpretation of results (with localized impacts supporting the assessment of national impacts).

Interpretation of results

What would emerge if SEEA EA data are used as indicated above?

- Macroeconometric models use data to estimate model formulation. With more data and more knowledge of causality for ecosystem extent, condition and services, these models could be greatly enhanced.
- CGE models use optimization, and the results of simulations will change when new factors are included in the objective function (eg. when the loss of ecosystem services translates in costs).
- Model boundaries for both types of models could be expanded, including environmental dimensions more explicitly in the estimation of economic performance. Economic productivity formulations could be expanded (or shocks included), featuring ecosystem services more explicitly, also through their economic valuation and their spatial characteristics.
- Spatial information may provide more insights as to the emergence of environmental problems (eg. water and air pollution), informing policy development to avoid the emergence of these trade-off related costs.

Table 8: *Characteristics of macroeconometric and CGE models, and summary of the potential contribution of SEEA EA (Report authors)*

Model type	Sector/thematic area	Actors	Dimensions of development	Time	Space
Macroeconometric	Economy (various sectors), often connected with energy consumption	Economic flows for public and private sector, households, banks and rest of the world	Economic	Continuous time (year on year projections)	Not explicitly included
CGE	Economy (various sectors, national and international trade)	Economic flows for public and private sector, households, banks and rest of the world	Economic	Snapshot (1 year or 5 year intervals)	Not explicitly included

Contribution of SEEA EA:

1 - New and standardized data inputs based on an integrated statistical framework

2 - Improved equations (improved understanding of dynamics) for the impacts of economic activity on the environment

3 - New indicators (extended model boundaries) for the inclusion of the impact of ecosystem services on production (full feedback loop) or the inclusion of Gross Ecosystem Product to be assessed together with other more conventional economic indicators

4 - Spatial disaggregation/interpretation of results (with localized impacts supporting the assessment of national impacts)

3.3.7 Energy models

Energy optimization models such as the *MARKAL* (MARKet ALlocation) energy model (Fishbone et al., 1983; Loulou et al., 2004) and *LEAP* (Heaps, 2012), optimize energy supply to, for instance, minimize production costs or curb emissions. With energy demand and prices being in most cases exogenous, the scenarios simulated lack the dynamic analysis of the market. Further, environmental concerns are not included, apart from the estimation of the generation of emissions from the burning of fossil fuels.

The *MARKAL* and *TIMES* models are technology-rich models for estimating energy dynamics on regional or multi-regional scale. The model relies on user inputs such as demographic and economic projections to estimate demand for energy services, whereby energy end-use is modelled using extensive sectoral detail (Loulou et al., 2004). The model computes energy balances for all levels of an energy system, aiming at supplying energy services at global minimum cost by making investment and operating decisions related to equipment and primary energy supply. *MARKAL* can be regarded as a vertically integrated model of the energy system (Loulou et al., 2004).

The LEAP (Long-range Energy Alternatives Planning System) is a software tool for conducting energy policy analysis and climate change mitigation assessments (SEI, 2019a). LEAP is a scenario-based tool with focus on long range energy planning, although it is possible to define calculation increments as small as fractions of a day. LEAP supports different modelling methodologies for energy demand, ranging from bottom-up end-use accounting and top-down macroeconomic modelling. The flow chart presented in Figure 21 illustrates the structure that LEAP uses for its calculations, based on the Stockholm Environment Institute (2019a).

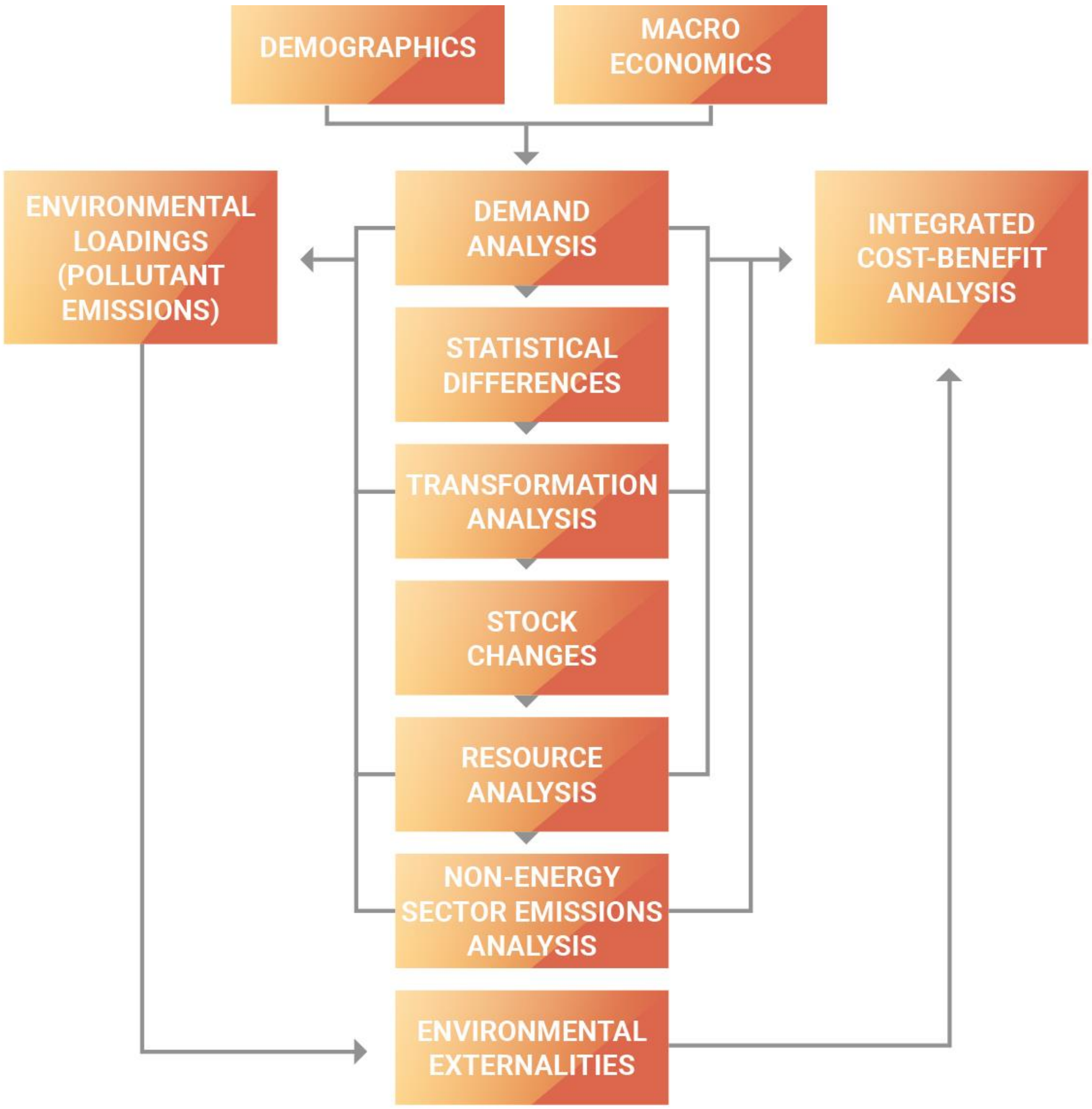

Figure 21: *The structure of LEAP's calculations based on (SEI, 2019a)*

Examples

The UK Energy Research Centre (UKERC) conducted a series of studies to analyse energy demand and supply until 2050. The country's energy system was analysed with a special focus on low carbon development options, based on the newly developed *UK MARKAL* elastic demand model (UKERC, 2009). In this study, the *MARKAL* model was used as exploratory tool for the analysis of trade-offs and tipping points between different energy system pathways.

LEAP-based scenario analysis was applied to explore and determine potential transition pathways to achieve Nigeria's pledge to reduce power sector emissions by 60 per cent until 2030, as outlined in their Nationally Determined Contribution (NDC). In addition, these scenarios consider goals related to electricity access, decarbonization and utilization of renewable energy. The results of the study describe what ambitions are realized under which scenario, and document the preconditions for reaching stated targets (Roche, et al., 2019).

Potential structural improvements with SEEA EA

Energy models use, in the vast majority of cases, optimization as the underlying methodology for solving equations. This means that energy supply decisions (or investments) are determined based on an objective function, eg. cost minimization.

There are several ways in which SEEA EA data can improve model formulations, both to improve forecasts for energy supply and for estimating the impact of energy used on social, economic and environmental indicators:

- **Extent**:
  For production – this data can inform the spatial location of supply for fuelwood and biofuels indicating if constraints may be emerging for the utilization of a specific energy source. If such a constraint may emerge, instead of limiting the use of a specific energy source, prices may be assumed to increase (eg. due to the need to import more expensive fuelwood or biofuels from elsewhere). Either way, the results of the model may change with the use of these new inputs to the optimization of the model.
  For impacts of production and use – the inclusion of new variables in the model can support the estimation of the impact of energy generation (by energy source) on land cover. This includes deforestation for fuelwood or for biofuels, or mining for fossil fuels, or a change in land use and ownership (rather than land cover).
- **Condition**:
  For production – this data can support the extent to which power generation capacity can be utilized (ie. load factor) in relation to water flow and water quality. It could also support the identification of areas that could be more productive for the generation of biofuels (based on soil characteristics, and resulting impacts on land productivity).
- *For impacts of production and use* – new variables could be added to the model to estimate water consumption, water pollution, impact on the quality of forest land (eg. in the case of fuelwood harvesting), habitat fragmentation and impacts on biodiversity.
- **Ecosystem services:**
  For production – this data could inform the supply for biomass provisioning services for

energy use as well as the extent to which infrastructure is at risk, for instance in the case of floods and landslides, leading to the reduction of uptime, or load factor.

For impacts of production and use – new variables could be included in the model to estimate generation of emissions as well as changes in carbon sequestration from land, both of which could then be connected to health impacts, via air pollution.

- **Economic valuation:**

  For production – this data could inform the extent to which energy production and power generation costs would change if the economic value of the loss of ecosystem services would be included in the calculation. This would allow for the estimation of the contribution of energy supply to society in a more holistic way, one that goes beyond capital expenditure and operational expenditure.

  For impacts of production and use - the consideration of the so called "externalities" of energy production and electricity generation may lead to a very different set of results from the optimization of the model, with certain technologies featuring more prominently than others when including the loss of value of ecosystem services.

In summary SEEA EA can support the improvement of energy models with:

- New and standardized data inputs, especially for bioenergy, renewable energy for power generation and mining for the extraction of fossil fuels.
- New indicators (extended model boundaries) with the additions of the impacts of energy demand and production trends on the environment.
- Spatial disaggregation/interpretation of results, for the identification of sensitive areas for deforestation or water/air pollution.

Interpretation of results

What would emerge if SEEA EA data are used as indicated above?

- Most energy models optimize supply to minimize costs, or to limit emissions. Information on total cost of energy and power generation (with the inclusion of ecosystem services, their impact on load factor, capacity and production costs) is likely to lead to different model outcomes. For instance, conventional thermal power generation would be less competitive when including costs related to air and water pollution, while renewables would look more attractive due to the lower impact on health costs, reduced vulnerability to water scarcity and rising air temperature.
- The use of spatially explicit SEEA EA data would allow to bridge national-level assessment with project finance studies for individual assets. Practically, it will be possible to connect ecosystem services and infrastructure location, not only based on a power distribution network (in the case of power generation) but also on nature-related risks (eg. floods, landslides, water shortages, exposure to heat waves).
- Policy implications could be relevant. For instance, many countries have been subsidizing coal power generation to keep energy prices low and stimulate economic growth. On the other hand, coals leads to health costs (air emissions) and several negative impacts on ecosystems, which negatively affect ecosystem services as well as all economic activities that rely on these services.

Table 9: *Characteristics of energy models, and summary of the potential contribution of SEEA EA (Report authors)*

Model type	Sector/thematic area	Actors	Dimensions of development	Time	Space
Energy	Energy supply, emissions	Private sector (producers) for power generation	Economic (investment required, price of electricity), environmental (emissions)	Snapshot (1 year or 5 year intervals)	Not explicitly included, may be considered for sub-national electricity dispatch models
Contribution of SEEA EA: **1** - New and standardized data inputs, especially for bioenergy, renewable energy for power generation, mining for the extraction of fossil fuels **2** - New indicators (extended model boundaries) with the additions of the impacts of trends of energy demand and production on the environment, eg. on the need for biomass provisioning services by the ecosystem and related changes in ecosystem condition, such as on species abundance or living plant index. **3** - Spatial disaggregation/interpretation of results, for the identification of sensitive areas for deforestation or water/air pollution					

3.3.8 Water models

A variety of water models are currently available, ranging from simple water balance and precipitation models to highly sophisticated spatially explicit integrated water resource planning models. Oftentimes, those models cover a specific aspect of the water sector and have been developed to address a specific research question or issue, such as, for example, crop irrigation requirements (*CROPWAT*), the assessment of future water availability in watershed areas (eg. *PRMS*) or the analysis of water efficiency requirements in face of future water shortages (eg. *SWAT, WEAP*).

SWAT (Soil and Water Assessment Tool) 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 (Texas University, 2015). SWAT was developed to forecast 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 of time. 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. Figure 22 illustrates a schematic representation of water flows in the SWAT model (Neitsch et al., 2009).

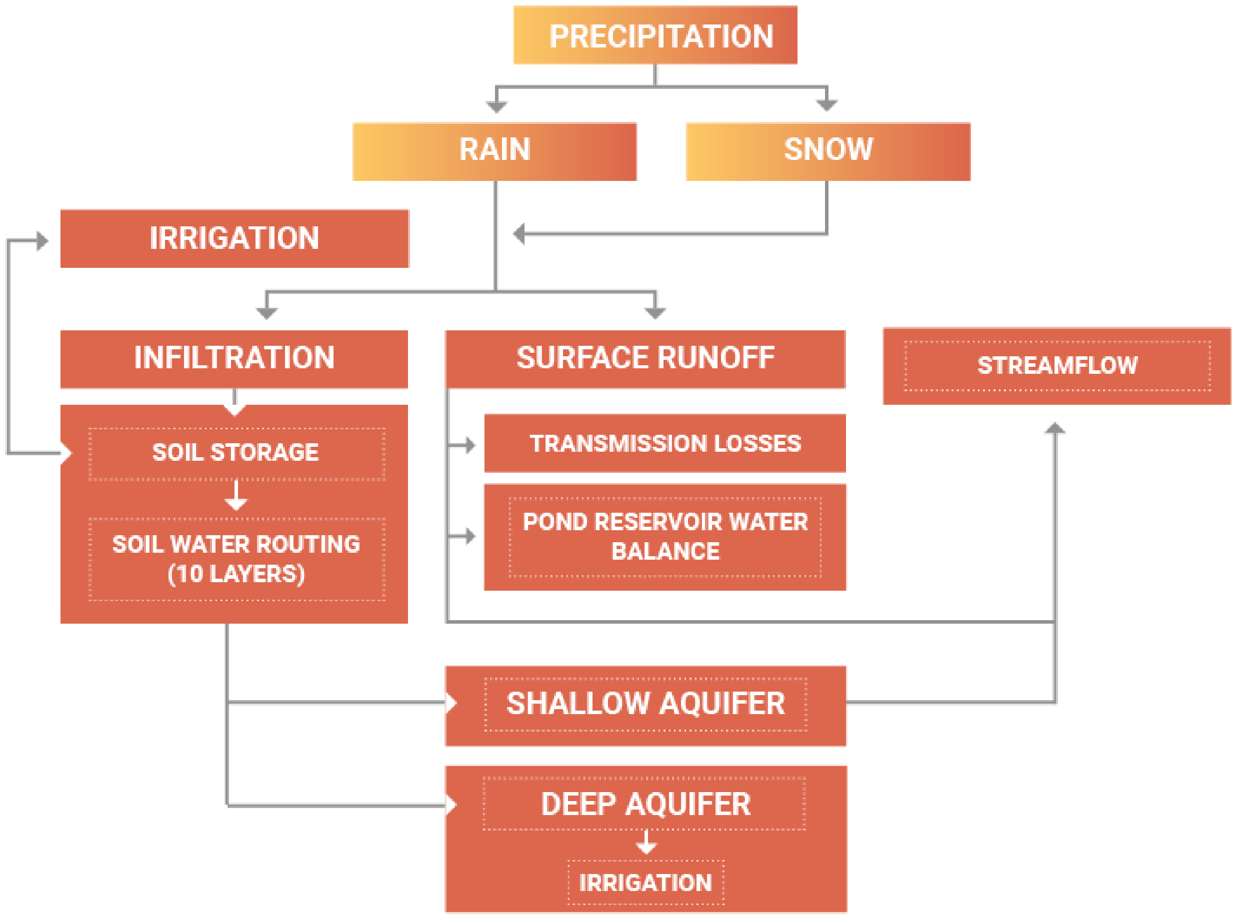

Figure 22: *Schematics of the SWAT model based on (Neitsch et al., 2009)*

CROPWAT is a decision support tool developed by the Land and Water Development Division of FAO. *CROPWAT* is a computer program for the calculation of crop water requirements and irrigation requirements based on soil, climate and crop data (FAO, 2019). In addition, the program allows the development of irrigation schedules for different management conditions and the calculation of required water supply for varying crop patterns. *CROPWAT* can also be used to evaluate farmers' irrigation practices and to estimate crop performance under both rainfed and irrigated conditions.

The *Water Evaluation and Planning (WEAP)* tool developed by the Stockholm Environment Institute uses an integrated approach to water resource planning (SEI, 2019b). To address the increasing challenges related to freshwater management, WEAP integrates both supply and demand of water, water quality and ecological considerations into the water resource planning process. WEAP uses a GIS based interface that allows users to overlay elements to an existing GIS map with the aim to explore potential impacts of changing assumptions. It has built-in models for rainfall runoff and infiltration, evapotranspiration, crop requirements and yields, surface and groundwater interaction and instream water quality.

The *Precipitation-Runoff Modelling System (PRMS)* is physical process based modelling system developed for the evaluation of how land-use changes and climate change affect watershed characteristics and watershed hydrological responses (USGS, 2019). The hydrological system is modelled based on physical laws or empirical relations and distributed-parameters and watershed partitioning features are applied to account for the spatial variation in rainfall across the watershed. These parameters are used to partition the watershed analysed into small units for which a separate water and energy balance are computed, which is then added up to an area-based weighted sum of the total responses of all units.

Examples

The *SWAT* model has been widely applied to water resource management questions. For example, *SWAT* was integrated in the Hydrologic Unit Model for the United States (HUMUS-SWAT) to conduct a national scale analysis of different water management scenarios (Arnold et al., 2010). *SWAT* has also been applied on different regional scales. Rafee et al. (2019) applied *SWAT* to model water resources for the Upper Paraná River Basin to forecast and analyse the development of water resources in order to improve planning and sustainable management. Specifically, the *SWAT* model was applied to estimate the discharge of the basin in monthly time steps at the highest spatial resolution supported by the software. Their findings address discharge variability observed in the basin and provide reference water data that can be used to simulate scenarios related to climate change or future land-use changes (Rafee et al., 2019).

To analyse the hydrogeological conditions and potential climate change impacts, the *SWAT* model was coupled to the *MODFLOW* model. The aim was to overcome limitations of the respective other model in order to conduct an analysis of groundwater and surface water dynamics in Alberta, Canada. In this study, *SWAT* contributed processes associated with surface water hydrology, such as precipitation, temperature, river flow, surface water runoff, soil water and actual evapotranspiration, while *MODLOW* contributed for groundwater related aspects (Chunn et al., 2019).

For a study conducted under UN Environment's TEEB initiative, *CROPWAT* information was integrated into a multi-method modelling framework for the analysis of the Southern Agriculture Growth Corridor of Tanzania (SAGCOT) (TEEB, 2018). For this study, *CROPWAT* data was integrated into a System Dynamics model developed for assessing the impacts of SAGCOT's implementation in the Kilombero Valley on socioeconomic and environmental key indicators. Specifically, *CROPWAT* data was used to estimate the change in irrigation water requirements emerging from the implementation of the SAGCOT ambition in Kilombero by comparing crop water requirements to seasonal precipitation (TEEB, 2018).

Surendran et al. (2017) applied *CROPWAT* for assessing crop water needs for various crops in different agro-ecological units of Kollam district. The results for net and gross water demand for each ecological unit were computed for major cultivated crops such as rice, coconut, rubber, pepper, banana, binjal, tomato, tapioca and others, using *CROPWAT*. The assessment of gross water demand was used to generate future projections and then compared against current and future water availability to assess whether future irrigation water demand is within the boundaries of sustainable water use (Surendran et al., 2017). Current water supply in the Kollam district is 1,117mm^3 per year. Current water demand (at 70 per cent irrigation efficiency) is 1,045mm^3 per year, while future irrigation requirements are indicated at 2,667mm^3 per year. The projections thus reveal a potential water shortage of 1,550mm^3 by 2021 if additional area is brought under irrigation.

Brown et al. (2019) applied *WEAP* for analysing water demand with respect to expected water shortages, and assess water efficiency interventions related to water withdrawal, storage and others. *WEAP* was applied for estimating water demand and for identifying future water shortages. Furthermore, *WEAP* was used to analyse an equity-based allocation of water resources among all consumers rather than excluding certain consumers from demand (Brown et al., 2019).

The U.S. Geological Survey applied the *PRMS* model for analysing the future availability of water in the Fena Valley Reservoir, Guam (Yeung, 2005). The runoff from the watershed captured in the Fena Valley Reservoir is an important source of freshwater supply for Southern Guam. The *PRMS* model was combined with a generalized water-balance model, and water availability was assessed under various combinations of water withdrawal rates and rainfall conditions (Yeung, 2005).

Potential structural improvements with SEEA EA

The contributions of the SEEA EA to water models depends on the scope and the methodology used. In case of spatially explicit models, SEEA EA data could contribute to an improvement of model formulations, and to extended boundaries. With non-spatially explicit models (eg. proxy-based, using multipliers) improvements can be expected in the quality of results, both for water demand and supply.

There are several ways in which SEEA EA data can improve model formulations, both to improve forecasts of water supply and for estimating the impact of water use:

- **Extent:** could contribute to enriching existing spatial information (with land-cover maps already being used to estimate water yield) and to the validation of information already generated by local, national or regional institutions. The SEEA EA could support the generation of a more consistent set of maps and supplementary information based on a standardized ecosystem extent classification that may enrich formulations in existing water models and support the validation of model results.

- **Condition**: could inform the existence or emergence of potential constraints required in water models (eg. water percolation, water runoff and water quality) to improve the customization of models to a specific geographic context. This can be estimated by using more accurate mathematical formulations (adding ecosystem condition to the model, through new variables), and may contribute to the identification of areas where more stringent water effluent regulations are required or mitigation measures are needed.
- **Ecosystem services**: information on available ecosystem services (eg. freshwater provisioning, nutrient filtration, soil erosion) contributes to improved parameterization of water models for the generation of future forecasts. It would therefore increase the accuracy of model outcomes, ultimately improving the validity and usefulness of modelling results.
- **Economic valuation:** information about the value of ecosystem services provided could allow for adding new variables to already existing models. Including the economic dimension to water models would highlight the monetary value of water provisioning or water quality and may provide guidance to integrated water management plans and water pricing schemes.

In summary SEEA EA can support the improvement of water models with:

- New and standardized data inputs based on an integrated statistical framework.
- Improved equations (improved understanding of dynamics) for the estimation of ecosystem services affected by water.
- New indicators (extended model boundaries) to include the impact of water availability on selected ecosystem services (with multipliers).

Interpretation of results

What would emerge if SEEA EA data are used as indicated above?

- Water models primarily use simulation to estimate water demand and supply.
- SEEA EA could improve the estimation of water demand (such as from crops, based on ecosystem condition information, eg. for soil) and water supply (eg. based on the availability of data for the creation of water balances at various spatial level) when using nationally approved maps that capture local circumstances.
- Water-related ecosystem services and ecosystem services from water-related ecosystem can support the economic valuation of water for various uses, and can shed light of the opportunity cost of water use (eg. what is the cost of water extraction for irrigation when little water is left for ecological purposes?).

- At the policy level, this improved assessment will allow for the evaluation of investments in a more systemic and coherent way, by highlighting the presence of trade-offs, and the emergence of unexpected and undesired costs.

Table 10: *Characteristics of water models, and summary of the potential contribution of SEEA EA (Report authors)*

Model type	Sector/thematic area	Actors	Dimensions of development	Time	Space
Water	Water demand and supply, land use	Generally, not specified (but may include considerations on demand for farmers and supply from reservoirs or built infrastructure)	Primarily environmental. May include economic (eg. access to water for food production) and social considerations (eg. access to water for sanitation or nutrition)	Continuous time (daily, weekly or monthly projections)	Explicitly represented
Contribution of SEEA EA: **1** - New and standardized data inputs based on an integrated statistical framework **2** - Improved equations (improved understanding of dynamics) for the estimation of ecosystem services affected by water **3** - New indicators (extended model boundaries) to include the impact of water availability on selected ecosystem services (with multipliers), including crop provisioning. Additionally, water-related ecosystem services could be estimated, including water purification services by ecosystem type.					

3.3.9 Infrastructure models

Infrastructure models are used to answer various questions, ranging from the assessment of financial viability and profitability of investments to projecting and evaluating infrastructure performance over time in the face of changing demand or systemic pressures. Most commonly, infrastructure models only cover conventional performance parameters related to financial indicators such as Net Present Value (NPV), the Internal Rate of Return (IRR), or the Debt Service Coverage Ratio (DSCR), assuming that service delivery provided by the asset is rather fixed (eg. project finance models). A new class of infrastructure models is more recently gaining traction, models that use a holistic approach to the valuation of asset performance, considering additional aspects such as socioeconomic and environmental externalities (eg. Sustainable Asset Valuation, SAVi). In other words, this new class of models regards infrastructure assets as a part of the system surrounding it, rather than assuming the asset being in isolation.

Several *project finance* models are developed to assess infrastructure projects, but they all share the same underlying structure. These models track financial flows (capex, opex, financing costs and revenues) to estimate the same indicators - IRR, NPV and DSCR. The results are packaged in an income statement, balance sheet, and cash-flow statement. Differences emerge among models in relation to the level of depth of the assessment, and depending on the type of infrastructure asset being analysed. Project finance models normally only track indicators that are relevant to the investor (eg. carbon emissions are not included in the model unless these generate a financial flow, eg. through carbon taxation).

SAVi (Sustainable Asset Valuation tool) is a suite of models developed by the International Institute for Sustainable Development (IISD). It combines a systems model with a project finance model, and it is a highly scalable infrastructure model that can be applied on various types of infrastructure (eg. power generation, buildings, roads, irrigation, water treatment, natural infrastructure) and at various levels of detail, from project-level to national assessments (IISD, 2019b). SAVi aims to analyse the asset as part of its surrounding system and to estimate the full economic, social and environmental costs related to it. Results are packaged in a cost-benefit analysis that represent the performance of the asset for the construction company, users, the government, as well for society as a whole (which includes a variety of externalities and their economic valuation).

Examples

In collaboration with the International Roads Federation and Autoroute du Maroc, SAVi was applied to analyse the cost of various management strategies for the Rabat bypass after its inauguration in 2017 (Bassi et al., 2019). A range of sensitivity analyses were conducted to assess the impacts of maintenance frequency on both economic indicators, such as capital and operations and maintenance costs, and social indicators, such as time savings, accidents and cost of carbon. The alternative scenarios simulated assessed how road maintenance requirements and cost would change if underlying assumptions concerning traffic patterns (eg. higher volumes, more heavy duty vehicles) or climate impacts would deviate from the baseline case.

Bassi et al. (2019) used SAVi for the estimation of the economic value of the ecosystem services provided by Pelly's Lake and the Stephenfield reservoir in Manitoba, Canada. Ecosystem services that were considered in the assessment were water supply for agriculture production (irrigation), carbon sequestration, nutrient retention and flood protection. The assessment revealed that, even if current operations and maintenance costs exceed the economic returns from tourism or water licensing, the monetary value of ecosystem services by far outweighs infrastructure cost (Bassi et al., 2019). Furthermore, the replacement of the services provided, especially in the case of Pelly's Lake, would require investing in multiple assets (eg. irrigation, water storage, nutrient removal) and be far more expensive in the longer term than maintaining natural capital.

SAVi was applied in a joint project between the Ministry of Tourism, Jammu and Kashmir, India, and IISD, assessing remediation and mitigation options for the rehabilitation of Lake Dal, the jewel of Kashmir (IISD, 2018a). Water quality in Lake Dal eroded over the last decades, and the lake is currently in a state of eutrophication where it experiences regular algae blooms. The assessment considered how conventional infrastructure (wastewater treatment, renewable energy) and natural infrastructure (artificial wetlands) solutions would affect key socioeconomic and environmental indicators. Among others socioeconomic indicators covered gross value added from tourism and fisheries, population growth and tourism, while environmental indicators focused on, for example, lake water balance, total nitrogen loadings, nitrogen concentration in the lake's water, and fish availability.

Potential structural improvements with SEEA EA

Infrastructure models use, in the vast majority of cases, financial modelling techniques as the underlying methodology. Information changing environmental conditions are included in the model in the form of an aggregate assumption, or contingency factor (eg. construction costs for a power generation plant could be 3 per cent higher than expected). This indicates that, in the vast majority of cases (and with the exception of SAVi), there is no dynamic interplay between infrastructure investments and ecosystem services, and such gaps could be addressed by SEEA EA.

There are several ways in which SEEA EA data can improve model formulations, both to improve forecasts of infrastructure performance and for estimating the impact of infrastructure assets on social, economic and environmental indicators:

- **Extent:**
  For construction and operations – this data can inform the preliminary assessment of the availability of land resources required for specific infrastructure types (eg. forest or agriculture land for biomass in the case of power generation). This assessment may anticipate the emergence of constraints for construction and operation, leading to higher costs, or lower revenues than expected.
  For impacts of production and use – information on land use and ecosystem extent could be used to estimate the land requirements of infrastructure (eg. land cleared for road construction, area that can be served by irrigation infrastructure), adding new variables to infrastructure models. This may allow to link infrastructure assessments to other scenario exercises (eg. for agriculture production) as well to estimate the potential foregone revenue in case of land-use changes (eg. when land is converted from agriculture to other uses for infrastructure).
- **Condition:**
  For construction and operations – this data can support the extent to which installed

infrastructure can be utilized (ie. load factor for power generation, water availability for irrigation, potential risk of infrastructure damage when ecosystem condition worsens). The condition account, by providing information on both the characteristic of ecosystems and by assessing their quality, could also support the identification of areas (location) that could be better suited for establishing infrastructure assets (based on topographical features, solar radiation, water flow quantity and consistency, and resulting impacts on infrastructure utilization). While data of this type are already often used, the availability of a consolidated, spatially explicit database at the national level would support the inclusion of this information in all infrastructure assessments.

For impacts of production and use – new variables could be added to the model to demonstrate how infrastructure pressures affect the condition of ecosystems. For instance, the impact that road construction could have on deforestation could be expanded, by assessing the extent to which deforestation may lead to a worsening of the condition of various related ecosystems.

- **Ecosystem services:**

  For construction and operations – data on ecosystem services could inform the extent to which infrastructure is at risk, for instance in the case of floods and landslides, leading to the reduction of uptime, or load factor or even to the potential damage of infrastructure. This information may lead to new considerations such as considering the positioning of infrastructure, the type of technological solution used (eg. flood vs drip irrigation infrastructure) and the size of the infrastructure (eg. for wastewater and stormwater management). In a project finance model this information would impact both the costs (higher) and revenues (lower) as well as the asset (potential capex expenditure to fix infrastructure damage).

  For impacts of production and use – new variables could be included in the model to estimate the impact that infrastructure could have, not only on extent and condition, but also on ecosystem services, which is fundamental for economic valuation.

- **Economic valuation:**

  For construction and operations – this data could inform the extent to which infrastructure investment and use costs would change if the economic value of the loss of ecosystem services would be included in the calculation. In the case of SAVi the contribution of infrastructure to society is estimated by including in the cost-benefit analysis the economic value of both loss in ecosystem services (in the case of built infrastructure) and the gain in ecosystem services (in the case of nature-based infrastructure). This information (eg. including the health cost from air pollution, cost of water pumping from reduced water flow) is also used to inform policy (eg. payment for ecosystem services) and project financing (eg.

determining the roles and responsibilities of public and private actors in a Public Private Partnership, PPP agreement).

For impacts of production and use - the consideration of the externalities of infrastructure assets may lead to a very different interpretation of the contribution of various types of infrastructure to development. It would highlight that many types of built infrastructure carry more costs, and generate more revenues than expected. Similarly, nature-based infrastructure costs less than expected and generates more value that currently considered.

In summary SEEA EA can support the improvement of infrastructure models with:

- New and standardized data inputs based on an integrated statistical framework.
- Improved equations (improved understanding of dynamics) for the impacts of infrastructure on the environment.
- New indicators (extended model boundaries) for the inclusion of the impact of ecosystem services on infrastructure (full feedback loop), including how costs and revenues may be impacted.
- Spatial disaggregation/interpretation of results, making project-level assessments more valid and allowing for the inclusion of environmental considerations in national-level assessments.

Interpretation of results

What would emerge if SEEA EA data are used as indicated above?

- Infrastructure models most often use optimization to find least cost options.
- Including impacts on ecosystem services are likely to generate different results (eg. more expensive infrastructure options that limit the impact on ecosystems may be a preferred option over the cheapest, eg. lowest capex, infrastructure option).
- Infrastructure deals may be structured differently (eg. with a more extensive use of Public Private Partnerships -PPPs-) when the outcomes of infrastructure investments are estimated for all economic actors.
- Adding SEEA EA data to the analysis allows for the estimation of the societal contribution of infrastructure. It is likely that, with these new data and expanded model boundaries it will emerge that the contribution of conventional built infrastructure is being overestimated, and the contribution of natural infrastructure has been underestimated.

Table 11: *Characteristics of infrastructure models, and summary of the potential contribution of SEEA EA (Report authors)*

Model type	Sector/thematic area	Actors	Dimensions of development	Time	Space
Infrastructure	Energy supply, buildings, roads, water supply and treatment, waste management, natural infrastructure	Generally focused on private sector (contracted entity), but may extend to operators (eg. government) and recipients of infrastructure benefits (society, households and private sector)	Primarily economic. May include environmental (eg. deforestation, emissions) and social considerations (eg. access to services, side effects of construction)	Continuous time (monthly, quarterly or annual projections)	Not explicitly included for national assessments, explicitly represented for project-level analysis
Contribution of SEEA EA: **1** - New and standardized data inputs based on integrated statistical model **2** - Improved equations (improved understanding of dynamics) for the impacts of infrastructure on the environment **3** - New indicators (extended model boundaries) for the inclusion of the impact of ecosystem services on infrastructure (full feedback loop), including how costs and revenues may be impacted. Indicators may include water regulation and water purification services, which could impact the performance of assets. Similarly, the impact of infrastructure on ecosystems could be considered, including on land-cover change and ecosystem extent (eg. loss of forest cover) and on ecosystem condition (eg. biomass of natural forest, an indicator of possible forest degradation), but also habitat quality and air filtration. **4** - Spatial disaggregation/interpretation of results, making project-level assessments more valid and allowing to include environmental considerations in national-level assessments					

3.3.10 Nested (or coupled) models.

Nested models couple several models in a unified framework of analysis. Combining existing models allows for a more holistic consideration of policy outcomes, or simply for the creation of more realistic scenarios of action and inaction. This is because coupling thematic models allows for the introduction of feedback mechanisms, non-linearity and delays - features that may not be captured in each (or any) of the individual models. On the other hand, nested models are complex to use and require advanced modelling skills, in addition to knowledge of various sectors and domains. This is one of the main drawbacks of nested models, in addition to the complexity underlying the integration of different models in the same framework of analysis (eg. different methods for solving equations may be used, and some models may be spatially explicit while others may only provide aggregate estimates at national level).

Among nested models, *Integrated Assessment Models (IAM)* are very commonly found for the creation of climate forecasts. These models account for feedbacks in the environmental sectors, but often lack detail and dynamics in their social and economic modules (Evans & Hausfather, 2018).

IAMs often are nested models and are based on partial equilibrium modules primarily driven by land and energy use, but can also include general equilibrium models for the economy.

Examples:

A key feature of the IPCC's Special Report on Emissions Scenarios (SRES) was the use of different methodologies and models for the development of scenarios. In total 40 scenarios were generated. The IPCC used six different models for generating the emissions projections. According to the IPCC (2018a), the models used for generating the SRES assessment are:

- **(i)** The *Asian Pacific Integrated Model (AIM)* from the National Institute of Environmental Studies in Japan
- **(ii)** *Atmospheric Stabilization Framework Model (ASF)* from ICF Consulting in the USA
- **(iii)** *Integrated Model to Assess the Greenhouse Effect (IMAGE)* from the National Institute for Public Health and Environmental Hygiene (RIVM)
- **(iv)** *Multiregional Approach for Resource and Industry Allocation (MARIA)* from the Science University of Tokyo in Japan
- **(v)** *Model for Energy Supply Strategy Alternatives and their General Environmental Impact (MESSAGE)* from the International Institute of Applied Systems Analysis (IIASA) in Austria
- **(vi)** *Mini Climate Assessment Model (MiniCAM)* from the Pacific Northwest National Laboratory (PNNL) in the USA

The six models applied for generating the scenarios are representative of the different approaches and integrated assessment frameworks used for emissions modelling. All of them include both top-down (macroeconomic) and bottom-up (systems-engineering) models (IPCC, 2000).

Rezai and van der Ploeg (2017) calibrated an IAM for the analysis of climate change mitigation policies. Their analysis focuses on investigating "how well a second-best Markov-perfect optimal subsidy for renewable energy production performs in the absence of a carbon tax in the decentralized economy" (Rezai & Van der Ploeg, 2017). Characteristics of their model, an IAM of growth and climate change, include stock-dependent fossil fuel extraction costs, structural change, and advances in technological progress.

The "Road to Dawei" project involves the construction of a road link from Bangkok (Thailand) to Dawei (Myanmar), across the highly biodiverse Dawna Tenasserim Landscape (DTL), and it was conceived under the framework of the "Dawei deep-sea port" project. Three methodologies were used by the World Wildlife Fund for Nature (WWF) to assess the outcomes of the "Road to Dawei" project in the DTL, all supported by data collection and surveys. In particular, the study was realized using the following approach (Bassi et al., 2014): (1) *InVEST*, to generate spatial information and estimate changes in natural capital stocks and ecosystem services, eg. carbon sequestration by forests; (2) the information produced by *InVEST* was coupled with a socioeconomic analysis in order to create the map of the system (or Causal Loop Diagram) and to identify the main drivers and impacts of land-use change in the DTL region; (3) the *Integrated Planning for Sustainability – Road Infrastructure (IPS-Road)* model was developed using the *system dynamics methodology (Green Economy Model -GEM-)*[12] and coupling it with *InVEST* to incorporate the key drivers of land-use change and impacts in a single framework of analysis. The result of the simulations generated with the System Dynamics model (eg. on green economy interventions) was then fed back into *InVEST* to visualize spatially the indirect and induced social, economic and environmental impacts of road construction. Simulation results highlighted the potential for growing deforestation in the future, well beyond the short-term impact of road construction and access to market. This is due to the progressive degradation of the environment, which results in reduced ecosystem services and ultimately lower land productivity and water availability. This degradation triggers commercial farmers to buy more land and relocate to more productive areas, leaving local farmers with degraded land and limited options and means to invest (Bassi et al., 2014).

The Flexible Ocean and Climate Infrastructure (FOCI) model[13] couples the ECHAM6.3 atmosphere model to the NEMO3.6 using the OASIS3-MCT coupling software. The coupled model allows for refining the ocean grid to resolve the meso-scale in an area of interest (Harlaß, 2018). The nested approach allows for a range of features such as multi-decadal and centennial simulations with an eddying ocean. The model reduces some long-standing biases in climate models related to sea surface temperature (SST); while northern Atlantic SST in climate modes is usually underestimated, the SST in the equatorial tropical Atlantic are overestimated. Increasing the ocean grid resolution in the FOCI model seems to reduce both biases, especially the North Atlantic cold bias.

Potential structural improvements with SEEA EA

Nested models link economic performance to resource use and the state of the environment. Often these models include feedback loops between natural resource availability and economic performance. Through the use of optimization or simulation, nested models generate forecasts taking into account the interrelations existing between the economy and the environment, but often miss (i) the contribution of ecosystem services to productivity and production, and (ii) the economic valuation of ecosystem services.

There are several ways in which SEEA EA data can improve model formulations, both to improve forecasts for economic performance and for estimating the impact of economic activity, resulting energy, water and land use on ecosystem condition and ecosystem services. Being nested models

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[12] See: https://www.unep.org/explore-topics/green-economy

[13] See: https://gmd.copernicus.org/articles/13/2533/2020/

an aggregation of existing sectoral models, most of the opportunities mentioned below have been proposed for other models as well:

- **Extent:**
  For production – this data can inform the estimation of whether the land resources and ecosystems required to maintain and expand economic production are available, indicating whether land-related constraints may emerge in the future. Most nested models make use of a land-cover/land-use module, as well as the availability of maps generated at the national level which are already validated by various stakeholders, to increase the accuracy of the analysis. Alternatively, the availability of SEEA EA data can facilitate the inclusion of land-cover/land-use and ecosystem extent modules where missing.
  For impacts of production – as indicated for CGE and macroeconometric models, the inclusion of new variables on land use and ecosystem extent can support the estimation of the impact of economic production on land cover, and as a result on potential changes in the condition of ecosystems and provisioning of ecosystem services.
- **Condition:**
  For production – this data can support the estimation of the economic productivity of land, allowing for the improvement of models to transition from the use of a proxy approach to a process-based one. Further, a better estimation of ecosystem condition can highlight other potential constraints to production, or the emergence of unexpected costs, such as in the case of reduced water quality (limiting water use or requiring treatment).
  For impacts of production – new variables could be added to the model that indicate environmental pressures emerging from activities that affect condition but not extent (eg. land management practices, logging practices).
- **Ecosystem services:**
  For production – including ecosystem services in various modules of nested models could strengthen the assessment of productivity of economic activities and ecosystem contribution at the sectoral level, as discussed for macro models. This could be done by estimating resource availability and ecosystem services, thereby influencing production directly or indirectly (eg. through energy and water provisioning, potential road disruption due to floods). The spatially explicit nature of ecosystem service provisioning is likely to improve the accuracy of the model in representing the link between environment and economy. Depending on the economic model used, this could be introduced through the use of "productivity shocks", or by changing efficiency parameters for infrastructure (eg. load factors for power generation) based on the location of ecosystem services and economic

activity or infrastructure (eg. sea level rise impacts on infrastructure and tourism, as well as on groundwater salinization and agriculture productivity).

- **Economic valuation:**
  For production – the integration of ecosystem service valuation in the economic model would change the economic performance of the sectors that rely on specific ecosystem services (eg. a productivity decline may be assumed when a lost ecosystem service needs to be replaced with built infrastructure, with the cost of infrastructure being used to determine the strength of such productivity decline). With changes to productivity and profitability, the outcomes of the optimization of the model would change, favouring sectors that are less reliant on ecosystem services or showing the importance of investing in maintaining ecosystem integrity.

In summary SEEA EA can support the improvement of nested models with:

- New and standardized data inputs based on an integrated statistical framework.
- Improved equations (improved understanding of dynamics) for the inclusion of ecosystem services in the model.
- New indicators, not necessarily extended model boundaries, but likely a better representation of the interconnections between models or thematic areas (eg. food, energy, water nexus), better representation of dynamic complexity.
- Spatial disaggregation/interpretation for all the thematic areas covered in the model.

Interpretation of results

What would emerge if SEEA EA data are used as indicated above?

- If nested models are solved using optimization, it is likely that their results will change, as discussed for sectoral models. If econometrics is used, model results are likely to change if model formulations are modified (eg. to modify the estimation of economic performance, taking into account the contribution of ecosystem condition and ecosystem services).
- Policy suggestions would likely change as well, when the costs (or productivity impacts) resulting from environmental degradation are added to the model.
- Further, when the boundaries of nested models are expanded, also including spatially explicit modules, the assessment of impacts across a broader range of output indicators would improve (eg. covering more SDGs in policy analysis).

__Table 12:__ Characteristics of nested models, and summary of the potential contribution of SEEA EA (Report authors)

Model type	Sector/thematic area	Actors	Dimensions of development	Time	Space
Nested models	Various sectors (primarily, energy-economy, economy-land)	Economic flows for public and private sector, households, banks and rest of the world, sectoral dynamics for specific economic actors	Social, economic, environmental	Depending on the methods used: snapshot (optimization) or continuous time (monthly or annual projections)	Not explicitly included for most national models, explicitly represented for some subsectors (eg. water, land-use and agriculture production)
Contribution of SEEA EA: **1** - New and standardized data inputs based on integrated statistical framework **2** - Improved equations (improved understanding of dynamics) for the inclusion of ecosystem services in the model **3** - New indicators, not necessarily extended model boundaries, but likely a better representation of the interconnections between models or thematic areas (eg. food, energy, water nexus), better representation of dynamic complexity. One example is the potential estimation of income, including environmental dimensions more explicitly, along the lines of the "GDP of the Poor" indicator (Sukhdev et al., 2015). **4** - Spatial disaggregation/interpretation for all the thematic areas covered in the model					

3.3.11 Integrated Models

Built by design as integrated models, these are generally less detailed at the sectoral level but include cross-sectoral feedback loops (horizontal integration). Integrated models also solve issues with computation, where all models use the same characterization of time (eg. same time-step with semi-continuous time), harmonized spatial representation, and approach for solving equations (eg. in most cases simulation). Integrated models are most often used as a complement to more detailed sectoral and thematic models. They provide an overview of the impacts across sectors, economic actors and over time, primarily supporting development planning across domains (eg. in the context of green economy, green growth, climate adaptation, circular economy).

Threshold 21 (T21) or *iSDG* is a system dynamics model designed to support comprehensive, integrated long-term development planning at the national level (Millennium Institute, 2005). *T21* integrates economic, social, and environmental factors in its analysis, thereby providing insight into the potential impact of development policies across a wide range of sectors, and revealing how different strategies interact to achieve desired goals and objectives.

The *Green Economy Model (GEM)* (see Figure 23) is a decision-support tool for assessing policy outcomes across sectors, actors, dimensions of development and over time (Bassi, 2015). It is a system dynamics model created to perform green economy assessments, and hence customized at the country level to include key sectoral indicators of performance in any given geographical and cultural context. *GEM* captures built, social, human and natural capital, and can estimate "green GDP" and national wealth. It can also carry out an economic assessment (with an integrated cost-benefit analysis) of each of the policies or investments assessed. *GEM* has been applied at provincial (eg. five provinces in Indonesia), national (in more than 30 countries) and regional/global level. Several applications include coupling with land-cover and ecosystem service models (eg. *InVEST*).

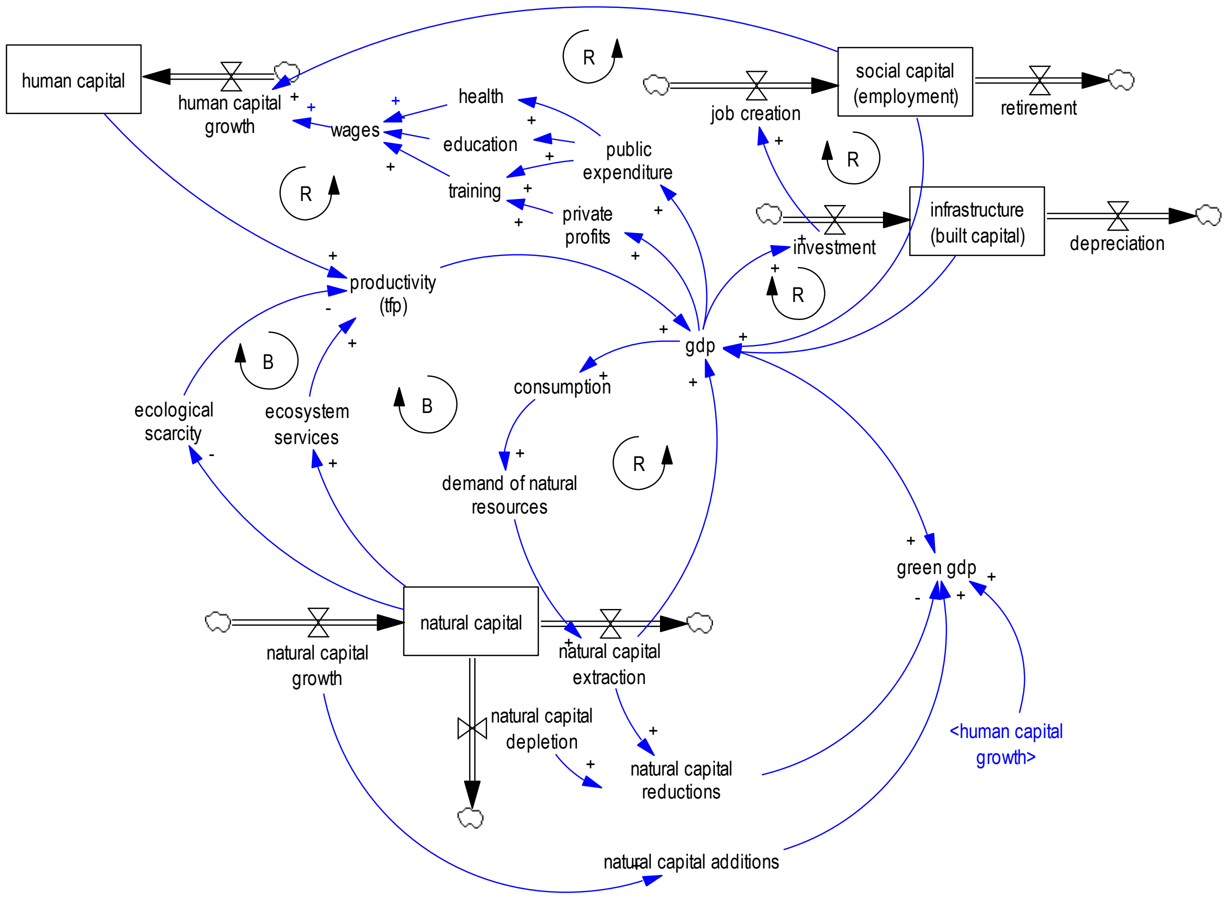

Figure 23: *Overview of the underlying structure of GEM, including built, social, human and natural capital (Bassi, 2015)*

Integrated Futures (IFs) is a large-scale integrated modelling system that was developed to mainly serve as a thinking tool for the analysis and exploration of various near to long-term development trajectories (Hughes et al., 2004). The tool allows for exploring the human leverage in the pursuit of specific goals (eg. human development, social capacity for fairness/peace, sustainable material well-being, and others) for a time horizon of up to 100 years. In essence, *IFs* assist with (i) understanding the state of the world and how different development trajectories materialize over time, and (ii) thinking about the future that we would like to see.

PoleStar is a comprehensive multiple-scale integrated sustainability-planning tool that can be customized according to the users' needs (PoleStar Project, 2019). *PoleStar* was launched by the Tellus Institute and the Stockholm Environment Institute in 1991 with the ambition to support the development of methods for sustainability assessments and conducting collaborative analyses. The *PoleStar* system was developed to conduct long-range scenario analysis and hence allows for the exploration of a wide range of different futures.

Examples

The *South-Africa Green Economy Model (SAGEM)* is based on the *T21* model and was specifically designed for green economy planning (Bassi, 2009; UNEP, 2013). *SAGEM* integrates information from the social, economic and environment sectors, which allows for analysing how these sectors interact and affect each other. Furthermore, capturing these interconnections allows for assessing cross-sectoral policy impacts and hence contributes to the alignment of policies within and across governmental units. The model was used to simulate various green economy scenarios to explore the impacts of sustainable development interventions on key socioeconomic (eg. GDP, employment, energy demand) and environmental indicators (eg. land use, emissions, invasive alien species) (UNEP, 2013).

The *Indonesia Green Economy Model (I-GEM),* the *Province of Kalteng Green Economy Model (KT-GEM*) and the *Province of Jakarta (JK-GEM)* illustrate the customizations of the *GEM* to national and provincial contexts respectively (Bassi, 2015). Bassi (2015), subsequently describes results and implications of *GEM* applications in Indonesia, Mauritius, Cambodia, and Mozambique. In all cases, the *GEM* was customized to the national context and applied for generating projections of future developments, based on which an integrated analysis and evaluation of policy options was performed.

Moyer and Bohl (2018) implement three "Roads from Rio+20" pathways to reach the SDGs (technology, lifestyle change and decentralized governance) within the IFs model to explore whether nine human development related SDGs can be achieved by 2050. The results are based on comparing multiple scenarios, each with different underlying assumptions, to a baseline scenario (Moyer & Bohl, 2018). They find that the integrated implementation of these three policies leads to achieving 63 per cent of targets by 2030 and 89 per cent of targets by 2050, which suggests that additional policies are required for realizing the outlined ambitions. Such policies would address the broad challenges of socio-economic and human development, as indicated in the SDGs concerning health, education, income, and gender equality.

Raskin et al. (2010) use the *PoleStar* system to explore different pathways to sustainability considering four contrasting scenarios for the 21st century. The *PoleStar* system was used because it allows for detailed exploration of full spectrum integrated long-range scenarios while allowing for alternative trajectories and structural discontinuity (Raskin & Rosen, 2010). They nuance their findings based on these four scenarios, from potential socioeconomic descent to the possibility of a great transition through which a civilization of enhanced human well-being and environmental resilience can be achieved.

Potential structural improvements with SEEA EA

Integrated models are made of several sectoral modules, tightly interconnected with one another. While these models provide a systemic view across dimensions of development, they often lack the detail that is found in sectoral and nested models. In other words, through simulation or econometrics, but at times also optimization, these models prioritize horizontal versus vertical integration.

There are two main ways in which SEEA EA data can improve model formulations, both by (i) adding detail to environmental modules and (ii) expanding the interconnections between the environment and social and economic performance. Further, SEEA EA can add a spatial dimension to the integrated models. Specifically, SEEA EA accounts can support improving integrated models as follows:

- **Extent:**
  For production – this data can add spatially explicit information to the model and inform the estimation of whether the land resources and ecosystem extent required to for economic production are either available or could constrain economic activity.
  For impacts of production and demographics – the inclusion of new variables on land use and ecosystem extent can improve the estimation of requirements on land and ecosystems in the future, based on population growth (for settlement land), food requirements (for agriculture land) and resulting impacts on forest and fallow land.
- **Condition:**
  For production – this data can support the improvement of model formulations (most integrated models are causal-descriptive and process-based) for the estimation of the economic productivity of land, water supply and quality, forest quality (eg. tree density). A better estimation of ecosystem condition can support the estimation of growth opportunities for tourism, or for primary activities (farming, fisheries and forestry).
  For impacts of production – new variables could be added to the model that indicate environmental pressures emerging from activities that affect condition but not extent (eg. land management practices, logging practices).
- **Ecosystem services:**
  For production – as indicated for other economic models, including ecosystem services into

integrated models could strengthen the assessment of productivity from economic activity and ecosystem contributions at the sectoral level. The spatially explicit nature of ecosystem service provisioning will improve the accuracy of this calculation, by allowing to "weigh" impacts based on location. This could be done by expanding the definition of productivity in the model (eg. considering air emissions, water quality, reliability of energy supply and access to markets, in addition to considering energy prices, education, health and technology improvement).

- **Economic valuation:**
  For production – as in the case of nested models, the integration of ecosystem service valuation in integrated models will change the economic performance of the sectors that rely on specific ecosystem services (eg. a productivity decline may be assumed when a lost ecosystem service needs to be replaced with built infrastructure, with the cost of infrastructure being used to determine the strength of such productivity decline).

In summary SEEA EA can support the improvement of integrated models with:

- New and standardized data inputs based on an integrated statistical framework.
- Improved equations (improved understanding of dynamics) with stronger behavioural and structural validation of the model for the estimation of ecosystem services.
- New indicators, not necessarily extended model boundaries, but likely a better representation of the interconnections between models or thematic areas (eg. food, energy, water nexus), better representation of dynamic complexity.
- Spatial disaggregation/interpretation for all the thematic areas covered in the model.

What would emerge if SEEA EA data are used as indicated above?

- If integrated models use simulation or econometrics to solve equations, results are going to change if model formulations are changed or if parameters are updated (eg. from the use of spatially explicit data inputs from SEEA EA or from the integration of spatially explicit modules). Major changes in results should not be expected, but rather more accurate results. If integrated models are solved using optimization, their results will change if the objective function is improved or if productivity shocks are introduced.
- Model outcomes when SEEA EA data are considered are likely to show that, in a business as usual scenario, the sectors that rely the most on ecosystem services are going to perform comparatively more poorly. This is due to the loss of ecosystem services and highlights the importance of resource efficiency, ecosystem restoration and conservation.

- The policy options considered in the model, as well as policy suggestions, would change as a result. In this respect, it is likely that models will be able to show the value of complementary policy interventions (as part of a policy package) that are designed to achieve stated growth targets and to avoid emerging environmental trade-offs.
- As in the case of nested models, when the boundaries of integrated models are expanded or extra detail is added on the ecosystem extent, condition and services, the assessment of impacts across a broader range of output indicators would improve (eg. covering more SDGs in policy analysis).

Table 13: *Characteristics of integrated models, and summary of the potential contribution of SEEA EA (Report authors)*

<table>
<tr><th>Model type</th><th>Sector/thematic area</th><th>Actors</th><th>Dimensions of development</th><th>Time</th><th>Space</th></tr>
<tr><td>Integrated models</td><td>Various sectors</td><td>Economic flows for public and private sector, households, banks and rest of the world, sectoral dynamics for specific economic actors</td><td>Social, economic, environmental</td><td>Continuous (or semi-continuous) time (monthly or annual projections)</td><td>Not explicitly included for most national models, explicitly represented for some subsectors (eg. water, land use and agriculture production)</td></tr>
<tr><td colspan="6">Contribution of SEEA EA:
1 - New and standardized data inputs
2 - Improved equations (improved understanding of dynamics) with stronger behavioral and structural validation of the model for the estimation of ecosystem services
3 - New indicators, not necessarily extended model boundaries, but likely a better representation of the interconnections between models or thematic areas (eg. food, energy, water nexus), better representation of dynamic complexity. As an example, the inclusion of both regulating services and provisioning services could inform planning for climate adaptation and improved resilience, emphasizing the role of stocks over flows in determining medium and long term sustainability.
4 - Spatial disaggregation/interpretation for all the thematic areas covered in the model</td></tr>
</table>

Box 1: *Complementary tools and approaches used to inform and/or evaluate scenarios*

A *Cost-Benefit Analysis* (CBA) is a systematic process for calculating and comparing benefits and costs of a given decision, and it is based on assigning a monetary value to all the activities performed (either as input or output). Different CBA techniques are commonly used to evaluate the feasibility and profitability of business strategies and projects, as well as (in some cases) public policy interventions. These techniques generally compare the total investment required for the implementation of the strategy/project against its potential returns. Among the most CBA techniques utilized, it is worth mentioning the payback period, net present value, internal rate of return and cost/benefit ratio.

Companies and policymakers may also use alternative techniques to assess the viability of investments, including, for example, *Cost-Effectiveness Analysis* (CEA) and *Multi-Criteria Analysis* (MCA). A CEA is a form of economic analysis that compares relative costs and outcomes (effects) of two or more courses of action for a given outcome or policy objective. It is broader than a CBA and includes the analysis of non-monetary impacts, evaluated qualitatively, or ranked, for instance, on a meaningful scale (eg. from 1 to 5, or 1 to 100). A MCA is a decision-making process that allows the assessment of different options against a variety of criteria, including quantitative and qualitative indicators. In contrast to CBAs and CEAs, MCAs can be conducted in cases where multiple objectives and criteria exist.

A policy *Impact Assessment* (IA) estimates the impacts of policy implementation across sectors (eg. such as in the case of Life Cycle Analysis -LCA-) and dimensions (eg. social, employment, economic, consumption and environmental emissions). Multipliers are generally used for IAs, estimated using historical data. IAs are typically static, and focus on short term analysis.

4 The policy questions scenario analysis can help to answer

4.1. Introduction

The many and varied tools presented in Chapter 2 and 3 of this guidance document all serve the same ultimate goal: to improve decision-making. Models support policymaking by facilitating the comparison of alternative policy interventions to shed light on the likely outcomes of action and inaction. Analysing scenario outcomes does not necessarily provide simple answers, but rather enables discussion via the provision of insights on drivers of change, potential trade-offs and synergies, the magnitude of change, with indications of the level of effort that is required to reach a stated goal (Figure 24). To do so, models have to capture earth systems and human behaviour (eg. socioeconomic dynamics) realistically, and be capable to estimate the outcomes of policy choices across dimensions of development and over time

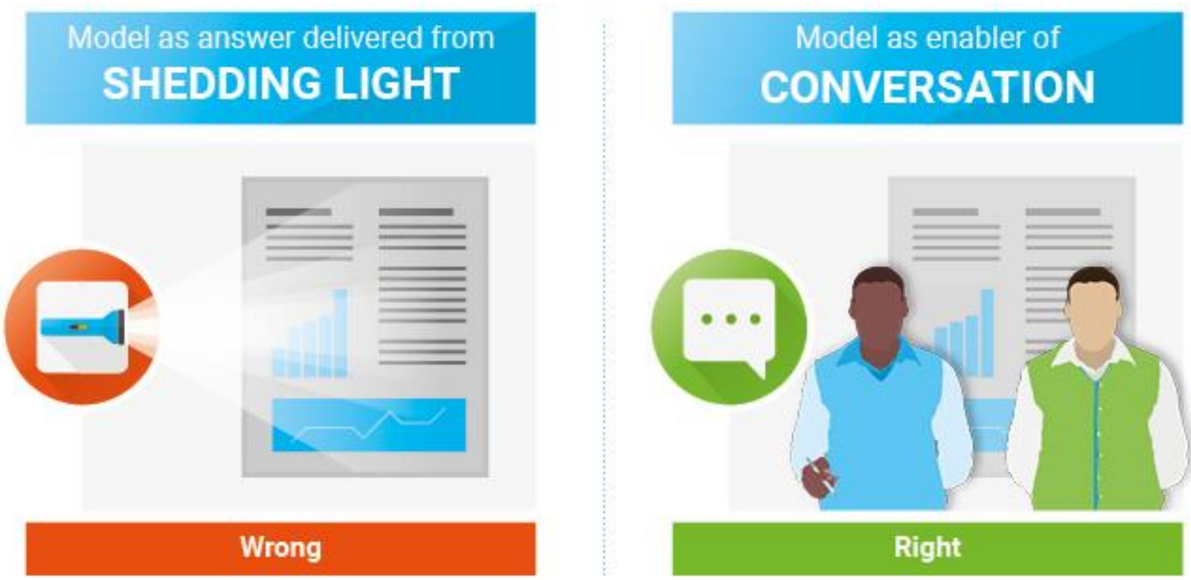

Figure 24: *Models to produce numbers vs models to produce conversation, with the latter being better suited to inform decision-making (IISD, 2019a)*

This section highlights how the use of SEEA EA data can support policy analysis, with examples of modelling exercises that use such data. As indicated above, the starting point of the analysis is a policy concern, which then leads to the review of data, identification of intervention options and the decisions of what models to use to carry out a scenario analysis. The following steps can be identified for the creation of a modelling assessment that includes SEEA EA for policy analysis:

- **Step 1:** identification of the policy issue, and corresponding policy goal.
- **Step 2:** identification of data, from national databases and in SEEA EA accounts that can support a deeper understanding of the issue, its causes and effect.
- **Step 3:** identify possible intervention options (policy formulation stage) to be assessed with simulation models.
- **Step 4:** review available models, assess the extent to which these include relevant variables and corresponding data. This includes a review of SEEA EA data (eg. are these already included in the model?) and the type of policy interventions the model can accommodate (eg. is it possible to simulate a target and optimize investments; is it possible to simulate and incentive and obtain simulated policy outcomes?).
- **Step 5:** customization of the model, to integrate new drivers of change (structural customization) or data (parametrization) and better align the model with the policy analysis needs. At times, instead of customizing an existing model, additional models could potentially be used in synergy with one another.
- **Step 6:** simulate the models and interpret results, assessing both desirable and undesirable policy outcomes, over time.

This section also provides examples of the implementation of the steps mentioned above, on how models that include SEEA or similar data have been used to inform decision-making. The GEO6 (UN Environment, 2019) is used as a starting point, where (i) earth systems, (ii) drivers, (iii) policy options and (iv) policy outcomes are identified (Figure 25).

These four elements should be considered in the context of scenario analysis and simulation due to different reasons: firstly, earth systems, coupled with socioeconomic systems of relevance, are the starting point for model selection. Secondly, drivers are necessary to capture past and future trends correctly, for model validation. Furthermore, policy options are a critical feature of models meaning that they can be used to support the policy formulation and evaluation steps of the decision-making process. Finally, policy outcomes are the results of modelling exercises. These can include expected or unexpected developments, desirable (synergies) or undesirable (side effects) developments.

Outcomes may be an endpoint of modelling, but represent a starting point for decision-making (if trade-offs emerge, new and complementary policies have to be identified, with a new decision-making cycle). The following policy areas, based on biodiversity, land, fresh water, air and oceans earth systems were analysed: climate change, biodiversity loss, air and water pollution, deforestation, and land degradation and desertification. More information on each policy area, including past and future trends and impact on the SDGs, are presented in the next section.

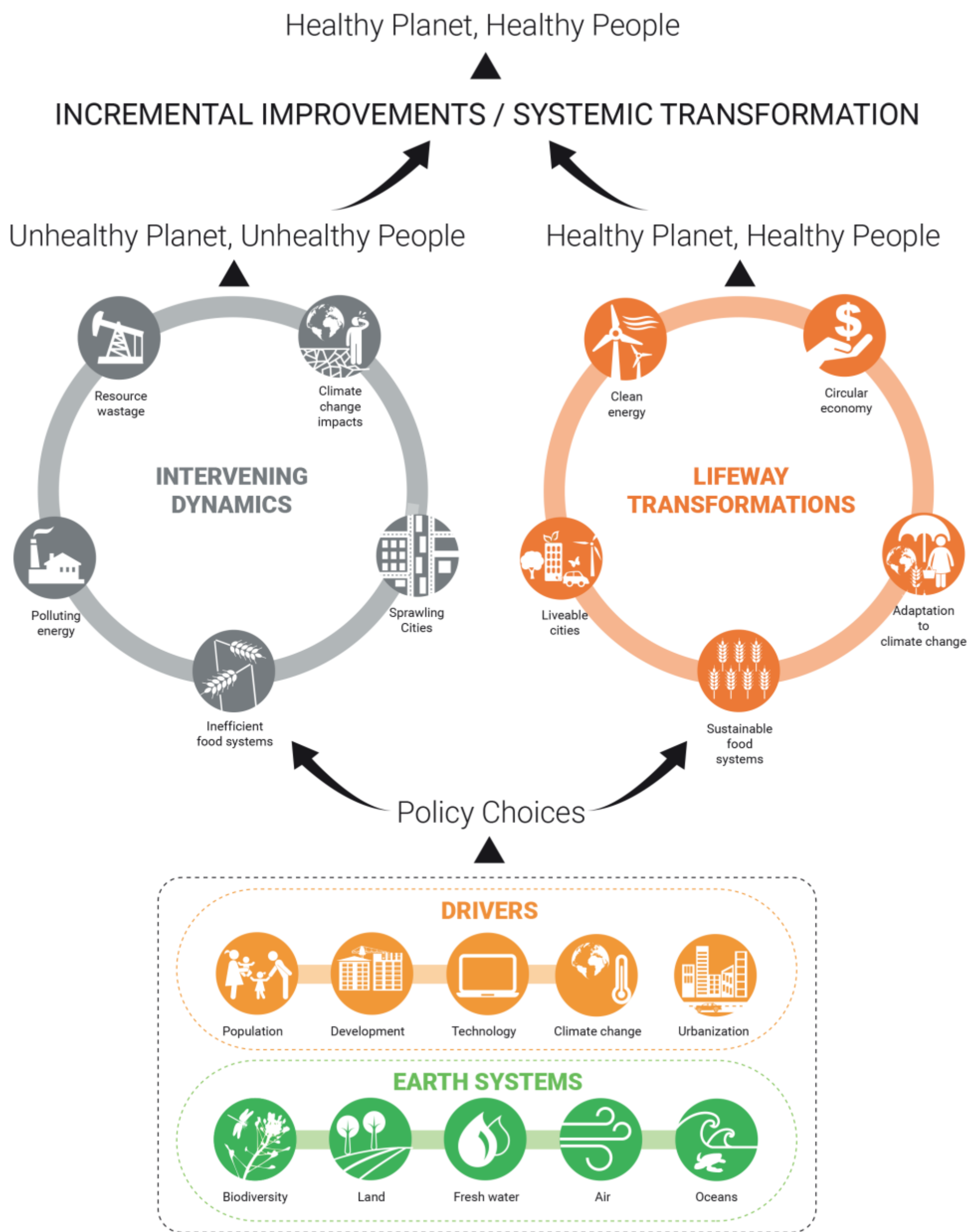

Figure 25: *Choices to be made to achieve a healthy planet for healthy people (UN Environment, 2019).*

Models contribute to policymaking by facilitating the assessment of the likely outcomes of action and/or inaction. The applicability of different types of models depends on context. It is therefore important to determine what policy options can be tested with different types of models, bearing in mind the objective to present policy outcomes within a coherent and validated framework that aid science-based policy discussion.

Some policy intervention options aim at solving or reversing current problems, while others aim at creating new opportunities. According to UNEP, it is possible to group intervention options in four different categories (UNEP, 2011). To begin with, investments would support the introduction of sustainable public procurement (SPP) in order to improve the footprint of public spending and increase investments in sustainable infrastructure (including nature-based infrastructure and green infrastructure in urban areas). Examples include the purchase of sustainable meals for kindergarten and schools, eg. from locally and sustainably grown food. Secondly, incentives and disincentives would be used to remove harmful subsidies, as well as introducing incentives for the use of sustainable practices. Examples include payment for ecosystem services (PES), or payment for performance (P4P), provision of guaranteed collateral for investments by low income families and entrepreneurs, or, as examples in the energy sector, fossil fuel subsidy removal, or the provision of incentives for clean technology and sustainable infrastructure (eg. for improving energy efficiency in buildings) and appliances (eg. with a cash rebate for the purchase of energy efficient refrigerators). Thirdly, the introduction of land-use planning exercises, such as zoning regulations, at national and subnational level that would support the establishment of protected terrestrial and marine areas. Examples can be found that target biodiversity (eg. designating protected spawning areas for the reproduction of fish), ecosystem services related to water (eg. supply, retention, filtration and purification), often in connection with goals related to the creation of a more sustainable tourism sector founded on ecological integrity. Finally, awareness raising programmes would help to organize public campaigns, helping to not only highlight the societal cost of environmental degradation but also create ownership and stewardship for the country's ecosystems, improving school curricula and ultimately supporting professional trainings for environmental literacy.

Different types of simulation models will incorporate the policy interventions mentioned above in different ways. There are generally three options to introduce policy interventions in a model:

(1) With a policy or outcome target in mind, the model is used to determine the changes and related investments necessary to reach such stated targets;

(2) With a “shock” - most often used for the analysis of incentives and disincentives and for the model to determine system responses as a result of the introduction of a time-based policy, and;

(3) With the introduction of specific investments or materials flows (eg. in the case of sustainable public procurement), which then forecast how these complement, replace and ultimately affect future trends.

The combined use of these complementary interventions could result in behavioural changes for various economic actors, including households, private and public sector, as well as the global community of investors. In fact, the outcomes of policies can be far-reaching and go well beyond the sectors in which interventions were implemented. It is possible that, due to ripple effects in the highly interconnected and dynamic socioeconomic and environmental systems that we live in (eg. the relationship between planetary health and human health, Figure 26), all dimensions of development are simultaneously impacted by our actions. If policies are designed to support development and impact many dimensions of development, the framework that is used to assess their outcomes has to be comprehensive. The use of the SDGs are proposed, as the goals and corresponding indicators allow for the assessment of policy outcomes across sectors, economic actors and dimensions of development. Further, the many interconnections existing among the SDGs allow for the identification of emerging synergies and trade-offs.

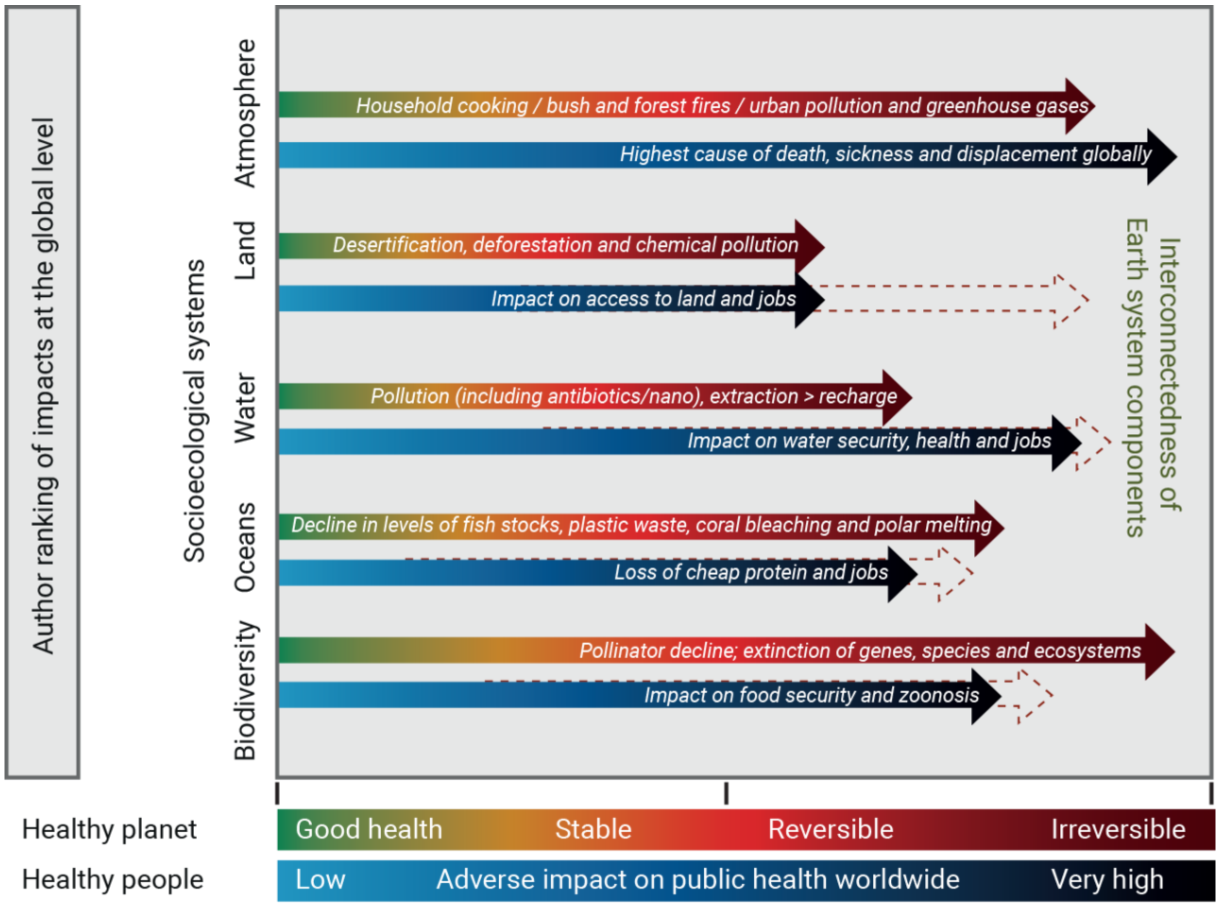

Figure 26: *Relationship between planetary health and human health (UN Environment, 2019)*

Several case studies are presented in the following sections that showcase the use of models that incorporate SEEA or similar data. Five Natural Capital Accounting and Valuation of Ecosystem Services (NCAVES) country projects are analysed in more detail, as these were explicitly designed with the goal to support policymaking with the use of scenarios that incorporate SEEA EA. The contribution of using environmental data in these country projects is explained in relation to (1) model building, in that it supports the interaction between science and policy (see Figure 26); and (2) results and their potential contribution to an informed policymaking process (see Figure 27). Other examples of scenario's analysis are provided to cover a broader set of policy priorities, with a broader geographical scope.

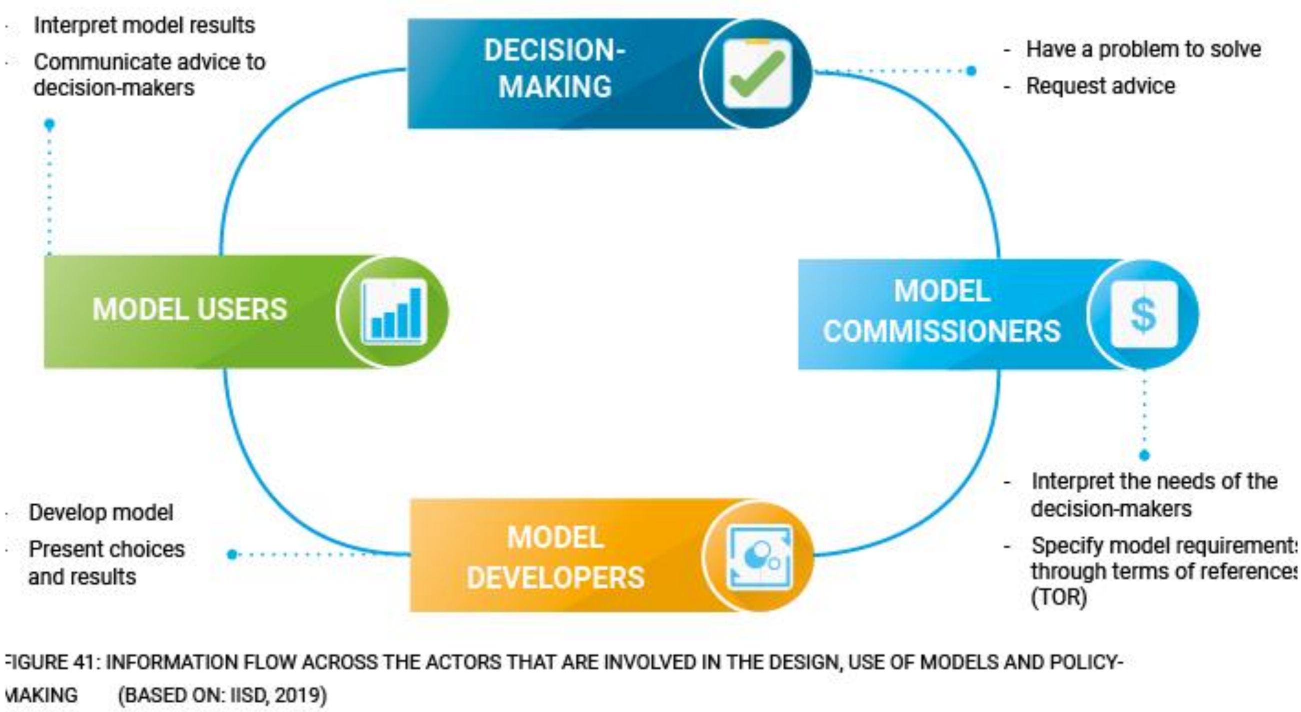

Figure 27: *Information flow across the actors that are involved in the design, use of models and policymaking (IISD, 2019a)*

4.2. Overview of policy areas and related priorities

Above, interventions were categorized following UNEP (2011) into (broadly) (i) sustainable procurement, (ii) fiscal incentives or disincentives, (iii) land-use planning and (iv) awareness raising programmes. Each of these (i) to (iv) are a suite of interventions that *impact on*, directly or indirectly, climate change, biodiversity loss, air and water pollution, deforestation, land degradation and desertification. Each of these areas that are impacted on by policy interventions are discussed below in sections 4.2.1-4.2.4. For each area, causes of policy concern, past and future trends, and connections to sustainable development are presented. The purpose of this section is to provide a broad overview for readers not familiar with environmental policy areas. Readers familiar with this issues may wish to skip to Section 4.3 where case studies of the application of SEEA EA accounts to this issues are presented.

4.2.1 Climate change

Greenhouse gases or GHG such as carbon dioxide and methane are the main drivers of climate change, as they absorb solar radiation in the atmosphere, capturing heat and producing the greenhouse effect (UNFCCC, 2019).

While CO_2 concentration in the atmosphere has increased since the industrial revolution that started around 220 years ago, most of the emissions occurred during the last decades (UN Environment, 2019). In other words, 910 gigatons of carbon dioxide have been released from 1750 to 1970, while 1.090 gigatons of CO_2 have been emitted between 1970 and 2010. Currently, the most relevant sectors that are responsible for GHG emissions are energy supply, industry, transport, and agriculture. Combined, these sectors emitted more than 80 per cent of all greenhouse gases in 2016 (UNFCCC, 2019).

Human-induced climate change will intensify current risks and produce new ones (UN Environment, 2019). Such risks include temperature increase, modification of the water and carbon cycles, ocean acidification, sea-level rise, and melting of polar icecaps to name a few. If the concentration of atmospheric CO_2 will reach 450-600 ppm, global temperature will increase by 2°C from pre-industrial level. As of today, the value of this concentration is 413 ppm in April 2020 according to NASA (2020).

In a 2°C world, extreme events will be exacerbated at the global level: ocean acidity will increase by 24 per cent, the number of hot days by 25 per cent, the frequency of extreme rainfalls by 36 per cent, and the chance of ice-free Arctic summers by 80 per cent (CarbonBrief, 2018). One suggestion that climate-induced loss events are becoming more frequent and severe is given by their rising number in the last decades (Figure 28), with these events being responsible for more than 400.000 deaths and for the loss of 1.6 per cent of global GDP (UN Environment, 2019).

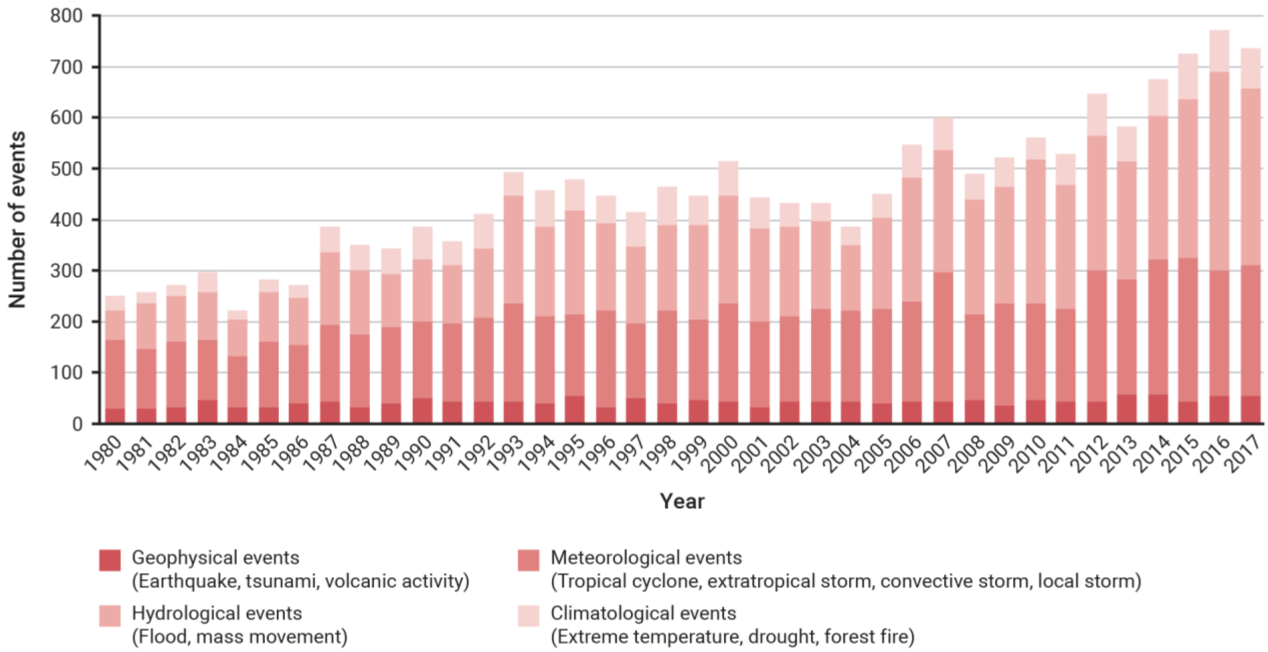

Figure 28: *Frequency of climate-induced disaster events (UN Environment, 2019)*

Climate change affects development. SDG 13 is entirely dedicated to climate action, emphasising adaptation measures in policies and plans. Nevertheless, other SDGs relate to climate adaptation and mitigation, creating interconnections between goals (UNA-UK, 2019). For example, embracing more resilient agriculture practices would allow to address food insecurity, increasing the quality of food production (SGD 2 – zero hunger, and SDG 12 - responsible consumption and production), while mitigation actions would directly curb emissions (SDG 7 - affordable and clean energy) and indirectly improve water quality (SDG 14 – life below water). Furthermore, climate action (SDG 13) would help to save millions of lives by protecting human health (SDG 3 – good health and wellbeing) also by reducing the footprint of the energy sector (SDG 7 - affordable and clean energy). Climate actions would also support economic growth and sustainable development (SDG 8 – decent work and economic growth) with employment creation (green jobs), and sustainable land management is also essential to combat desertification and biodiversity loss (SDG 15 – life on land) (UNCCD, 2018). Women are also found to be detrimentally affected by the adverse environmental effects of climate change, with gender imbalances and hardships magnified as influenced by the ascribed socio-economic structures (Eastin, 2018). Gendered SDG13 action would thereby address the inequalities in achieving economic independence, enhancing human capital, acquiring equal rights and participation, and maintaining health and wellbeing (SDG 5 – gender equality), in the midst of challenges such as out-migration, declining food and water access, and increased disaster exposure (ibid). It results that, as the SDGs are interconnected, the policy areas that are being discussed in this section are also interconnected. This is important to acknowledge, as the policy interventions to be identified and used to solve a specific policy area will impact, positively or negatively, other policy areas as well. The use of an integrated, systemic approach is therefore necessary for policy analysis.

Furthermore, the activities included in National Determined Contributions (NDCs) also highlight other themes that are relevant to other sustainable development, such as SDG 11 (sustainable cities), and SDG 4 (education), in addition to the already mentioned SDG 7 (clean energy) and SDG 2 (zero hunger) (DIE & SEI, 2018).

4.2.2 Biodiversity loss

In 1992 the Convention on Biological Diversity recognized at the international level the importance of conserving biodiversity and the sustainable utilization of its components and services (UN, 1992). Sustainable use, conservation and fair shares are key pillars of the convention that are required to stop and reverse the current reduction rate in the variability of living organisms. It has been estimated that the current rate of biodiversity loss is one thousand times greater than normal, which not only means that global biodiversity is in crisis, but also that we are probably living during the sixth mass extinction event from the beginning of life on Earth (UN Environment, 2019). Pressures on biodiversity are produced by a variety of factors (causal, direct and indirect) that hamper the delivery of essential ecosystem services such as food or climate regulation (Figure 29).

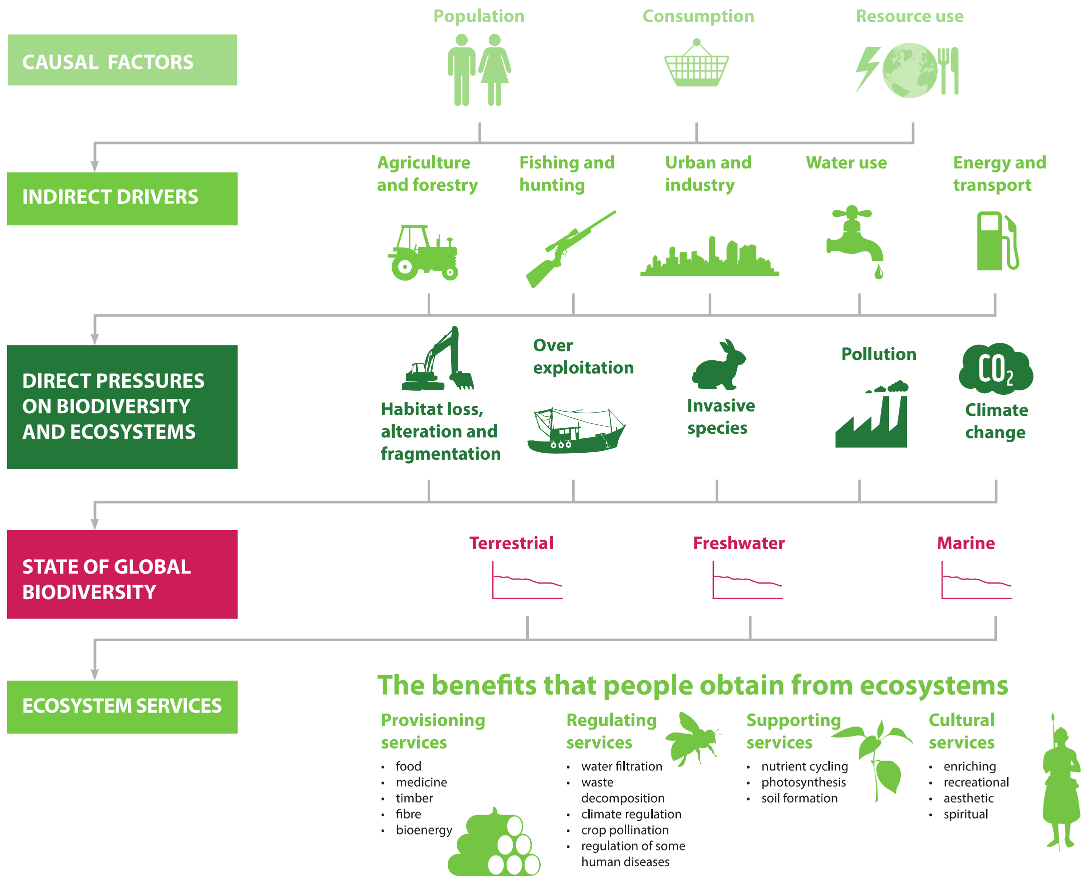

Figure 29: *Drivers of biodiversity loss and delivery of ecosystem services (UN Environment, 2019)*

Species loss has variety of direct and indirect outcomes. For example, some estimations concluded that the reduction of biodiversity affected more than 50 per cent of the agriculture production in the US; this figure increases to almost 100 per cent in South Africa and Brazil (Perrings & Kinzig, 2015). The loss of species within a habitat produces indirect negative impacts, affecting the delivery of ecosystem services such as forest and non-forest products (eg. food, medicinal herbs, fuelwood). This is relevant especially for the livelihoods of 70 per cent of the global population living in poverty since it depends to some extent to the delivery of such services. As women represent the vast majority of the world's marginalised population (making up 70% of the world's chronically poor), women are disproportionately disadvantaged moreso than men, with regards to natural resource degradation and the loss of biological diversity (Bechtel, 2010). Recognising the difference between the use of natural resources by women and men to accomplish their defined roles in the community highlights the necessary address of gendered differences in natural resource access within biodiversity conservation efforts.

Additional undesirable outcomes derive from infectious diseases that can start from the interaction between wildland and farmland, or in other words, from the interaction between humans, farmed and wild animals, caused by factors such as habitat change or degradation, since many diseases are zoonotic (Perrings & Kinzig, 2015). To provide two examples, the SARS pandemic resulted in a total cost of US$50 billion; COVID-19, that as of June 2020 is still underway, is estimated to cost around US$8.8 trillion globally (ADB, 2020).

The Convention on Biological Diversity has identified various linkages existing between biodiversity and the SDGs (CBD, 2018). There is a direct and explicit connection with SDG 14 and 15 (life below water and life on land respectively), as well as indirect ones with SDG 2 (zero hunger), since around three-quarters of crops are pollinated by insects and other animals; SDG 6 (clean water and sanitation) due to the ability of ecosystems to purify water; SDG 7 (affordable and clean energy) in particular biomass delivered by forests; SDG 11 (sustainable cities and communities) whose examples include temperature decrease and reduction of pollutants thanks to ecosystem services; and SDG 12 (responsible consumption and production) since efficient use of resources are essential for the sustainable utilization of biodiversity.

4.2.3 Air and water pollution

Air pollution represents one of the four main human-induced impacts on the atmosphere, whose causes and impacts are interlinked to the other three: climate change, persistent, bio-accumulative and toxic substances, and ozone depletion (UN Environment, 2019). The main sources of air pollution are summarized in Figure 30.

Air pollution can be distinguished in indoor and outdoor pollution. On the one hand, the number of deaths attributable to the former has been halved since 1990, from 2.7 million deaths to 1.6 million in 2017 (Ritchie & Roser, 2019a). This decline has been driven by a steady reduction in indoor fuel in low-income countries, being replaced by modern forms of energy (eg. electricity). However, more than 3 billion people still burn solid fuels indoors for cooking or heating (Cameron, et al., 2016); this practice, which is frequent in low-income countries, also contributes to GHG emissions (Bhojvaid, et al., 2014). Women and children below five years are disproportionally affected as a result of such practices, due to the pollutants released during the burning of bio-fuels in traditional stoves (Parikh et al., 1999). On the other hand, deaths from outdoor pollution have risen from 2 million in 1990 to 3.4 million in 2017 (Ritchie & Roser, 2019b), due primarily to industrialization and growth in the consumption of fossil fuels.

In economic terms, the World Bank estimated that the cost of air pollution amounts to more than US$5 trillion per year (World Bank, 2016). Moreover, it is expected that by 2060 air pollution will be responsible for the loss of 3.6 billion working days per year (OECD, 2016). These costs, which will mainly impact the private sector, derive from reduced productivity and lower capacity of delivering services.

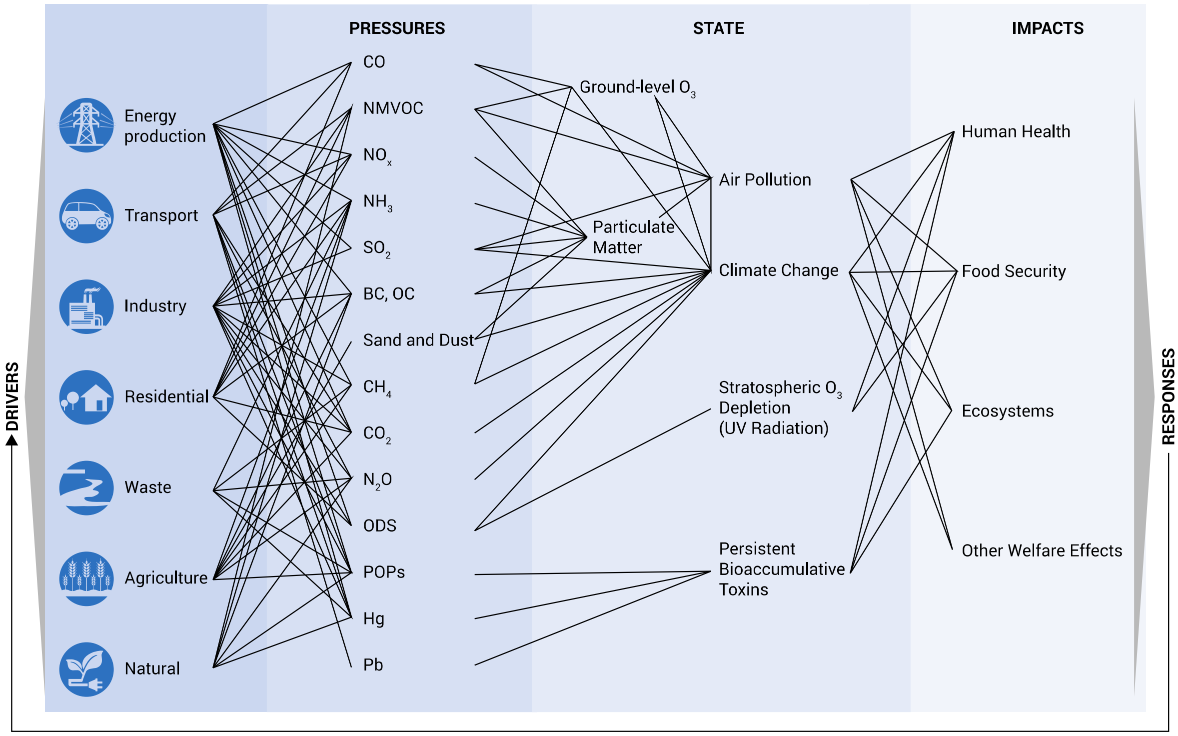

Figure 30: *Sources and impacts of atmospheric change (UN Environment, 2019).*

Combating air pollution can also address various SDGs. A reduction in the concentration of harmful chemicals and substances in the atmosphere a) reduces pollution-linked health impacts such as respiratory disease, thereby lowering the number of premature deaths (SDG 3 – good health and well-being) and b) improves air quality of cities (SDG 11 – sustainable cities and communities). Secondly, it encourages access to cleaner energy (SDG 7 – affordable and clean energy). Finally, due to the close connection with climate change, reducing air pollution would also support SDG 13 (climate action) (Mead, 2018).

4.2.4 Deforestation

Deforestation is one of the main threats to forests (UN Environment, 2019). Wood demand, as well as other drivers such as mining, transportation, agriculture, and urban growth, contribute to the degradation and to the destruction of forests in various regions, especially in tropical and boreal areas. For instance, the tropics accounted for more than 30 per cent of global forest losses between 2000 and 2012.

Global forest cover decreased from 32.5 per cent of total land in 1990 to 30.8 per cent in 2020 (FAO & UNEP, 2020). In other words, a forest area of almost 180 million acres, similar to the size of Libya, has been lost in three decades. Africa and South America have experienced the highest net losses in forest cover in the last three decades, of almost 4 and 2.6 million hectares per year, respectively (FAO & UNEP, 2020). Nevertheless, the global annual deforestation rate has also declined by 40 per cent during the same period, from almost 8 million hectares per year to roughly 4.7 million hectares per year.

Due to the importance of forests in combating climate change, land degradation and desertification, as well as improving the livelihoods of the local population, the Rio Conventions on Biodiversity, Climate Change and Desertification called for increased protection of these ecosystems (UN, 2012). Broader participation of developing economies in promoting sustainable use of forests, as well as reducing their degradation and deforestation would improve the ability of these ecosystems in delivering their essential services.

Forests can deliver essential ecosystem services, such as climate regulation through carbon sequestration, as well as the protection of both soils and water (UN Environment, 2019). They represent around 30-40 per cent of the global surface (Hui, 2017), and they capture around one-third of all anthropogenic emissions each year (Bellassen, 2014). On the other hand, deforestation and forest degradation are leading to a transition where forests may become carbon sources rather than carbon sinks in the not too distant future (UN Environment, 2019).

Forests support livelihoods to more than 1 billion people by providing food, fuel and employment. For instance, around 80 per cent of Africans depend on forests for fuel supply (eg. charcoal) (UN Environment, 2019). An estimated 880 million people worldwide also derive incomes and maintain household livelihoods by collecting fuelwood or producing charcoal, many of them women (FAO & UNEP, 2020). Additionally, the gathering of food, medicinal plants, craft materials, other non-wood forest products and wood fuels also makes up a significant component of contributions by forest-dependent peoples, and particularly women as indicated by the available gender-disaggregated data (ibid). Overall, wood and non-wood products accounted for more than US$220 billion in 2015; at the same time, the contribution of forests to developing economies has been evaluated at US$250 billion (UN Environment, 2019). However, these economic benefits can be maintained only if forests remain intact. Furthermore, forest degradation and loss would also produce health consequences, such as increasing the risk of infectious diseases, including vector-borne parasites like malaria or damaging physical and mental health.

Forests are associated with many Sustainable Development Goals (Whalén, 2019): to begin with, SDG 15 (life on land) defines targets connected with forests, such as contributing to biodiversity. Secondly, by capturing and storing carbon, forests contribute to climate change mitigation (SDG 13 – climate action). Moreover, forests habitats are related to other SDGs such as “no poverty” (SDG 1), since they represent an essential source of income for local populations. Forests are also a source of food, medicinal plants and, shelter from climate hazards such as coastal flooding (SDG 2 – zero hunger, and SDG 3 – good health and well-being) (Whalén, 2019; Hochard, 2019). Thanks to the delivery of freshwater, forests also provide water for irrigation and drinking (SDG 6 – clean water and sanitation) (Hochard, 2019).

4.2.5 Land degradation and desertification

Land degradation and desertification pose several challenges, both for environmental and food security (UN Environment, 2019). Population growth, globalization, urbanization, land grabbing as well as shifting of dietary preferences, are some of the main factors that are negatively impacting land ecosystems, threatening the delivery of essential services such as pollination or hydrological regulation. In particular, food production represents the largest human-induced threats on healthy soils, since it accounts for half of all habitable lands. Climate change is further exacerbating desertification (UNCCD, 2019a). Nearly half of the global population lives in water-scarce regions for at least one month per year and by 2050 this figure could increase to almost 5-6 billion people.

Unsustainable land management practices have been responsible for reducing the global net primary productivity of both agriculture and ecosystem biomass by 5 per cent (IPBES, 2018). In the last 200 years, 8 per cent of soil organic carbon, which is a crucial indicator of soil health, has been lost due to land degradation and desertification; this figure amounts to around 180 gigatons of carbon (Gt C). By 2050, 35 Gt C will be further lost from global soils. The annual cost of these losses that have already been incurred amounts to approximately US$6-11 trillion, or about 10-17 per cent of global GDP. Overall, the livelihood of 3.2 billion people is currently threatened, while it is expected that by 2050 between 50 and 700 million will have to migrate due to land degradation and desertification. Such forecasts consider the impacts of climate change, to which land degradation contributes by emitting around 4 billion tons of CO_2 each year.

Rural populations, where 80 per cent of the poorest live, are threatened by land degradation (UNCCD, 2019b). Land represents an important source of livelihood for rural communities, where 65 per cent are employed in agriculture. However, land degradation would deprive these populations of key services such as food and energy, negatively impacting their income, consumption, and health.

Maintaining and restoring land would support the achievement of several SDGs: “life on land” (SDG 15), since it aims to halt land degradation and desertification (UNCCD, 2018); poverty alleviation through land and ecosystem restoration (SDG1 – no poverty, and SDG 8 – decent work and economic growth), which would also directly involve women as the majority labour force in the rural and small-holder agricultural sector (SDG 5 – gender equality); education, for the improvement of land management practices (SDG 4 – quality education). Restoring land would also support food production and nutrition, improving the health of local populations (SDG 2 – zero hunger, SDG 3 -

good health and wellbeing, SDG 12 - responsible production and consumption). Sustainable land management practices would encourage water efficiency (SDG 6 – clean water and sanitation), as well as renewable energies (SDG 7 – affordable and clean energy). Maintaining and restoring land requires improved and more effective spatial development planning in rural areas as well as in cities, supporting sustainable land use (SDG 11 – sustainable cities and land use). In addition, efficient agroforestry practices would help to combat climate change (SDG 13 – climate action).

4.3. NCAVES Project: experience at country level

The case studies presented next form part of the Natural Capital Accounting and Valuation of Ecosystem Services (NCAVES) project, which was launched in 2017 by the United Nations Statistics Division (UNSD) and United Nations Environment Programme (UNEP) with funding from the European Union (EU).

The NCAVES project aims to assist five participating partner countries to advance the knowledge agenda on environmental and ecosystem accounting and initiate pilot testing of System of Environmental-Economic Accounting: Experimental Ecosystem Accounting (SEEA EA), with a view to improving the management of natural biotic resources, ecosystems and their services at the national level as well as mainstreaming biodiversity and ecosystems in national level policy, planning and implementation. The results of work performed in China and South Africa are presented next.

4.3.1 China

Policy context

The Xijiang River is located in the upper reaches of the Pearl River Basin and is the main tributary of the Pearl River. It originates from the Maxiong Mountain of the Wumeng Mountain Range, and it has a drainage area of 356,000 km2, of which 57.6 per cent is in the Guangxi Zhuang Autonomous Region. The status of the ecosystems in Guangxi plays a crucial role in the development of the Guangxi province, and it is also relevant for downstream regions.

To protect and improve the quality of ecosystems, the Guangxi government has invested large amounts of manpower, material and financial resources in various areas, including water resource conservation, water pollution and soil erosion control. During the past twenty years, the Grain to Green Project has restored over 10 million hectares of forest, also with the goal to reduce soil erosion.

Since 2016, the local government has been implementing new pollution control models for livestock breeding and has invested nearly 3 billion yuan to strengthen pollution control in the Nanliu River

Basin in Guangxi. During 2008 – 2015, the central and local governments issued an investment plan of over 2.7 billion yuan for the control of rocky desertification in Guangxi. In November 2018, the Ministry of Ecology and Environment and the Ministry of Natural Resources approved the “Ecological Protection Red Line Plan”, which covers more than 25 per cent of the area under the jurisdiction of Guangxi.

These investments in ecological restoration and environmental protection have prevented land conversion and, as a result, have created opportunity costs for social and economic development of Guangxi. To sustain economic activity in rural areas, and strengthen stewardship for the environment, the government of Guangxi has introduced eco-compensation practices in many areas, including eco-compensation for the ecological benefit of forest, the control of soil erosion and rocky desertification, the protection and restoration of water environment and the establishment of conservation areas based on the ecological functions provided by the land. On the other hand, the implementation of eco-compensation schemes has not delivered the outcomes expected. Several issues have emerged, both concerning the design and the implementation of such schemes.

This study addresses one of the main challenges faced so far: the calculation of eco-compensation has to be based on the actual ecosystem service provisioning of the area assessed. Only with this approach it is possible to have a more balanced and effective intervention, which prioritizes areas and landscapes that provide (or could provide, when restored) the most benefits. In addition, scenarios are used to support the identification of critical areas that are, and will be at risk, given present and future development strategies and paths in Guangxi and surrounding areas.

Overview of the issue

The implementation of eco-compensation payments has not been effective, for three main reasons.

First, the existing laws and regulations related to eco-compensation are not aligned. There are issues with the definition of roles and responsibilities, with many departments of local administrations being involved simultaneously. It results that, while current rules are well designed in principle, implementation has missed expectations.

Second, existing eco-compensation policies cover only a few selected areas, while demand is broader. These include the Grain for Green Project[14], natural forest conservation, ecological function zone conservation, water resources and water environment protection, mineral resource protection and ecological restoration of mining areas.

[14] Liu, J., Li, S., Ouyang, Z., Tam, C. & Chen, X. Ecological and socioeconomic effects of China's policies for ecosystem services. Proc. Natl. Acad. Sci. USA 105, 9477–9482 (2008).

Third, while there are several differences in biophysical and socioeconomic conditions across regions, as well as for the attributes of specific compensation objects, the existing eco-compensation policies ignore such differences. Practically, the same level of compensation is given for a single object or a single type of ecosystem. This affects investment decisions, and leads to unfair compensation when the investment that is required to qualify for the eco-compensation scheme differs across regions or landscapes.

To further improve eco-compensation schemes and advance the implementation of the eco-compensation policies in Guangxi and in the whole Xijiang River Basin, it is necessary to strengthen the estimation of ecosystem service provisioning. With this information it will be possible to design payment schemes that support a more even distribution of investments, rewarding the most those investing in current and future priority areas, via the use of modelling and scenarios.

Modelling approach: data collection and model development

Taking into account the SDGs and planning priorities of the Guangxi Zhuang Autonomous Region, this study generates future scenarios for land-cover and ecosystem service provisioning. It considers both human activities, and resulting land-cover changes, and climate change impacts on ecosystem service provisioning.

The ecosystem services assessed include water retention, flood mitigation, carbon storage and sequestration, sediment retention and biodiversity conservation. The *InVEST* and *SWAT* models have been used for the estimation of these ecosystem services.

The estimation of required eco-compensation amounts was based on the provisioning of ecosystem services forecasted with *InVEST* and *SWAT*.

Scenarios, and related assumptions

Scenarios include:

a) Business-As-Usual (BAU): the historical trend of land-cover changes from 1995 to 2015 was assumed to continue over the next 20 years (2015-2035).
b) Ecological Protection Priority (ECOL): this scenario focuses on the protection and restoration of forests, grassland and wetlands.
c) Economic Development Priority (ECON): this scenario focuses on economic development, with the expansion of built-up land at the expense of forest, grassland and wetlands.

These three scenarios were simulated using two climate scenarios: RCP4.5, approximating action to realize the Paris Agreement and curb global warming, and RCP8.5, approximating a no-action scenario with no effort to reduce GHG emissions and reduce global warming. In total, six scenarios were considered in the study.

Results of the analysis

Compared to the baseline, the habitat importance index (an index that considers the quality of habitat based on the land-cover extent) under the ECOL scenario increased by 21.82 per cent and decreased by 6.36 per cent in the ECON scenario (Figure 31).

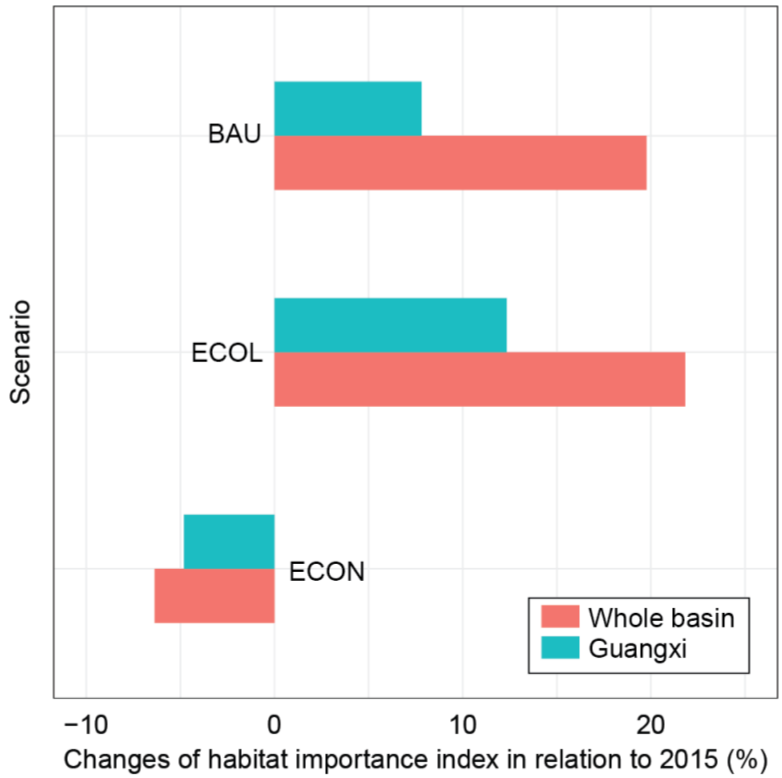

Figure 31: *Changes of habitat importance index under different scenarios (Chinese Academy of Sciences, 2021)*

When specific ecosystem services are considered with the same representative concentration path, the comparison of different land-cover scenarios indicate higher water and sediment retention, as well as higher water purification in the ECOL scenario. The ECON case is instead characterized by higher water yield, as a sign of reduced ecosystem quality (Figure 32).

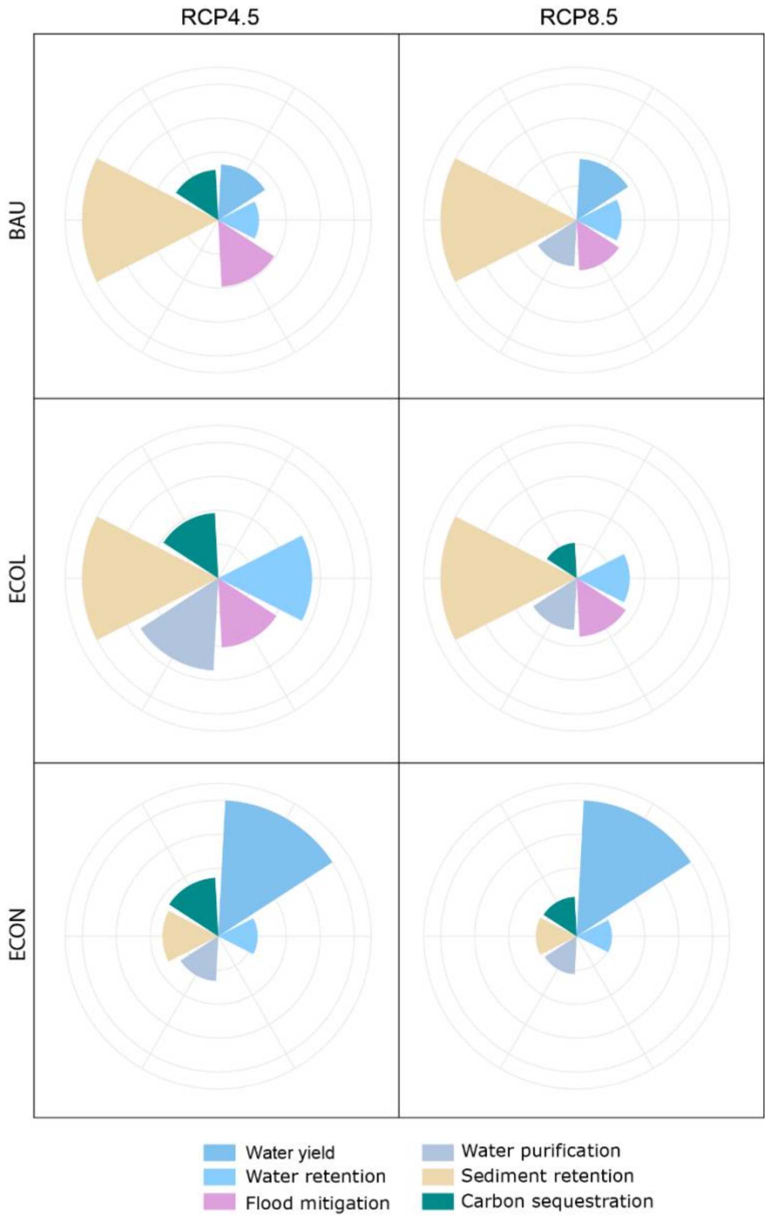

Figure 32: *Proportional changes in the biophysical supply of ecosystem services in relation to the baseline under different scenarios (Chinese Academy of Sciences, 2021)*

Spatial differences were found in the variation of the biophysical supply of ecosystem services under different scenarios, both due to land-cover change and climate change. As an example, under the RCP4.5 scenario, a comparison analysis of different land-cover scenarios indicated that the variations in the biophysical supply of water yield, flood mitigation, water purification, soil retention and carbon sequestration services mainly concentrated in the west and south parts of Guangxi and parts of Guizhou and Yunnan provinces, while the variation in the biophysical supply of water retention service mainly concentrated in the west and north parts of Guangxi and the south part of Guizhou.

When it comes to the economic valuation of ecosystem services, the total value of water yield service under different future scenarios was estimated to be 71.94 – 93.51 billion yuan with a proportional increase of 46.71 – 90.72 per cent as compared to the baseline. The total values of regulating services under different scenarios were estimated to be 208.81 – 593.49 billion yuan for the Xijiang river basin, among which the values of water retention, flood mitigation, water purification, soil retention and carbon sequestration services increased by 47.90 – 390.79 per cent, 36.93 – 331.78 per cent, 65.18 – 395.48 per cent, 50.57 – 386.25 per cent and 50.16 – 321.57 per cent, respectively, as compared to the baseline.

The difference in the type of ecosystem service and the geographical location had great impacts on the distribution of ecosystem service value (Figure 33).

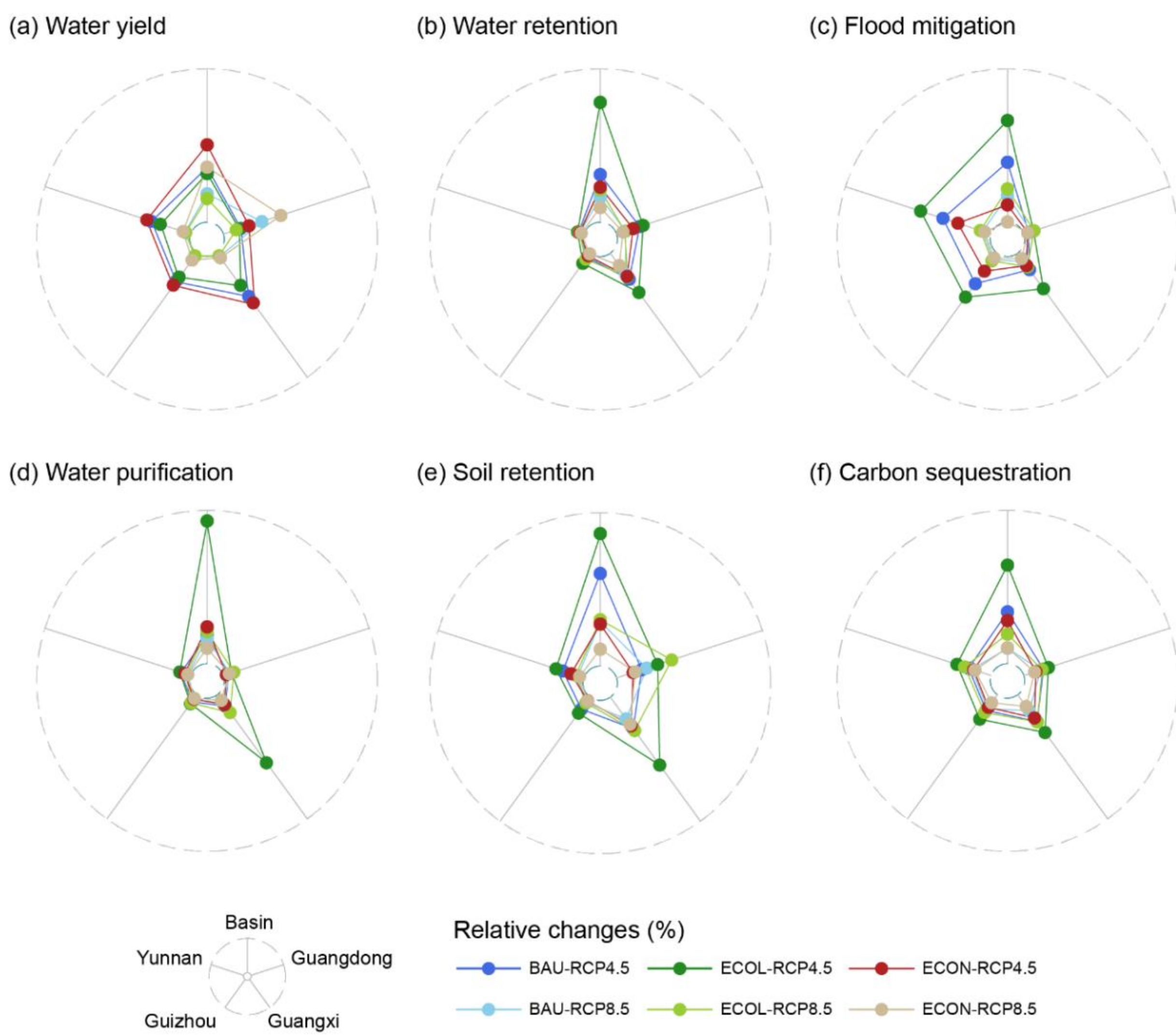

Figure 33: *Changes of ecosystem service value under different scenarios (Chinese Academy of Sciences, 2021)*

Having estimated changes in ecosystem provisioning, and the economic value of ecosystem services, the cost of ecological protection was estimated next (Figure 35). The ecological protection costs were calculated using data related to prevention and control of water pollution, comprehensive treatment of water and soil conservation, forestry conservation and reforestation. As the basis of eco-compensation, the value of the biophysical supply of ecosystem services in the upstream region were determined to estimate the ecological benefits for the whole basin. This is because the downstream region enjoys the ecosystem services provided by the upstream region and is the beneficiary of ecological protection. The upstream region is of course also a beneficiary of the improved ecosystem services realized upstream.

The total cost of ecological protection in the upper reaches of the Xijiang river basin was 53.11 billion CNY, of which the cost of water pollution prevention and control was 25.43 billion yuan, accounting for almost half of the total cost of ecological protection. The costs of comprehensive treatment of water and soil conservation and forestry construction were 11.60 billion yuan and 16.08 billion yuan, respectively, accounting for 21.85 per cent and 30.27 per cent of the total cost of ecological protection, respectively. Among the provinces covered by the basin, the cost of ecological protection in Guangxi was 37.64 billion yuan, which was higher than that in Guizhou (8.90 billion yuan) and Yunnan (6.57 billion yuan).

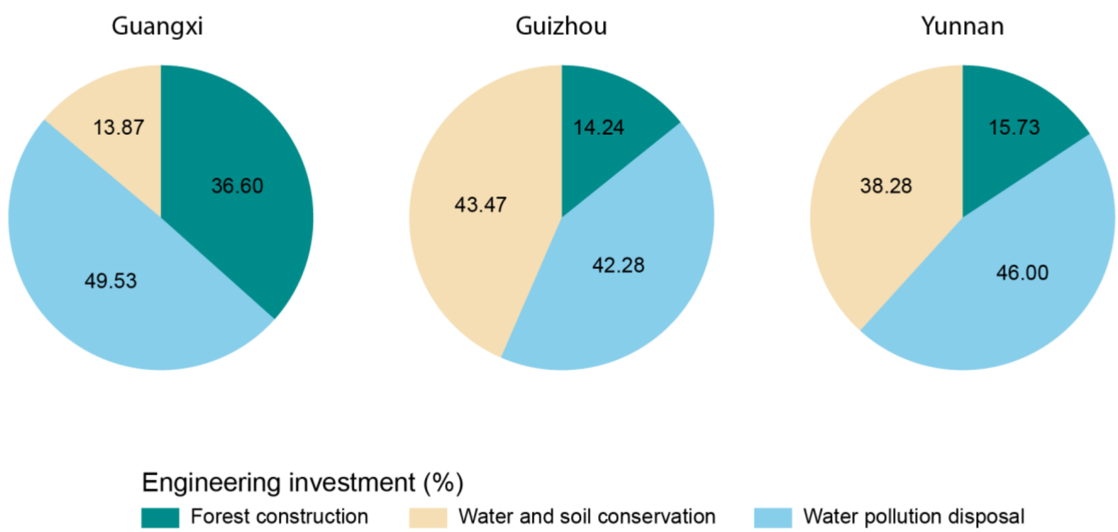

Figure 34:*. Costs of ecological protection in the upstream regions (Chinese Academy of Sciences, 2021)*

In light of the cost of ecological protection, it was estimated that the eco-compensation to be obtained by the upstream regions was 36.76 – 136.00 billion yuan in 2015. Specifically, the eco-compensation was found to be 4.91 – 18.14 billion yuan for water yield, 5.01 – 18.54 billion yuan for water retention, 5.36 – 19.82 billion yuan for flood mitigation, 8.63 – 31.92 billion yuan for water purification, 8.05 – 29.77 billion yuan for soil retention and 4.82 – 17.81 billion yuan for carbon sequestration.

A significant difference was found for the compensation due to the different ecosystem services under different scenarios of future climate and land-cover changes. Generally, compared to the baseline, the upper limit of eco-compensation under the ECOL-RCP4.5 scenario increased by 82.22 per cent, which was higher than those under other scenarios.

The thresholds of eco-compensation varied from region to region, with a relatively higher proportional increase of the upper limit found for Guangxi as compared to that for Guizhou and Yunnan (Figure 35). The proportional increases in the upper limits of eco-compensation in Guangxi were found to be higher for water purification, soil retention and carbon sequestration services as compared to those for other types of ecosystem services, while the greatest proportional increases were found for soil retention in Guizhou and for flood mitigation in Yunnan under the same climatic scenario.

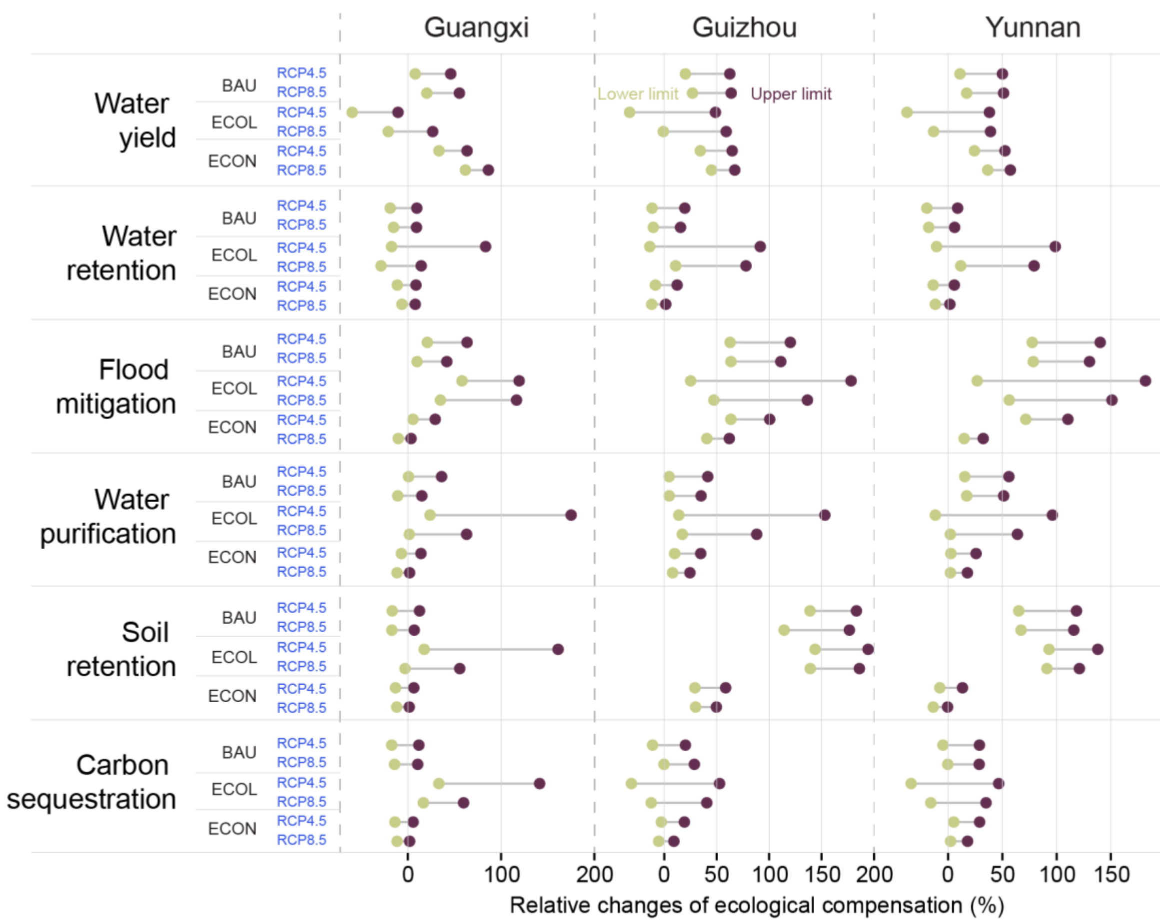

Figure 35: *Changes of eco-compensation thresholds for upstream regions under different scenarios (Chinese Academy of Sciences, 2021)*

Value addition from the use of SEEA EA in scenario analysis

This case study has made extensive use of spatial information and has adopted the SEEA EA to inform the eco-compensation analysis. Specifically, this study generates future scenarios for land cover (Table 14), using SSP scenarios as a starting point, then adjusted to the local context. Forecasts were created for water retention, flood mitigation, carbon storage and sequestration, sediment retention and biodiversity conservation (Table 15). The *InVEST* and *SWAT* models were used to generate ecosystem service forecasts, with land-cover maps used as input for the different scenarios. The estimation of required eco-compensation amounts used the monetary valuation assessment (Table 16), based on the biophysical results presented in Table 13.

Table 14: *Areas and proportion of different ecosystem types under different scenarios of 2035 (Chinese Academy of Sciences, 2021)*

	Area (km²)				**Proportion (%)**			**Changes in relation to 2015 (%)**		
	2015	**BAU**	**ECOL**	**ECON**	**BAU**	**ECOL**	**ECON**	**BAU**	**ECOL**	**ECON**
Forest	**177952**	179636	184366	170520	55.5	56.9	52.7	1.0	3.6	-4.2
Grassland	**27336**	20684	28292	20121	6.4	8.7	6.2	-24.3	3.5	-26.4
Cropland	**90868**	92482	83807	91335	28.6	25.9	28.2	1.8	-7.8	0.5
Wetland	**10118**	11208	12900	10034	3.5	4.0	3.1	10.8	27.5	-0.8
Built-up land	**16237**	17391	13644	28487	5.4	4.2	8.8	7.1	-16.0	75.4
Bare land	**1347**	2457	849	3361	0.8	0.3	1.0	82.4	-37.0	149.5

Note: BAU, ECOL, ECON represent the future scenarios of business as usual, ecological protection priority and economic development priority, respectively.

Table 15: *Physical ecosystem services flow account for Xijiang basin in 1995 and 2015 (Chinese Academy of Sciences, 2021)*

		Ecosystem types				
		Forest	Grassland	Cropland	Wetland	**Total**
1995	**Unit**	**T1.1**	**T2.1**	**T3.1**	**T4.1**	
Provisioning service						
Water supply	10^8 m^3	76.42	715.16	6465.05	65.58	**7322.22**
Regulating services						
Water retention	10^8 m^3	768.23	206.94	3.95	108.47	**1087.59**
Flood mitigation	10^8 m^3	3434.30	668.81	19.75	258.53	**4381.39**
Water purification	10^8 tons	3575.68	236.33	37.58	9.38	**3858.97**
Soil retention	10^8 tons	3749.26	348.92	56.39	29.17	**4183.73**

		Ecosystem types				
		Forest	Grassland	Cropland	Wetland	**Total**
2015	**Unit**	**T1.1**	**T2.1**	**T3.1**	**T4.1**	
Provisioning service						
Water supply	10^8 m^3	225.14	608.65	7675.84	316.18	**8825.81**
Regulating services						
Water retention	10^8 m^3	662.77	204.46	5.88	77.02	**950.13**
Flood mitigation	10^8 m^3	739.00	270.48	16.27	70.36	**1096.11**
Water purification	10^8 tons	5472.56	288.10	89.37	19.75	**5869.78**
Soil retention	10^8 tons	5330.58	326.63	75.78	49.67	**5782.66**
Carbon sequestration	10^8 tons	359.33	8.43	1.22	0.17	**369.15**

Note: Carbon sequestration for 2015 was calculated as the variation in the amount of carbon storage during 1995 - 2015.

Table 16: *Monetary ecosystem services flow account for Xijiang basin in 1995 and 2015 (Unit, 108 yuan) (Chinese Academy of Sciences, 2021)*

	Ecosystem types				
	Forest	Grassland	Cropland	Wetland	**Total**
1995	**T1.1**	**T2.1**	**T3.1**	**T4.1**	
Provisioning service					
Water supply	309.48	2896.42	26183.46	265.62	**29654.98**
Regulating services					
Water retention	3111.32	838.10	16.02	439.30	**4404.74**
Flood mitigation	13908.93	2708.67	79.98	1047.06	**17744.64**
Water purification	35756.82	2363.26	375.76	93.84	**38589.67**
Soil retention	8659.94	805.92	130.24	67.38	**9663.48**

	Ecosystem types				
	Forest	Grassland	Cropland	Wetland	**Total**
2015	**T1.1**	**T2.1**	**T3.1**	**T4.1**	
Provisioning service					
Water supply	911.81	2465.04	31087.14	1280.55	**35744.54**
Regulating services					
Water retention	2684.24	828.07	23.82	311.91	**3848.04**
Flood mitigation	2992.94	1095.43	65.91	284.97	**4439.25**
Water purification	54725.59	2880.96	893.72	197.51	**58697.78**
Soil retention	12543.43	754.44	175.04	114.73	**13587.64**
Carbon sequestration	20616.52	483.71	69.90	9.96	**21180.08**

Note: Carbon sequestration for 2015 was calculated as the variation in the amount of carbon storage during 1995 - 2015.

Table 17: Ecosystem service value account for Xijiang basin in 1995 and 2015 (Unit, 10^8 yuan) (Chinese Academy of Sciences, 2021)

	Ecosystem types				
	Forest	Grassland	Cropland	Wetland	**Total**
1995	**T1.1**	**T2.1**	**T3.1**	**T4.1**	
Provisioning service					
Water supply	309.48	2896.42	26183.46	265.62	**29,654.98**
Regulating services					
Water retention	3111.32	838.10	16.02	439.30	**4404.74**
Flood mitigation	13908.93	2708.67	79.98	1047.06	**17,744.64**
Water purification	35756.82	2363.26	375.76	93.84	**38,589.67**
Soil retention	8659.94	805.92	130.24	67.38	**9663.48**

	Ecosystem types				
	Forest	Grassland	Cropland	Wetland	**Total**
2015	**T1.1**	**T2.1**	**T3.1**	**T4.1**	
Provisioning service					
Water supply	911.81	2465.04	31087.14	1280.55	**35,744.54**
Regulating services					
Water retention	2684.24	828.07	23.82	311.91	**3848.04**
Flood mitigation	2992.94	1095.43	65.91	284.97	**4439.25**
Water purification	54725.59	2880.96	893.72	197.51	**58,697.78**
Soil retention	12543.43	754.44	175.04	114.73	**13,587.64**
Carbon sequestration	20616.52	483.71	69.90	9.96	**21,180.08**

4.3.2 South Africa

Policy context

This study focuses on the catchment area of the Thukela River system (Figure 36), which is one of the least modified catchment areas (in terms of conversion to agriculture or urban land uses) in the province of KwaZulu-Natal, but one in which the geographic extent of the land degradation problems is greatest (Turpie *et al,* 2021, forthcoming). The catchment area is 2.91 million hectares (ha) and occupies about a third of the province. It is largely under grassland and savanna vegetation, with much of this natural land being under communal tenure. The catchment also has several large water supply dams in its higher lying areas.

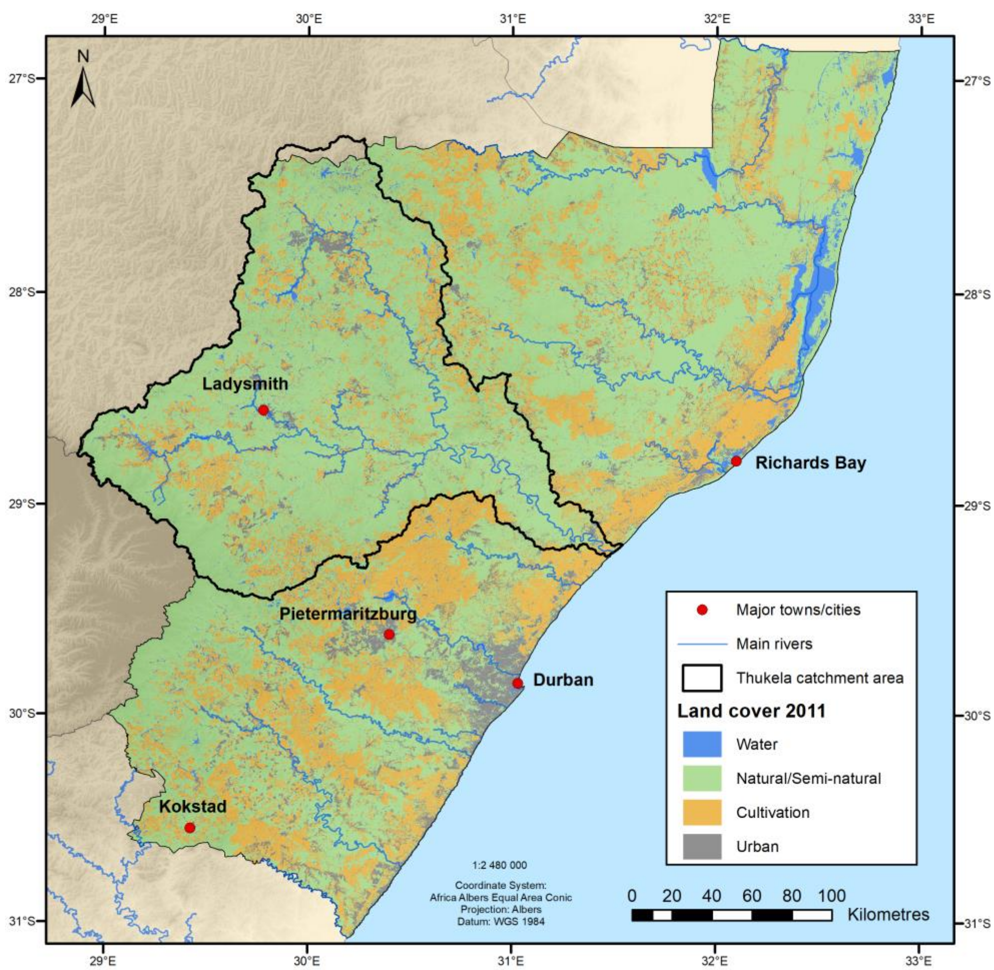

Figure 36: *Land cover map of the Thukela River catchment area (Turpie et al., 2021)*

The national government aims to combat land degradation in the area by removing Invasive Alien Species (IAPs) such as *Eucalyptus sp.* that reduce water flows and negatively impact on ecosystem functioning and provisioning. Moreover, the government also intends to address bush encroachment, erosion rehabilitation as well as farming and livestock management interventions. Since 1995, the Natural Resource Management (NRM) programmes, such as Working for Water[15], have been the main means by which the South African government addresses land degradation. In 2015, South Africa's adoption of the SDG's included a goal to achieve land degradation neutrality (LDN) whereby "the amount and quality of land resources necessary to support ecosystem functions and services and enhance food security remain stable or increase within specified temporal and spatial scales and ecosystems". South Africa is a signatory to the UNCCD and has established voluntary targets to achieve LDN by 2030, with respect to a 2015 baseline. South Africa's LDN targets are given as areas (in ha) of croplands, wetlands and eight biomes, that will be rehabilitated and sustainably managed by 2030. In addition, area targets are given for clearing IAPs and bush encroachment. A range of measures have been suggested to achieve these targets including improved grazing management, erosion control, clearing alien species, bush clearing and sustainable land management practices.

Overview of the issue

Pilot ecosystem services accounts in monetary and physical terms have been complied for 2005 and 2011 for the province of KwaZulu-Natal as part of the NCAVES project. These accounts were developed based on the SEEA EA, using spatially explicit estimates of the supply of ecosystem services in physical terms and their benefits in monetary terms.

The results indicate a decline in the provision of most ecosystem services between 2005 and 2011. The losses in ecosystem services from natural ecosystems were due to a combination of the overharvesting of resources, overgrazing leading to denudation in some areas and bush encroachment in other areas, the spread of invasive alien plants, and the loss of natural habitat due to expanding cultivation, human settlements and other activities such as mining. Loss and degradation of natural habitat, which largely comes about in the poorly managed pursuit of provisioning services, has had a measurable negative effect on the supply of every type of regulating service, including carbon storage which is of global concern. As a result, the value of the annual flows of many ecosystem services – notably hydrological services, carbon sequestration and harvested wild resources – have decreased over time, particularly the grassland and savanna biomes which dominate the landscape.

Achieving LDN involves a combination of avoiding degradation, reducing the rate of further degradation of land (ideally to negligible levels) through sustainable land management (SLM) and offsetting new degradation by restoring already-degraded lands. Designing measures to prevent further degradation requires a good understanding of the drivers, process and rate of degradation, and an assessment of the type and level of investment required to prevent this future degradation.

[15] https://www.environment.gov.za/projectsprogrammes/wfw

The aim of the study is to conduct a scenario analysis of the costs and benefits of restoration interventions for the period 2021-2030, which is the remaining period of LDN commitments pledged by South Africa.

Modelling approach: data collection and model development

The study used a land-cover map of the KZN created in 2017, the closest available to the 2015 reference year for the LDN targets for South Africa. The land-cover map did not include information on land degradation drivers like IAPs or bush encroachment since these are both woody plants that cannot be discriminated between the different land-cover classes. The increase of IAPs from a 2010 baseline was modelled from literature and integrated into the 2017 land cover map, as shown in Figure 37.

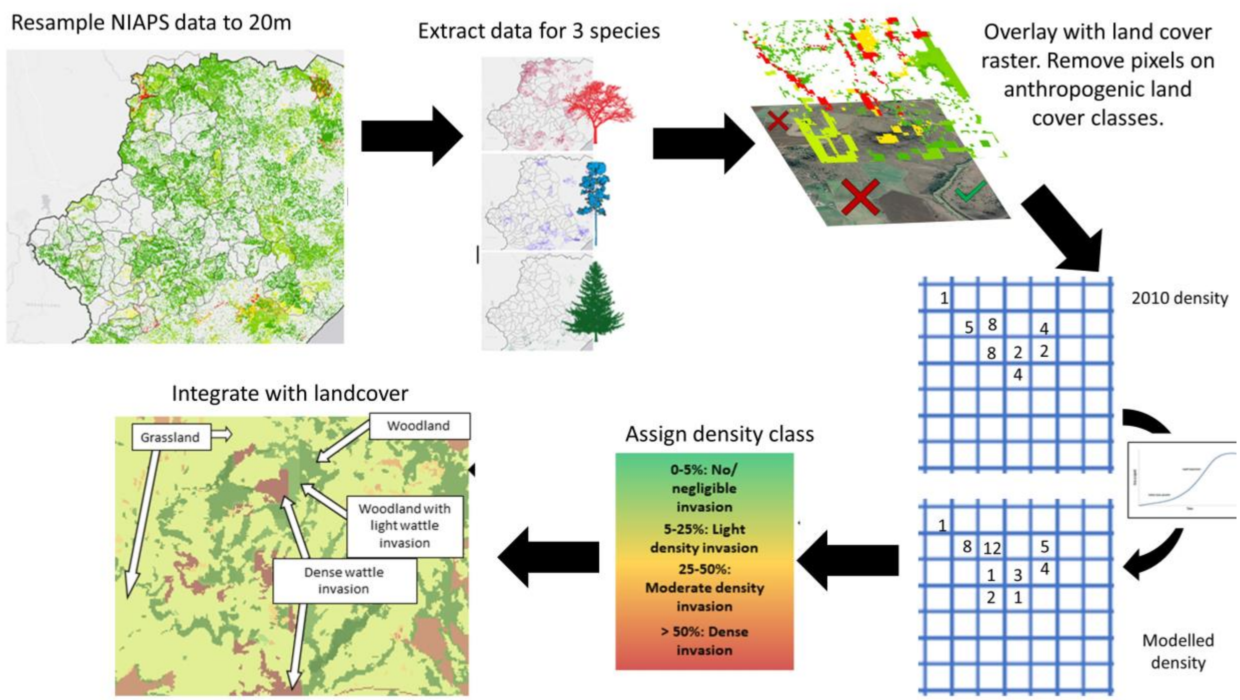

Figure 37: *Schematic process of integration of Invasive Alien Species data into the land cover (Turpie, et al., 2021)*

The extent of bush encroachment was estimated by comparing the 2017 land-cover map with another created in 2005. This information was used in different scenarios to project bush encroachment, IAPs extent, loss of vegetative cover, erosion and for the hydrological modelling.

The land-cover data sets for different scenarios were used to assess changes in the value of ecosystem services. The *SWAT* model was used to generate changes in sediment yields and stream flows in different scenarios relative to the 2017 baseline.

Scenarios, and related assumptions

The following scenarios were included into the analysis:

- A **business-as-usual (BAU)** scenario with low levels of intervention and continued land degradation though spread of IAPs, bush encroachment and loss of vegetative cover and erosion.
- An **optimistic** (SLM halts all future degradation) **land-degradation neutrality (LDN)** scenario in which interventions are implemented from 2021-2030 that result in the equivalent 2015 condition by 2030. This requires restoration of the degradation from 2015-2021, with SLM measures very optimistically stopping any further degradation.
- A **pessimistic** (SLM will not succeed) **land-degradation neutrality (LDN)** scenario in which interventions are implemented from 2021-2030 that result in the equivalent 2015 condition by 2030. This requires restoration of an area equivalent to all projected degradation from 2015-2030. The optimistic and pessimistic LDN scenarios essentially bound the potential costs of the LDN scenario.
- A **full restoration** scenario in which interventions are implemented from 2021-2030 that restore all degraded areas as at 2021 to a healthy condition. This assumed that SLM would stem further degradation.

Results of the analysis

Around 555 000 ha or 26% of the remaining natural area of the Thukela catchment (which is mostly grassland and savanna) was degraded in 2015. This full restoration scenario implied that grassland increased from 42% of the catchment area in 2015 to over 56% and native woody vegetation cover increased relative to 2015, to 18.6% of the area. Under the BAU scenario, continuing degradation reduced ecosystem service capacity, whereas achieving LDN would return ecosystem service capacity to 2015 levels, and restoration would lead to an increase in capacity.

Table 18 shows the results in terms of ecosystem service provision and value under different scenarios. This result indicates that IAPs and bush encroachment have a minor impact on water yield in the catchment. However, the avoided losses were estimated to be R171 million under the LDN scenario and R709 million under the Restored scenario in 2030, relative to the BAU. Addressing land degradation was estimated to have a significant impact on sediment yields. Under the full restoration scenario, the landscape retained 588 000 tonnes of sediment more than under the BAU scenario, essentially preventing this amount of sediment from reaching rivers and dams, and downstream environments. The annual value of erosion control, valued as the replacement cost of lost storage capacity, was estimated to increase from R287 million under the BAU Scenario to R289 million for the

LDN scenario and R291 million for the Restored scenario. Total estimated carbon storage increased under the BAU scenario due to invasion by woody IAPs and bush encroachment. The potential total ecosystem carbon storage under the fully Restored scenario was higher than under the LDN scenario. Assumed changes in grazing capacity on communal and commercial land, coupled with an assumed proportional change in livestock production, lead to an overall gain in resource rent would be some R39 million per year under the LDN scenario and R92 million per year under the Restored scenario relative to the BAU. Provisioning of wild resources was estimated to be worth some R1.60 billion under the LDN and R1.74 billion under the Restored scenario, higher than the value of R1.59 billion under the BAU. KwaZulu-Natal is an important tourist destination that contributes significantly to the local and national economy. Under the BAU Scenario it was assumed that growth in tourism would be constrained by degradation of existing conservation areas as well as the reduced opportunity to develop the wildlife sector following the further degradation of wildlife habitats across the catchment. Conversely, restoration could have a positive impact on tourism in the catchment by improving opportunities for developing the wildlife economy in this part of the province.

Table 18. *The biophysical supply and value (R millions) of ecosystem services per scenario. (Turpie, et al., 2021)*

Biophysical supply	**BAU 2030**	**LDN 2030**	**Restored 2030**
Mean annual runoff (Mm^3)	3 012.0	3 024.0	3 026.0
Sediment retention (t/ha/y)	9.7	9.8	9.9
Carbon storage (Tg C)	357.1	354.0	363.2
Livestock production (LSU/y)	496 590.2	534 161.4	571 425.1
Wood products (m^3)	410 932.0	370 057.0	352 165.0
Non-wood products (t)	22 136.0	24 232.0	28 477.0
Nature-based tourism value (R million)	243.6	270.7	297.8
Value (R millions)	**BAU 2030**	**LDN 2030**	**Restored 2030**
Sediment retention	286.6	289.3	290.9
Carbon storage (global)	261 317.0	259 093.0	266 006.0
Carbon storage (national)	2 064.0	2 047.0	2 101.0
Livestock production	826.02	864.71	918.08
Wood products	688.7	615.7	584.4

Biophysical supply	BAU 2030	LDN 2030	Restored 2030
Non-wood products	21.5	22.7	22.0
Nature-based tourism value	85.3	94.7	104.2

Cost-benefit analysis

The results of the cost-benefit analysis suggest that the implementation of restoration interventions and SLM in the Thukela catchment would result in a net benefit under the optimistic LDN scenario and with full restoration. Using a discount rate of 3.66%, the net present value over 25 years was estimated to be R435.5 million in achieving LDN (optimistic) and R6389.6 million for full restoration, respectively (Table 19). The higher costs under the pessimistic LDN scenario resulted in a net loss.

Table 19. *Present value of the costs of interventions and value of ecosystem service benefits under the expected base case scenario for LDN and Full Restoration (2020 R millions, 3.66% discount rate, 25 years) (Turpie, et al., 2021)*

	Present value (R millions) base estimate		
Costs	**LDN Pessimistic**	**LDN Optimistic**	**Full restoration**
Clearing IAPs	514.4	514.4	2 355.2
Addressing Bush Encroachment	507.2	237.6	691.1
Active restoration of grasslands, erosion	2 623.6	-	-
Sustainable land management	-	1 981.02	6 093.62
Total present value of costs	**3 645.18**	**2 733.09**	**9 139.98**

Benefits			
Water supply	2 591.4	2 591.4	10 757.2
Sediment retention	38.9	38.9	63.1
Tourism	121.8	121.8	243.6
Carbon storage (avoided national cost)	-274.91	-274.91	597.5
Harvested resources	70.6	70.6	2 391.3
Livestock production	620.7	620.7	1 476.9
Total present value of benefits	**3 168.6**	**3 168.6**	**15 529.6**
Net Present Value	**-476.6**	**435.5**	**6 389.6**
BCR	**0.9**	**1.2**	**1.7**

The noticeable difference between the LDN scenarios and the full restoration scenario was the difference in benefits gained relative to the BAU for carbon storage, harvested resources, livestock production, and water supply. Under the Restored scenario, large areas of formerly degraded and denuded grassland added significant ecosystem service benefits in the form of carbon storage, higher stocks of wild non-woody resources, more productive rangelands for livestock farming, and the clearing of over 100 000 condensed ha of IAPs gave rise to significant water supply gains. This result suggests that the protection and restoration of grassland areas through sustainable land management could yield significantly more benefit than the benefits gained through addressing bush encroachment and IAPs which was largely the focus in achieving LDN. The benefit estimates only include the tangible benefits that can be monetised and these estimates are conservative.

Value addition from the use of SEEA EA in scenario analysis

This case study has made use of the principles of SEEA EA in that it consistently accounts for land cover and land-cover changes in a systematic manner. It also uses several published and available spatial data in a structured spatial architecture (ie. reference grid and projection) to assess the costs and benefits associated with addressing land degradation. Moreover, the study made explicit use of the physical and monetary ecosystem service accounts developed for KwaZulu Natal as part of the NCAVES project.

Further, on the policy side, considering that LDN targets refer to 2015 as a reference year, the approach in quantifying areas based on explicit spatial data is a robust method that can be applied consistently regardless of region, assuming sufficient spatial data is available, and used to forecast land-cover change and prioritize efforts in the future. Using this approach creates additional opportunities, such as informing the environmental degradation criterion of the IUCN Red List of Ecosystems (RLE), which identifies ecosystems that are “undergoing loss or disruption of key biotic processes or interactions,” and assists in categorising the risk of ecosystem collapse based on abiotic and biotic degradation (both of which are fundamentally different in their mechanisms, Keith et al., 2013; Bland et al., 2017).

This study thus demonstrates that the use of SEEA EA has informed and could further contribute to policy work on land degradation neutrality. Additional potential analysis includes computing land area that has experienced a negative change in condition, using metrics and condition accounts to evaluate the condition of land used for crop production.

4.4. Examples from other countries

Seven additional case studies are presented below that focus on the policy areas mentioned above:

(i) climate change,

(ii) biodiversity loss,

(iii) air and water pollution,

(iv) deforestation,

(v) land degradation and desertification.

While each case study uses a specific policy issue as entry point, the models used and the analysis performed cut across various policy areas, as presented in Table 20. This is often the case for studies that utilize mixed-methods, or use a systemic approach to identify and analyse various intervention options to solve the stated problem. The use of SEEA EA, as indicated earlier, can expand the boundaries of the analysis. Similarly, the TEEB approach can support the identification of critical drivers of change, indicating the need to use a more comprehensive framework of analysis. Below we describe these examples and highlight how the use of SEEA EA and TEEB could further strengthen the work and provide more insights to policymakers.

Table 20: *Overview of the additional seven case studies analysed, with indications of the policy areas analysed (Report authors)*

		Climate change	Biodiversity loss	Air and water pollution	Deforestation	Land degradation and desertification
1	Low-carbon development in Indonesia	X		X	X	
2	Agriculture expansion in the face of climate change in Tanzania	X	X	X	X	X
3	Biodiversity and tiger habitat conservation in Indonesia	X	X		X	X
4	Forest certificates for reducing deforestation in Brazil		X		X	
5	Water pollution reduction in India and Sri Lanka	X		X	X	X
6	Deforestation and development planning in Rwanda				X	X
7	Integrated planning for ecosystem conservation in the Heart of Borneo		X		X	X

4.4.1 Low-carbon development in Indonesia

Policy context and overview of the issue

The Ministry of Planning, BAPPPENAS, in cooperation with several development partners has launched the Low-Carbon Development Initiative for Indonesia (LCDI). The goal is to inform the country's next five-year plan 2020-2024 with new information, so that the next mid-term development plan (abbreviated as RPJMN) will balance and deliver progress simultaneously for GDP growth, employment creation and emission reduction by investing in Indonesia's natural, human, social and physical capital (BAPPENAS, 2019).

The LCDI was designed to serve as a knowledge integrator for data, science and policy, in a unified framework of analysis. As a result, a systemic approach was used, taking into account the fact that economic activity drives, and is affected by, *carrying capacity* (in this study defined as ecological scarcity and ecosystem services) (Figure 38). Economic activity requires the use of natural resources, and generates pollution. Pollution in turn, can lead to health impacts, resulting in reduced labour productivity and an increase of health costs. Further, unsustainable consumption can lead to resource scarcity, resulting in higher commodity prices and possibly reduced access to resources. Businesses and households are negatively impacted by the erosion of carrying capacity.

Acknowledging the existence of the feedback loops linking social, economic and environmental dimensions of sustainable development, and incorporating them in quantitative analysis in support of policy making can support the anticipation of side effects, and maximize value for money for the investments envisaged in Indonesia's Medium Term Development Plan.

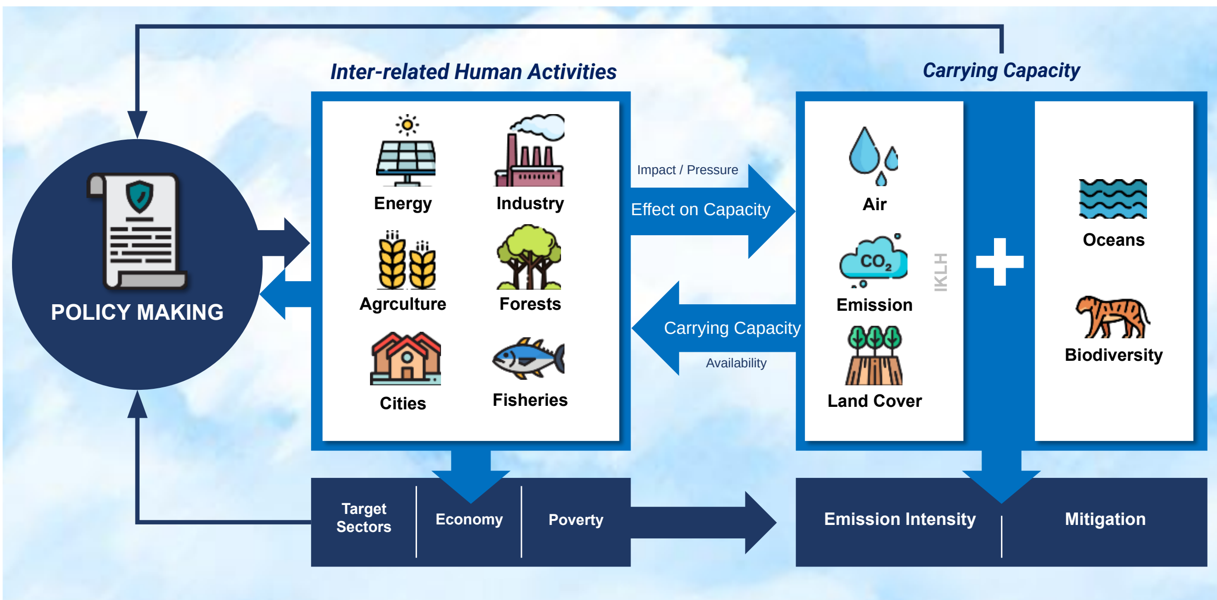

***Figure 38**: Relationships between policy, human activities and carrying capacity in the LCDI modelling approach (BAPPENAS, 2019).*

Modelling approach

The LCDI modelling captures the social, economic and environmental dynamics underlying national performance. The novel application of Systems Thinking and System Dynamics to generate forecasts was supported by several local and international organizations, BAPPENAS, NCE, WRI Indonesia, and GGGI. The following quantitative approach was adopted:

- **Integrated Socioeconomic-Environmental model, Indonesia Vision 2045 (*IV2045*)**: based on the *Green Economy Model (GEM)* (Bassi, 2015) and used to project growth in population, economic activity and natural resource use (eg. water, energy, land), resulting impacts on ecosystem services and economic productivity (which is impacted by technology, energy prices, education, health, air and water pollution, and more). SEEA accounts, SISNERLING in Indonesia, for land cover, perennial crops, water supply and use, and peat account, were created by the National Statistics Office (Badan Pusat Statistik, BPS) embedded in the model with the support of WAVES, both to improve its structure and calibrate simulations.

- **Spatial models (*SpaDyn* and *GLOBIOM-Indonesia*)**: used to forecast land-cover change based on projected GDP growth and changes in ecosystem services. Both models use data on economic activity from *IV2045* by sectors of economic activity, consider changes in land productivity, incorporate the presence of transport infrastructure and trends of demographics, which, combined with hazard risk maps, provide a year-to-year estimation of land-cover and land-use changes. The two models are complementary. *SpaDyn* utilizes cellular automata inspired logic to determine projected land-cover changes based on land-cover status combined with land suitability and road availability. The model also projects changes in mining land and urbanization to cover possible land-cover classes more exhaustively. *GLOBIOM-Indonesia* is a spatially explicit partial equilibrium model with detailed representation of agriculture and forestry sectors. The model depicts land-use competition using an optimization logic that is informed by agro-ecological modelling that generates biophysical productivity information.
- **Nonmarket environmental valuation methods**: used to value the external costs/benefits of losing/maintaining ecosystems and their services.
- **Integrated Cost-Benefit Analysis**: used as a systematic process for calculating and comparing benefits and costs of a given decision. Normally carried out by project implementers, in this study it did include economy-wide and societal costs and benefits resulting from ecosystem services.

Combining these tools allows for a holistic consideration of socioeconomic and environmental policy and investment outcomes. Systems Thinking[16] generates information on the causality among variables and identifies the main feedback loops responsible for change in the system. The *IV2045* model generates quantitative projections on socioeconomic trends and resulting land use impacts. These spatially aggregated values as used as input for the creation of future LULC maps that account for the impact of socioeconomic trends on land cover. Future LULC maps are then used as input for ecosystem service models, which estimates the extent to which ecosystem services will be provided in future years (eg. 2020 and 2030). The results for carbon sequestration, water yield and quality, nutrient loadings, peat land, subsidence and peat fires are subsequently used as inputs in the

[16] Systems thinking is a paradigm aiming to contribute to a comprehensive and holistic understanding of complexity within a system, such as ecological or earth systems, and the interactions and trade-offs between different sub-systems involved. This has implications upon environmental decision-making, as a means to gain better insight and systemic analysis of the natural systems on Earth.

IV2045 model, to improve calibration and ensure that the results (eg. for value added and GDP) reflect the LULC and ecosystem services, captured as carrying capacity.

As shown in Figure 39, *IV2045* includes feedback relationships for:

- The economy, including the real sector (value addition and employment; total and by main economic activities; and demand and supply components), the government sector, and trade;
- Society, including modules for demographics, labour force participation, and poverty;
- Natural resources, including land use, biodiversity, energy, water and fisheries;
- Absorptive capacity, which is a representation of carbon emissions and the climate system.

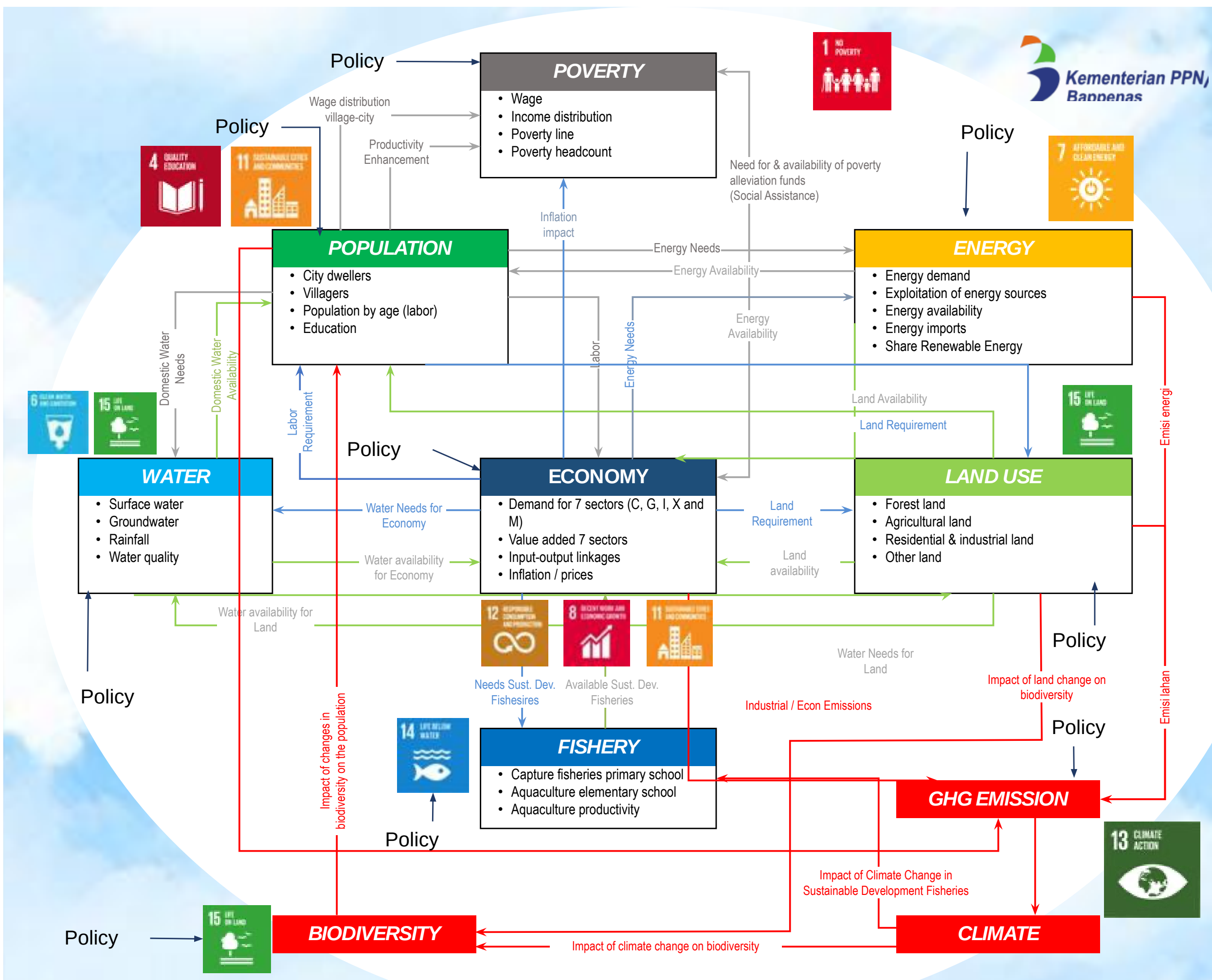

Figure 39: *A high level representation of IV2045 (BAPPENAS, 2019)*

Scenarios, and related assumptions

Four main scenarios were simulated with *IV2045* to inform the creation of the *RPJMN*. Full details on the assumption used and policy ambition, for each scenario, is available in Appendix 4 of the full LCDI report (BAPPENAS, 2019). In summary the four scenarios analysed are:

1. **The Base Case**: **no new policies, but reflects environmental degradation.** This scenario reflects a continuation of historical trends for the economy, society, climate, and the environment. No new policies are introduced under this scenario. The Base Case does reflect the impacts that environmental degradation, including pollution and increased scarcity of environmental good and services, has on people and the economy. Key elements of this scenario are:
    - Continuation of historical trends for the economy, society, climate, and the environment;
    - No new policies introduced;
    - Reflects impact of environmental degradation, including pollution and increased scarcity of environmental good and services
2. **The LCDI Moderate Scenario: includes new low-carbon policy measures for 2020-45; achieves the unconditional NDC target.** This scenario is consistent with Indonesia meeting its unconditional nationally determined climate target (NDC) of 29 per cent less emissions in 2030 compared with the baseline. This scenarios includes a full, immediate enforcement of forests, peat land, mangroves, and mining moratoria; the undertaking of a significant effort in restoration also in terms of avoided losses of forests not currently under moratorium; the adoption of agriculture productivity enhancing, and other food and waste reduction policies; the acceleration in the pace of reduction in energy intensity relative to historical trends, and the movement towards meeting renewable energy targets that have already been defined in Indonesia's energy policy. Key elements of this scenario are:
    - Indonesia meets its unconditional nationally determined climate target (NDC) of 29 per cent less emissions in 2030 compared with baseline;
    - Full, immediate enforcement of forests, peat land, mangroves, and mining moratoria;
    - Increased forest restoration, agricultural productivity enhancement, food and waste reduction; accelerated reduction of energy intensity; adherence to Indonesia's renewable energy targets.
3. **The IHigh Scenario: includes more ambitious policy measures than LCDI-Moderate for 2020–45; achieves the conditional NDC target.** This scenario leads to 43 per cent less emissions in 2030 compared with the baseline, consistent with Indonesia meeting its conditional national climate target (NDC) of a 41 per cent reduction in emissions by 2030. Meeting the conditional

NDC requires meeting all the actions in LCDI Moderate Scenario, plus the scaling up of efforts in restoration, forest protection, energy intensity reduction and increase in renewable energy shares through 2045. Key elements of this scenario are:

- 43 per cent less emissions in 2030 compared with baseline, consistent with Indonesia meeting its conditional national climate target (NDC) of a 41 per cent reduction in emissions by 2030.
- LCDI Moderate Scenario, plus the scaling up of efforts in restoration, forest protection, energy intensity reduction and increase in renewable energy shares through 2045.

4. **The LCDI Plus Scenario: reflects LCDI-High for 2020–24, and additional, more ambitious policy measures thereafter.** This scenario incorporates an extra level of effort in low-carbon policymaking starting at around 2025, so that emissions continue falling through 2045 and beyond. This fourth scenario requires a set of measures not currently under consideration in *RPJMN*, such as i) the introduction of mechanisms to put a price on carbon; ii) bigger reforestation targets, and iii) policies for even higher improvement in energy efficiency and reduction of waste, mainly from actions at the urban level. These would be part of a new generation of policies to be implemented beyond the *RPJMN* 2020-2024 window, that require transformational changes in government, the private sector, and civil society in general. Key elements of this scenario are:
    - Extra level of effort in low-carbon policymaking starting at around 2025, so that emissions continue falling through 2045 and beyond
    - New generation of policies to be implemented beyond the *RPJMN* 2020-2024 window that require transformational changes: i) the introduction of mechanisms to put a price on carbon; ii) bigger reforestation targets, and iii) policies for even higher improvement in energy efficiency and reduction of waste, mainly from actions at the urban level.

Results of the analysis

Relative to the Base Case, the LCDI High Scenario would deliver sustained average economic growth rates of 5.6 per cent through 2024, and 6.0 per cent through 2045 (Figure 40). In 2045, it would also deliver (a) over US$5.4 trillion to GDP; (b) more than 15.3 million additional jobs, which are greener and better paid; (c) a reduction in poverty from 9.8 per cent of total population in 2018 down to 4.2 per cent; (d) 40,000 avoided deaths each year, due to improved air quality; and (e) prevention of the loss of nearly 16 million ha of forestland relative to a Base Case. The LCDI High Scenario would also lead to (f) a closing of the gender and regional opportunity gaps, as well as (g) a lower required investment to GDP ratio. And in terms of emissions, the LCDI High Scenario would deliver (h) a GHG emissions reduction of almost 43 per cent by 2030, exceeding Indonesia's conditional national climate target (NDC) of 41 per cent below baseline (Figure 41).

Crucially, Indonesia does not have to wait to reap the benefits of a low-carbon development pathway. The pace of economic growth under a Base Case will immediately (post-2019) start falling behind that that is estimated under any of the climate action scenarios. This divergence reflects a boost from the additional investments that the climate action scenarios will attract as well as the effects of environmental degradation, pollution and increased scarcity of resources in the Base Case (see the example of energy in (Figure 42).

Moreover, failing to act on low-carbon policies would lead to over one million more people living in poverty relative to the LCDI High Scenario; as well as higher mortality and lower human development. Opportunities to tackle the Indonesian gender and regional opportunity gaps, and the resulting economic growth and poverty reduction, would also be foregone without the uptake of an LCDI High Scenario and its policies, relative to the Base Case.Annual deaths would be more than 40,000 higher per year in the Base Case than in the LCDI High Scenario. Progress in education and health would be slowed down. A failure to act would also lead to cumulative losses of income of US$130 billion over the period 2019–2024.8 In short, Indonesia has so much more to gain by taking a low-carbon pathway.

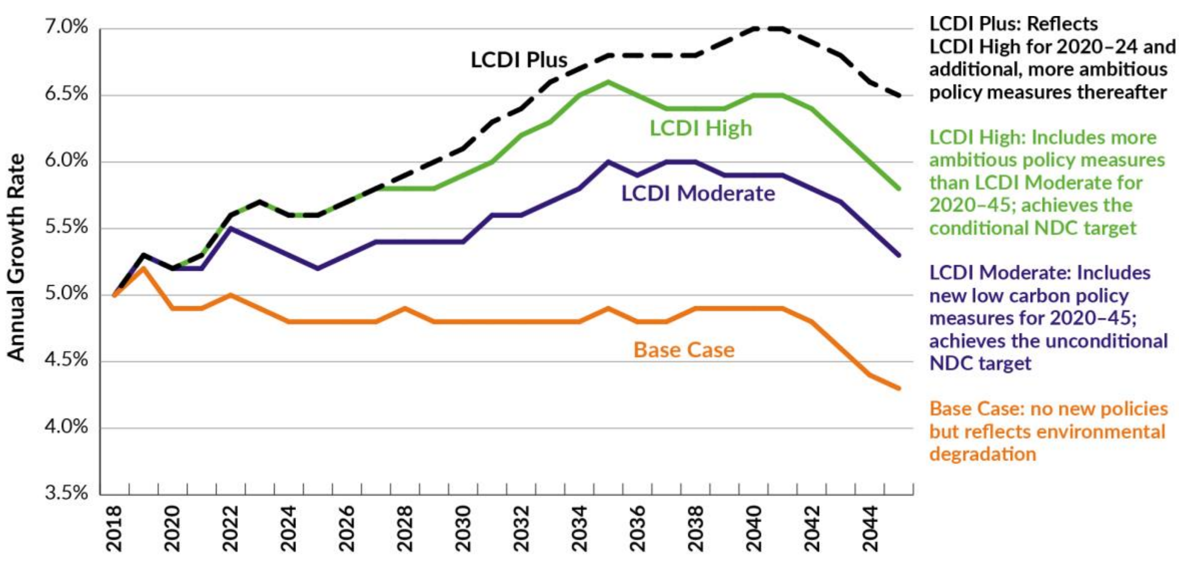

Figure 40: *GDP growth trajectories for scenarios modelled with IV2045 (BAPPENAS, 2019)*

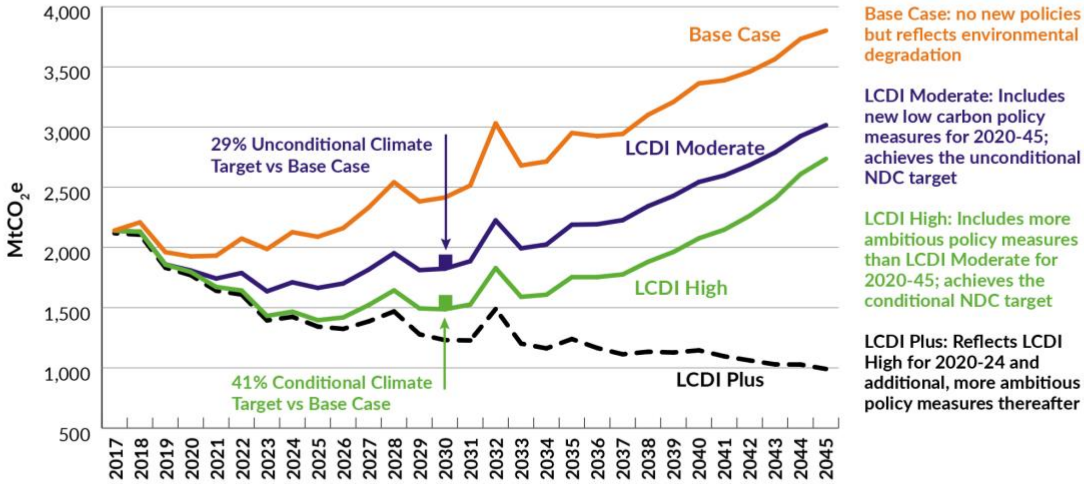

Figure 41: *Emissions trajectories for scenarios modelled with IV2045 (BAPPENAS, 2019)*

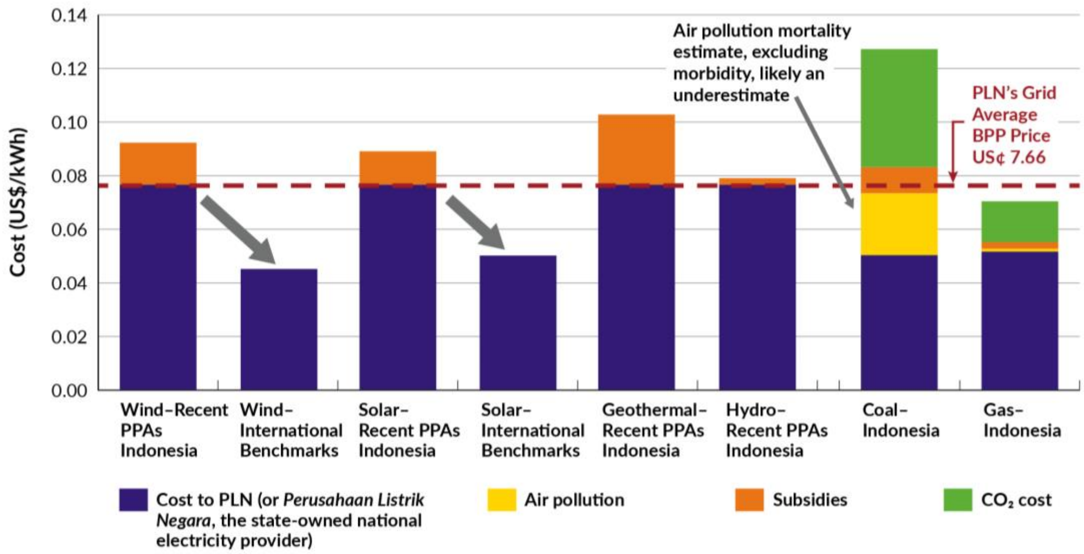

Figure 42: *Cost of coal and renewable energy in Indonesia (BAPPENAS, 2019)*

Concerning the economic assessment of the intervention options included in the LCDI scenarios (eg. energy efficiency), an integrated cost-benefit analysis indicates positive returns (Table 21). Specifically, GDP is close to six times higher than the investment required (taking a societal perspective), government revenues are at the same level as the investment (taking a government perspective) and income creation reaches about 80 per cent of the investment required (taking a household perspective). In addition, it should be considered that the investment estimated totals 1 per cent of GDP in the LCDI Moderate scenario and 1.7 per cent of GDP in the LCDI High scenario (or 2.8 per cent and 6.3 per cent of total investment respectively).

Table 21: *Integrated CBA resulting from the simulation of the LCDI scenarios with IV2045*

Integrated CBA *(US$ million)*	**Unit**	**LCDI High**	**LCDI moderate**
	Expenditure		
Investments			
Energy	bn US$	62.4	38.9
Fishery	bn US$	7.4	7.4
Land and forestry	bn US$	13.0	8.7
Peat	bn US$	4.3	4.3
O&M			
Energy	bn US$	6.4	1.9
Fishery	bn US$	4.3	4.3
Forestry	bn US$	8.9	8.9
Total investment and O&M	**bn US$**	**106.7**	**74.4**
	Avoided costs		
Energy expenditure	bn US$	51.4	19.6
Social cost of carbon	bn US$	367.8	254.3
Total avoided costs	**bn US$**	**419.2**	**273.8**
	Added benefits		
Real GDP	**bn US$**	**520.9**	**422.2**
% relative to 2018	*%*	*49%*	*40%*
Revenues and grants	**bn US$**	**99.0**	**80.2**
Labour income	**bn US$**	**83.2**	**63.3**

Box 2: *Potential contribution of SEEA-EEA to the case study Low Carbon Development in Indonesia*

SEEA accounts have been used as input in this modelling exercise. SISNERLING is the Indonesian application of the SEEA CF, which is done at national scale. In addition, Indonesia has produced partial (spatial) SEEA EA accounts for the islands of Sumatra and Kalimantan, including extent, condition, carbon and services. This work was carried out by the national Statistics Office (BPS), with support from the World Bank and the WAVES partnership. These were used to strengthen model formulations, improve parametrization and calibration.

Ecosystem extent	***Ecosystem condition***	***ES supply and use, physical***	***ES supply and use, monetary***	***Thematic accounts***
National accounts would support model parametrization and calibration. ***Indicators***: - *Cropland (also on peat)* - *Plantations (also on peat)* - *Mangroves* - *Area affected by fires* - *Public green spaces (urban areas)*	Required to improve the calculation of ES provisioning. ***Indicators***: *Living plant index* *Species abundance index* *Nutrient concentrations (N)* *Nutrient concentrations (P)* *Air pollutant concentration* *Habitat quality*	Required to strengthen the estimation of carrying capacity. ***Indicators***: - *Carbon retention* - *Blue carbon retention* - *Crop provisioning* - *Timber provisioning* - *Air filtration* - *Water regulation* - *Water purification*	Required to estimate the impact of carrying capacity on the economy. ***Indicators***: - *Value of carbon and blue carbon retention* - *Value of crop and timber provisioning* - *Health cost from air pollution* - *Value of water supply and purification* - *Value of tourism activity*	Land (especially peat), affecting emissions and land productivity; species and biodiversity, influencing the tourism sector and culture; water accounts for assessing water balance and pollution for urban areas; carbon accounts (including blue carbon) to strengthen policy assessment for low carbon development (eg. NDC) and health.

4.4.2 Agriculture expansion in the face of climate change in Tanzania

Policy context and overview of the issue

The Government of Tanzania's economic growth has developed a variety of policy initiatives include '*Big Results Now!*', a nation-wide policy aimed at socioeconomic development, the Five Year Development Plan, and '*Kilimo Kwanza*' - a region-wide policy that is designed to provide funding for the implementation of the Southern Agriculture Growth Corridor of Tanzania (SAGCOT). These policies seek to reduce poverty and ensure food security, in line with the Sustainable Development Goals.

The Kilombero basin in Tanzania covers an area larger than 40,000 km^{2}with a local population of over 300,000 people who rely on agriculture, forestry, fisheries and livestock for water and food security (IISD, 2018b). SAGCOT aims to facilitate the development of clusters of profitable agricultural businesses within the southern corridor, including the Kilombero valley. Building on existing operations and planned investments, the clusters are likely to bring together agricultural research stations, nucleus larger farms and ranches with outgrower schemes[17], irrigated block farming operations, processing and storage facilities, transport and logistics hubs, and improved 'last mile' infrastructure to farms and local communities. To realize the food production potential of the Kilombero basin, the SAGCOT initiative aims to attract more than US$3 billion of investments, transforming the area in a regional food exporter as well as increasing farmer revenues by more than US$1.2 billion. The SAGCOT Blueprint, which was released in 2011, described the timing and methods for unlocking investments in the agricultural sector as well as indicating how these could be further expanded and better coordinated to support the local economy.

The initiative recognizes possible conflicts of interest, such as competition of resources between farmers and livestock breeders, including land and water. The availability of natural resources and ecosystem services underpin livelihoods for the local population and sustain ecological integrity in the Kilombero valley. The SAGCOT plan aims to foster economic development in the agricultural sector, maximising social utility without damaging natural services offered by healthy ecosystems that are the foundation of local livelihoods.

Modelling approach

Two studies have analysed the potential outcomes of the implementation of SAGCOT: a biophysical assessment that included the creation of a cost-benefit analysis (CBA) (TEEB, 2018) and a project financing assessment of investments planned under various scenarios (IISD, 2018b).

[17] A nucleus is large farm which sources input procured from smallholder farmers linked through outgrower arrangements to the nucleus.

Five quantitative models were used, supported by surveys on land-use and land management practices, and land-cover maps to better understand the socioeconomic and environmental dynamics of the basin (Figure 43). *CROPWAT* was used to estimate irrigation requirements and *SWAT* was used to estimate water yield and runoff. The combined use of these models allows the estimation of the suitability of different crops based on their water requirements. This information is important in the context of concerns related to water availability and the required river flow that would ensure the ecological integrity of the delta. In order to fully account for the potential impact of upcoming investment strategies, a socioeconomic analysis was carried out with the creation of a customized System Dynamics model based on the *Green Economy Model (GEM)*[18]. This model was used to forecast land use, water and labour requirements, as well the economic performance of SAGCOT. Water requirements were estimated by embedding the SAVi irrigation model in *GEM*, providing technology detail for investments in different types of irrigation (flood, centre pivot and drip). *InVEST* was then used to estimate the provision of ecosystem services in the area (carbon sequestration, food provisioning and nutrient retention), as a result of the expansion of agriculture land. Then, and in order to estimate the economic viability of SAGCOT under different scenarios, the investment required to meet policy objectives, resulting revenue stream and societal benefits (ie. the economic valuation of ecosystem services) were analysed with a project-financing model.

Combining these models allows for a holistic consideration of development impacts and land-use change – planned or otherwise – and the socioeconomic implications of such change in a spatially explicit manner.

The CLD (Figure 44) shows that there are four main feedback loops that underlie the dynamics of the area studied. The first feedback loop (i) causes the expansion of agriculture land, and is driven by population and the demand for food. Population growth results in an increased demand for food, which leads to the conversion of land for subsistence agriculture. The additional income which results from agriculture production increases the attractiveness for people to migrate to the region, which in turn increases population and thereby the demand for food. A second loop (ii) is represented by the increase in employment that is caused by the expansion of agriculture land under policy scenarios, such as in the case of SAGCOT. A similar dynamic to the first feedback loop emerges, but it is driven by agribusiness investments rather than by land availability and local food supply. The next feedback loops are related to water availability. With water being an important constraint during the dry season, the extent to which agriculture land can be expanded depends on total water availability and efficiency of water use. The latter is influenced by (iii) the presence of vegetation (which increases groundwater recharge and lowers surface

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[18] Green Economy Models (GEM) are approaches to integrate the four main capitals (physical, human, social, and natural capital) and their interconnections, to analyse green economy scenarios (Bassi, 2015).

water and runoff) and by (iv) the type of crops planted and their respective water requirements. The lack of water in the dry season causes water stress, reduces agriculture yield and production, and affects human and ecosystem health.

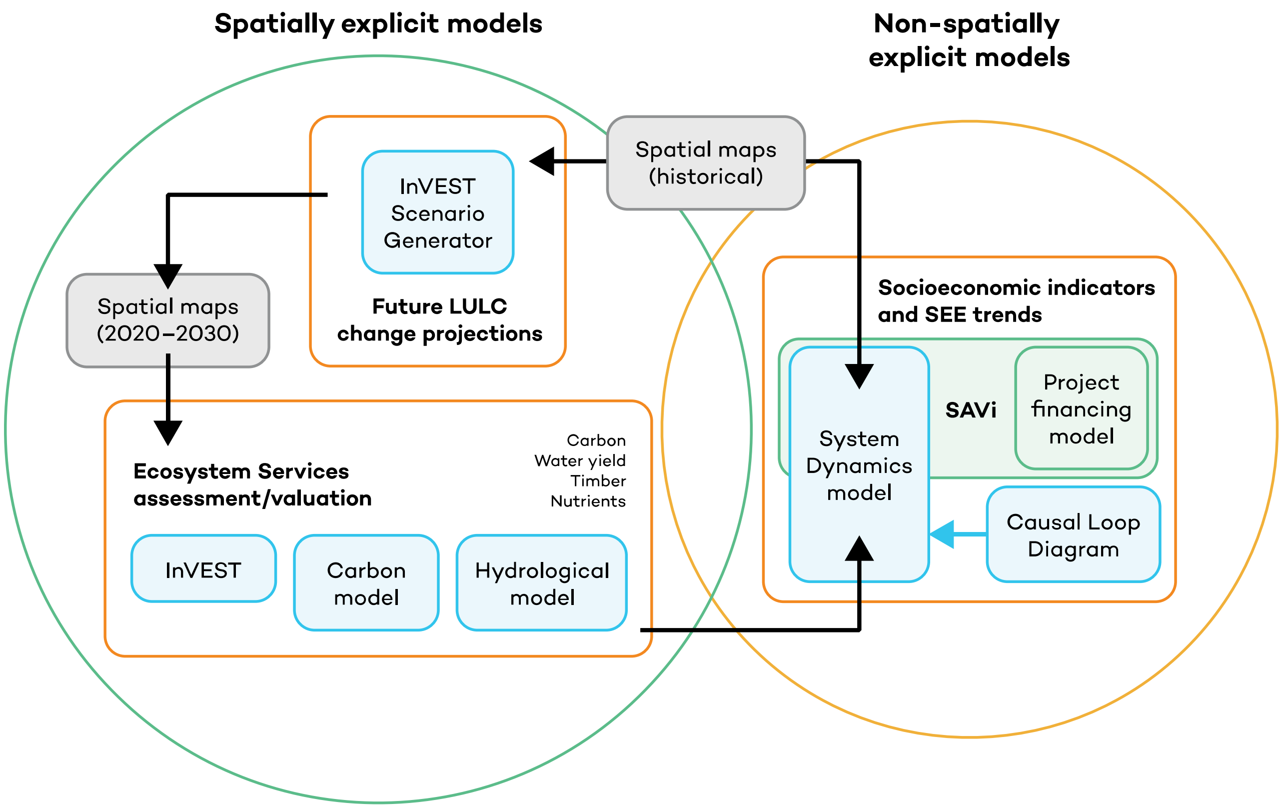

Figure 43: *Modelling framework (IISD, 2018b)*

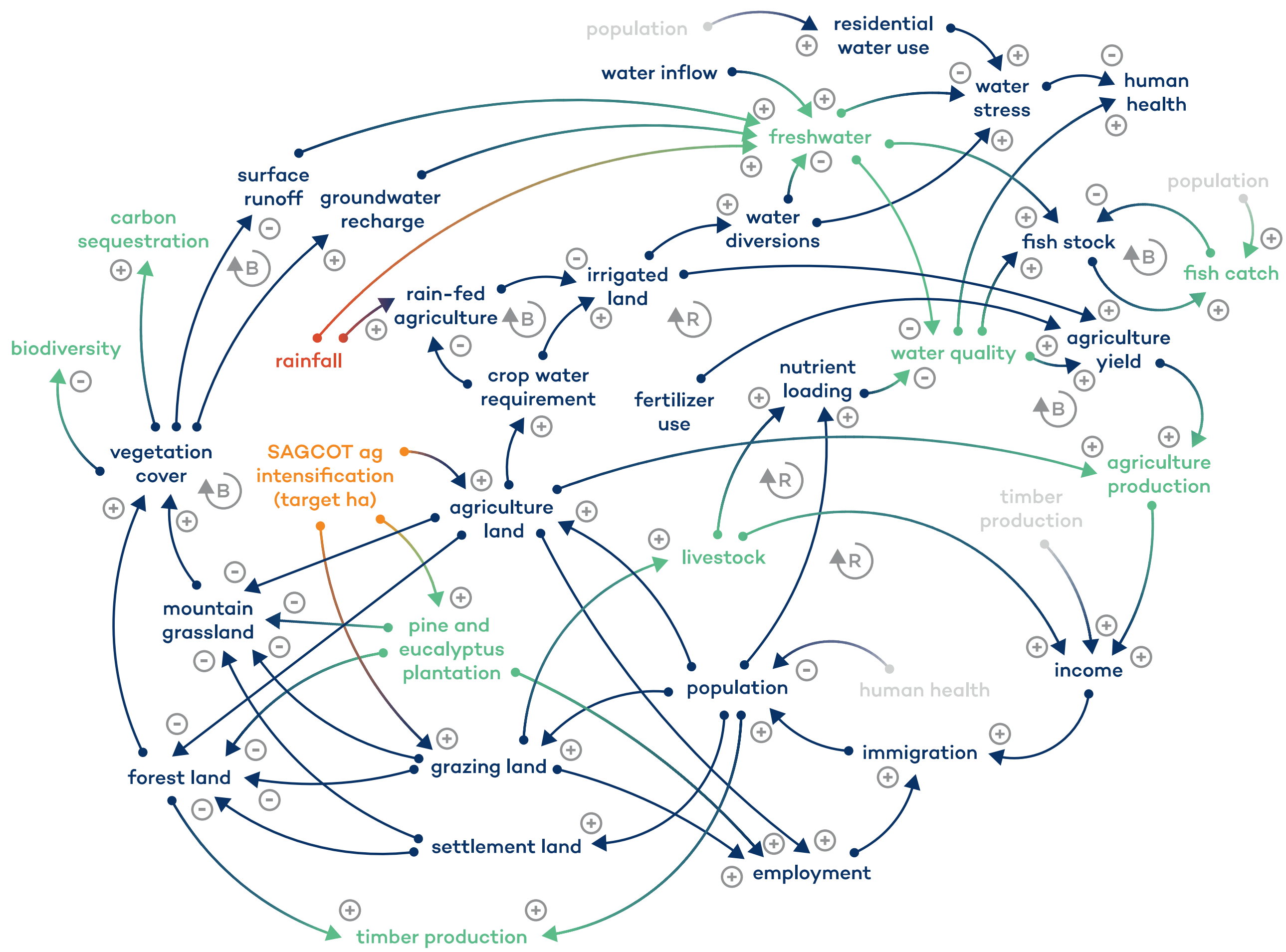

Figure 44: *Causal Loop Diagram of the Kilombero basin (TEEB, 2018)*

Scenarios, and related assumptions

Several scenarios were simulated to evaluate the impacts of the implementation of the SAGCOT initiative. These scenarios can be grouped as follows:

- **Business-as-usual (BAU):** this scenario assumes that existing trends on population, land conversion for agriculture and settlements, and related impact on the environment will be stable.
- **SAGCOT Reference (RE) and Green Economy (GE):** these two scenarios represent two different SAGCOT implementation options; one using flood irrigation (reference or RE) and the second one utilizing drip irrigation (green economy or GE). Both scenarios assume the achievement of the targets of the SAGCOT initiative for land expansion. The GE scenario considers two cost assumptions: low drip irrigation cost (US$500 per hectare) and high drip irrigation cost (US$3000 per hectare).

Furthermore, for each SAGCOT scenarios two assumptions were made:

- Unconstrained water supply;
- Constrained water supply, considering known maximum sustainable extraction thresholds that constrain water use from surface and groundwater.

Results of the analysis

The results of the business-as-usual (BAU) scenario show that population growth in the Kilombero basin will increase the demand for food, driving land-use change to support both agricultural and settlement expansion. As a consequence, the demand for water for irrigation and human consumption will rise as well. The agricultural sector will therefore remain a source of subsidence; in other words, the income per capita of farmers will not improve over time.

The implementation of SAGCOT in the Kilombero cluster is expected to increase the amount of agriculture land by around 52,000 hectares. The expansion of agriculture land will create employment opportunities for the local population and beyond, which leads to an increase in migration by drawing people into the region for work. The production output in the SAGCOT case is exceeding the subsistence level, since the increase in agriculture production is aiming at the economic development of the region. Higher employment and more production output, and subsequently turnover, cause per capita income to be higher than in the BAU scenario.

In addition to social and economic benefits, environmental pressures emerge in the SAGCOT scenario. Higher population growth and an increase in cultivated area lead to higher water demand, resulting in the potential depletion of surface water and the exploitation of groundwater. Nevertheless, during dry months, the available water is not sufficient to satisfy irrigation requirements, leaving land stranded, or with lower productivity. Ecosystems in and around riverbeds would be negatively impacted in this scenario. In light of these projections, the sustainable use of surface water (through the use of a minimum requirement for runoff) was evaluated, further constraining water availability. The minimum runoff value for the Kilombero river, at Ifakara Ferry, was proposed by a USAID study on the environmental flows in the Rufiji river basin (Smith, 2016). Constraining the use of surface water avoids the river from being depleted during the dry season. As a result of the constraint on surface water supply, higher consumption of groundwater is envisaged, which could then exceed overall sustainable extraction (Helmin-Söderberg, 2014). Based on these insights, a constraint on groundwater use was also introduced. The threshold value for ground water use was estimated based on the study of Helmin-Söderberg (2014), who estimated the annual natural refill of the ground water aquifers in the Kilombero valley.

Under both scenarios, the full area to be converted to agriculture will only be available during the rainy season. Both production and revenues would be lower, as they are impacted by higher value fruits that are grown in the dry season. In addition, the seasonality of production will significantly affect employment and income (Figure 45). Based on the assumption that land is expanded during the rainy season and left stranded during the dry season (Figure 46), there would be a severe difference in employment opportunities during the year, leading to marked fluctuations in total income. This difference is likely to cause seasonal immigration into and out of the Kilombero cluster.

The analysis indicates a trade-off between the development through SAGCOT and the sustainable management of the water resources of the Kilombero cluster. The implementation of SAGCOT without the careful management of water resources bears the risk of overusing surface and ground water. In the long run this would erode the capacity of the cluster, as well as of the delta, to maintain its role as a provider of food and livelihood.

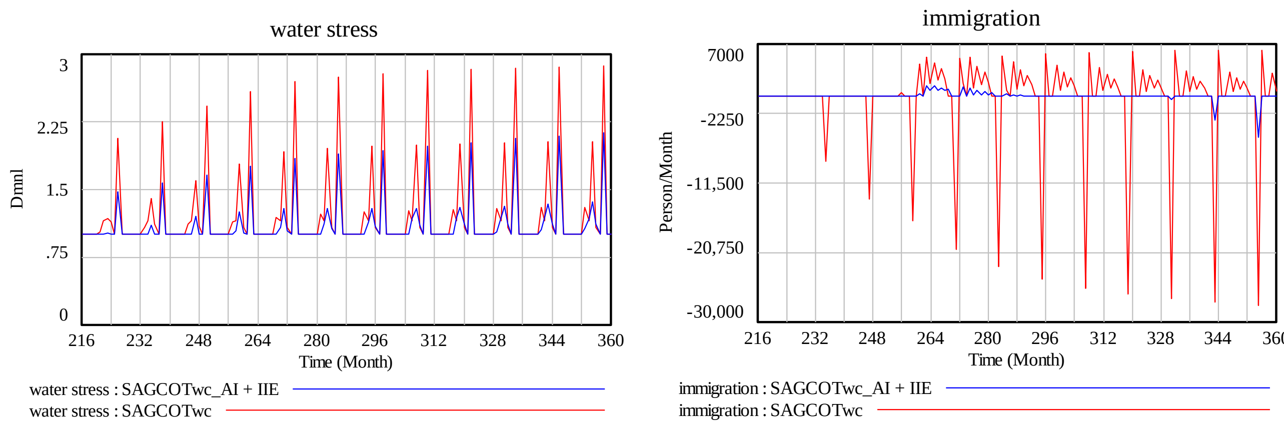

Figure 45: *Water stress and immigration in the SAGCOT and SAGCOT GE scenarios (TEEB, 2018)*

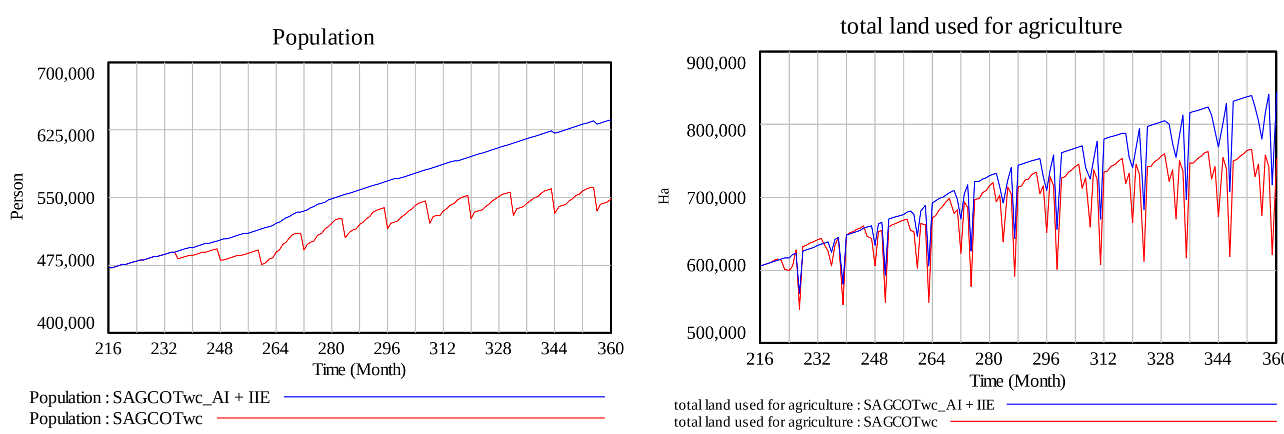

Figure 46: *Population and total agriculture land in the SAGCOT and SAGCOT GE scenarios (TEEB, 2018)*

Three other scenarios were evaluated to reduce the negative impacts on land and water use.

- Increasing agricultural intensification can reduce the demand of land by approximately 50 per cent, while achieving the same production targets. As a result, water demand and seasonal volatility in employment decline in relation to the SAGCOT scenarios (Figure 46).
- Increasing irrigation efficiency with the use of drip irrigation can reduce water consumption from agriculture, increasing the carrying capacity of water resources and thus improving food security in the area. This scenario reduces migration volatility, supporting the stabilization of income from agriculture.
- Combining the intensification of agricultural production with water efficiency would support the achievement of sustainability of SAGCOT, as shown in Table 22. This scenario maintains agricultural production and employment creation, while improving the environmental impact of the agricultural sector in the long-term.

Table 22: *Performance of different scenarios of SAGCOT (TEEB, 2018)*

	Land use	Water stress	Carbon sequestration	Production	Employment
SAGCOT	↑	↑	↓	↑	↑
Water constraints	↓	↑	↑	↓	↓
Water efficiency (30%)	=	↓	=	↓	↓
Intensification (50%)	↓	=	↑	=	↓
Combination	↓	↓	↑	=	=

Having established that the SAGCOT scenario with the addition of the sustainable management of land and water is the most desirable from the point of view of revenue generation, income creation and environmental performance (eg. carbon sequestration, in-stream water flow), the International Institute of Sustainable Development (IISD) has assessed the financial viability of investments in flood and drip irrigation, to gauge the potential interest of private investors (IISD, 2018b). The use of a project-financing model shows that a conventional SAGCOT scenario would lead to an internal rate of return of 6.2 per cent, making it a viable project, despite the poor social and environmental performance. Nevertheless, it can be noted that the potential profitability of the project would be much higher, should there be no water constraints, therefore leading to production being lower than expectations. When water constraints are taken into account and drip irrigation is considered, the internal rate of return (IRR) is negative (Table 23). The IRR turns positive if part of the water savings that are realized with drip irrigation are used to expand agriculture land, ie. the water that remains available after in-stream requirements are met. In this case, and when considering externalities (eg. income created, social cost of carbon, value of water for environmental services) the IRR equals the value of flood irrigation at 6 per cent when considering high capital expenditure for drip irrigation, or grows as high as 13.42 per cent when considering low capex for drip irrigation.

Table 23: *Key financial indicators for investments in flood (SAGCOT scenario) and drip irrigation (SAGCOT GE scenario). Source (IISD, 2018b)*

Scenarios	IRR (%)	NPV (USD million)	Min. DSCR (ratio)	Ave. DSCR (ratio)	Min. LLCR (ratio)
1) Flood irrigation (SAGCOT RE)	6.20%	(0.61)	1.18×	1.51×	1.19×
2) Drip irrigation (SAGCOT GE), high capital expenditure (CAPEX)	Negative	(45)	0.14×	0.17×	0.14×
3) SAGCOT GE, low CAPEX	Negative	(20)	0.32×	0.36×	0.32×
4) SAGCOT GE, high CAPEX, incl. social cost of carbon (SCC)	Negative	(45)	0.15×	0.19x	0.15×
5) SAGCOT GE, high CAPEX, incl. SCC and additional revenues	3.06%	(22)	1.11×	1.13×	1.11×
6) SAGCOT GE, high CAPEX, all externalities	6.04%	(12)	1.22×	1.50×	1.22×
7) SAGCOT GE, low CAPEX, all externalities	13.42%	10	2.33×	2.64×	2.34×

The analysis shows that it is critical to consider social, economic and environmental dimensions in project development, as well as in the assessment of the financial viability of projects. This is a critical requirement when the goal is to balance the performance of various economic actors, as it depends on environmental carrying capacity – a key parameter to consider when implementing sustainable development policies.

***Box 3:** Potential contribution of SEEA-EA to the case study Agriculture expansion in the face of climate change in Tanzania*

The modelling work presented in this study makes use of spatial information, incorporating ecosystem extent. At the same time, the analysis of ecosystem condition is limited to crop production and water availability. Refining and deepening ecosystem condition would provide more valid results. Expanding the list of ecosystem services, in addition, would allow for the improvement of model formulations for crop production, water use, all with validated accounts. It would then support expanding the cost-benefit analysis, with new economic valuation of ES.

Ecosystem extent	***Ecosystem condition***	***ES supply and use, physical***	***ES supply and use, monetary***	***Thematic accounts***

Required to better determine the land cover changes caused by expansion of agriculture. ***Indicators***: - *Subtropical deciduous forests and shrublands* - *Subtropical wooded savannas* - *Subtropical grasslands* - *Croplands* - *Pastures* - *Plantations* - *Mangroves* - *Permanent upland streams* - *Permanent lowland rivers*	Useful to better estimate ecosystem services, especially in relation of crop production and water. ***Indicators***: - *Biomass of natural forest* - *Living plant index* - *Nutrient concentrations (N)* - *Nutrient concentrations (P)* - *Habitat quality*	Required to expand the list of ES quantified, and to improve the calculation of ES provisioning. ***Indicators***: - *Carbon retention* - *Blue carbon retention* - *Soil retention* - *Crop provisioning* - *Timber provisioning* - *Air filtration* - *Water regulation* - *Water purification*	Necessary to better assess the economic viability of the project, from a societal perspective. ***Indicators***: - *Value of carbon and blue carbon retention* - *Value of crop provisioning* - *Value of water supply and purification*	Water accounts would be valuable to extend the analysis to the Rufiji delta (eg. to lowlands) and to improve the calculation of the societal impacts of agriculture expansion (including for the calculation of project IRR for the government and farmers).

4.4.3 Biodiversity and tiger habitat conservation in Indonesia

Policy context and overview of the issue

Sumatra is a large island in Indonesia that is rich in biodiversity, and where the last forest habitats of the critically endangered Sumatran tiger, *Panthera tigris sumatrae,* can be found. However, in the last 20 years this region has experienced one of the highest deforestation rates in the world due to large demands of palm oil and other plantations. The deforestation in Sumatra contributed to making Indonesia one of the main carbon emitters from forest loss worldwide.

Conservation in the early 2000s was difficult to implement in Indonesia due to various reasons, such as lack of incentives to protect ecosystem services, high economic opportunities from palm oil and other sectors that drive deforestation, as well as lack of payment systems to encourage sustainable land management. Notwithstanding, in 2009 the National Government approved two laws (Indonesia Laws No. 26/2007 and No. 32/2009) that required the enforcement of environmentally sustainable spatial planning at different administrative levels. At the same time, payment schemes as well as pilot projects had also started to emerge. For instance, both the RUPES (Rewarding Upland Poor for Environmental Services) programme and the REED+ funding agreement with the Government of Norway aimed to protect ecosystem services as well as alleviate poverty.

Such improvements in policy ambition and coordination provided the motivation to carry out a study that assessed the overlap between tiger habitats and the distribution of ecosystem services in central Sumatra (Bhagabati et al., 2014). The goal of the study was to assess whether the range of tiger habitat overlapped with areas providing high ecosystem services (eg. carbon storage and sediment retention, high water yield and nutrient retention). The outcomes of this assessment were intended to support the creation of environmentally sustainable spatial planning, as mandated by the National Government in 2009, by identifying areas that provide the requisite ecosystem services that practically support tiger habitat conservation.

Modelling approach

Several steps were implemented to carry out the assessment of ecosystem services and habitat quality: (i) identification and comparison of the spatial distribution of ecosystem services and tiger habitat in 2008; (ii) quantification of ecosystem service provision by tiger habitat; (iii) assessment of whether land parcels with high levels of ecosystem services contain substantially more tiger habitat; (iv) creation of future land cover maps under two alternative scenarios; (v) performed the same analysis, described in items i, ii and iii above, and quantified the change relative to 2008.

In this study, *InVEST* was used to map and quantify the following ecosystem services: tiger habitat quality (using land cover and habitat treats, such as roads and other infrastructure), carbon storage and sequestration, water yield, sediment retention and nutrient retention.

Scenarios, and related assumptions

Two future scenarios were considered and compared to the spatial distribution of ecosystem services and the tiger habitat quality of 2008 (base year for when the study was conducted). The first scenario, the Sumatra Ecosystem Vision, which considers that, in the future, the study area will deliver essential ecosystem services for human needs, as well as for conservation, and will also support sustainable economic development. In this scenario, the forest cover will double in 12 years, by 2020. The second scenario, the Government Spatial Plan – or "the Plan" – does not prioritize conservation nor ecosystem services. It will conserve the forest area as it was in 2008, and all remaining land would be assigned to plantations and other uses.

Results of the analysis

Results for the assessment of the 2008 LULC indicate that sub-watersheds with high levels of ecosystem services contained more tiger habitats than others. Specifically, tiger areas coincided with forests, which hold substantial carbon stocks. High value of carbon, water yield and nutrient retention were also found outside of forested areas, for instance in deforested peat swamps. Water yield instead reflects rainfall and has a causal relation with forests, and a correlation with tiger habitat.

When considering future scenarios, as shown in Table 24, both scenarios show gain and losses depending on service and location, as well as by spatial grain of the analysis. Therefore, both the *Vision* and the *Plan* do not achieve simultaneous environmental and social goals across the whole landscape. However, the Vision results in higher tiger habitats and improvements in most ecosystem services than the Plan, where tiger habitat remains constant and all ecosystem services worsen, due to higher rates of afforestation. Thus, the Vision scenario is better suited to support conservation.

Table 24: *Number of watersheds gaining or losing more than 5% of ecosystem services and tiger habitats under two scenarios from the baseline of 2008, based on Bhagabati et al., 2014.*

Habitat/Ecosystem Service	Vision		Plan	
	Gain	Loss	Gain	Loss
Tiger habitat	62 (96)	0 (0)	25 (40)	38 (52)
Carbon storage and sequestration	39 (59)	4 (4)	5 (11)	38 (52)
Water yield	1 (1)	62 (93)	3 (2)	51 (82)
Avoided sediment export	36 (54)	33 (46)	18 (29)	46 (62)
Avoided N export	55 (78)	10 (15)	40 (57)	20 (29)
Avoided P export	60 (84)	6 (9)	42 (57)	21 (32)

The values of tiger habitat and ecosystem services, except for water yield, will increase in the Vision scenario and are primarily driven by the growth of forest area relative to the Plan scenario. These results show an important synergy: habitat quality is the result of the simultaneous presence of various conditions that can be measured through the assessment of ecosystem services. It results that this type of assessment, considering ecosystem extent and condition, as well as ecosystem services can bring together various actors, with different goals and agendas (eg. related to carbon sequestration, soil degradation, water yield) to ultimate support habitat conservation.

The results of this study have been used by WWF to provide technical expertise to Indonesian spatial planners. The paper indicates that before this assessment, local governments and other relevant stakeholders did not consider ecosystem services when carrying our spatial planning exercises. The study stimulated the incorporation of ecosystem services in environmental assessments at the provincial level in Sumatra. The national government appointed part of the study area as an ecosystem corridor through a Presidential decree (Sumatra Spatial Planning and Corridor RIMBA). Practically, a legal framework for sustainable land management and conservation was established.

Box 4: *Potential contribution of SEEA-EA to the case study Biodiversity and tiger habitat conservation in Indonesia*

This modelling exercise considers land cover and various ecosystem services to determine habitat quality for tigers. Ecosystem condition accounts could strengthen the analysis, as would the addition of other ecosystem services that are relevant to tigers. In this respect, the creation of a species account could support the analysis by linking ecosystem extent and condition accounts. Adding the economic valuation of ecosystem services may provide more incentives to keep habitat intact, by turning the assessment into an economic valuation related to specific policy options (eg. PES schemes). Both physical and monetary accounts ES accounts could demonstrate the many ancillary benefits of maintaining tiger habitat.

Ecosystem extent	***Ecosystem condition***	***ES supply and use, physical***	***ES supply and use, monetary***	***Thematic accounts***
Required to better estimate the impact of land cover change on habitat quality and ecosystem services. ***Indicators****:* - *Tropical lowland rainforests* - *Tropical montane rainforest* - *Tropical dry forests and shurbs* - *Plantations* - *Tropical flooded forests and peat forests* - *Croplands* - *Pastures* - *Settlement land* - *Roads*	Required to improve the calculation of ES provisioning and for the estimation of habitat quality. ***Indicators****:* - *Biomass of natural forest* - *Species abundance index* - *Living plant index* - *Nutrient concentrations (N)* - *Nutrient concentrations (P)* - *Habitat quality*	Required to expand the list of ES quantified with InVEST, better parametrize the model. ***Indicators****:* - *Carbon retention* - *Soil retention* - *Crop provisioning* - *Timber provisioning* - *Water regulation* - *Water purification* - *Species appreciation services* - *Nursery population and habitat maintenance services*	Necessary to assess the economic viability of the policy options, as well as the value currently provided by nature. ***Indicators****:* - *Value of carbon* - *Value of crop provisioning* - *Value of water supply and purification* - *Value of tourism activity*	Protected area accounts Species accounts for tigers

- *Protected area*				

4.4.4 Forest quotas for reducing deforestation in Brazil

Policy context and overview of the issue

The main policy to support biodiversity conservation in Brazil is through direct regulation, which is implemented through the Forest Code (FC) - a command and control instrument that requires land owners to establish a Legal Reserve (LR) in the property area covered with natural vegetation. Such reserves cover about 20 per cent in the State of São Paulo, but reaches up to 80 per cent in the Amazon region.

However, compliance has not been high, with only around 10 per cent of farms having LR. LRs are perceived to negatively impact the revenue generation potential of the area owned, indicating an incompatibility between conservation and agricultural development.

To increase the effectiveness of the FC and LR, the “Environmental Reserve Quotas or CRA” were introduced by the government. The CRA is a tradable forest certificate that provides a payment to landowners, and hence: (1) reduces the cost (or foregone revenue) from compliance with the FC; and (2) compensates landowners that decide to go beyond the required LR. An additional benefit of tradable CRA is that it has the potential to reduce social inequality, by transferring payments to parts of the State with lower income, or with land that is comparatively less production, but still forested. On the other hand, tradable CRA do not allow for the planning of effective conservation, as the loss or fragmentation of habitat can result from market dynamics, rather than being influenced with a clear plan.

In the state of São Paulo, the most industrialized and populated of Brazil, the challenge is to conserve two critical biomes: the Atlantic Forest and Cerrado. This study evaluates the cost-effectiveness of CRA in the state of São Paulo when introducing market constraints to address conservation goals (ie. to conserve clearly identified areas). In the study, the software Marxan with Zones was used to simulate different CRA markets, as well as to evaluate their cost-effectiveness in maintaining forestland with existing command-and-control regulations, such LR compliance.

Modelling approach

The assessment starts with the identification of the spatial distribution of LR, and with the determination of possible additional LR areas that would allow for the maintenance of forests with high biodiversity that deliver valuable ecosystem services. The authors used a database with data on forest areas on each Units of Agricultural Production (UPA). A UPA roughly corresponds to the size of a farm in the State of São Paulo. Next, the deficit and surplus of LR in each UPA were calculated, using the reference value of 20 per cent of forest cover required by the FC. Subsequently, the UPAs was combined in hexagons of 500ha each.

The opportunity costs for forest conservation were calculated by using land value as a proxy. This is done to reflect the willingness to accept payment for CRA. Land value data were obtained from semi-annually statistics on land market prices per hectare. The database contained, for groups of municipalities (EDR), maximum, minimum, and average land values for different land-use categories.

To associate the value of land in EDRs to land productivity, a map of administrative units classified by land price was overlaid with one indicating suitability for agriculture, as shown in Figure 47.

The analysis performed with *Marxan* indicated the priority class of forest certificate allocations. Classes of priority for conservation and restoration range from 0 (low priority) to 8 (high priority). Classes, between 5 and 8 were used as indicators for conservation effectiveness, while the planning units with classes that range from 0 to 4 were excluded.

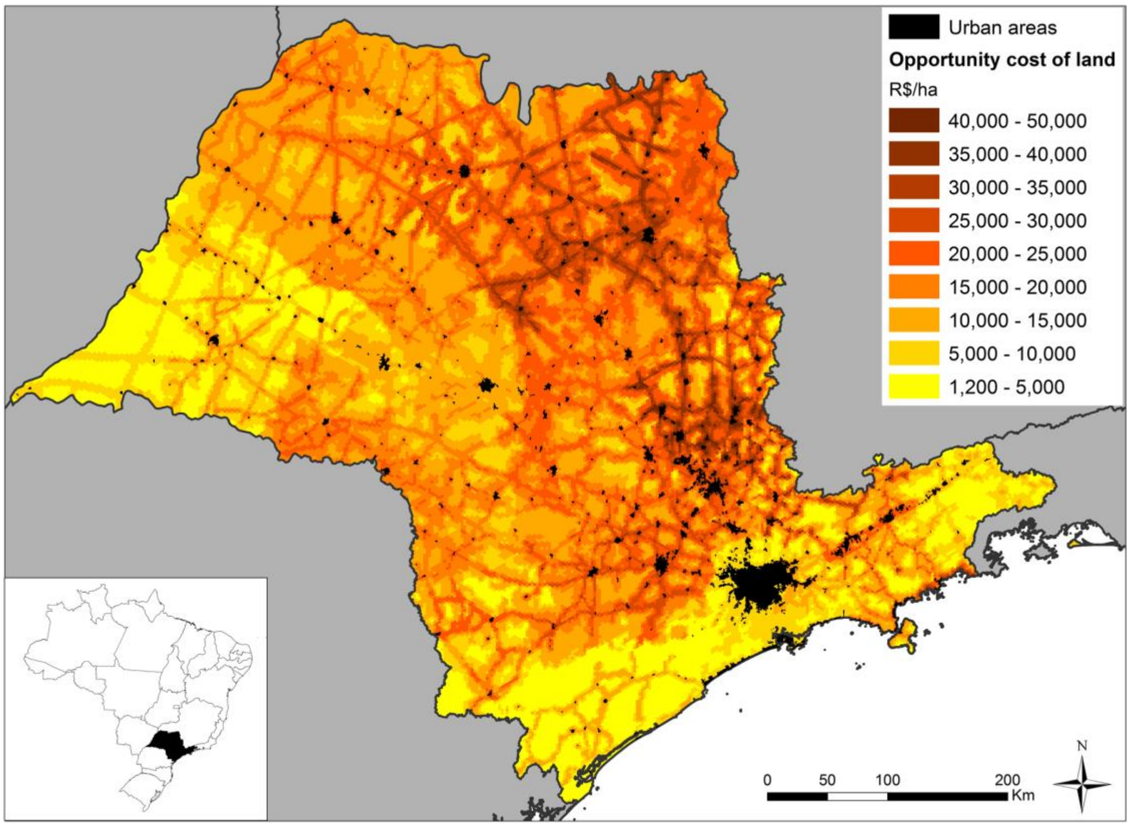

Figure 47: *São Paulo State – levels of opportunity-costs for forest conservation (Bernasconi et al., 2016)*

Scenarios, and related assumptions

To assess the cost-effectiveness potential of LR in the State of São Paulo three different scenarios were considered:

- **Baseline scenario:** the compliance of LR is based only on the current regulation without the introduction of CRAs.
- **Scenario 2:** the compliance of LR was assessed considering the introduction of tradable CRAs under the current legislation.

- **Scenario 3:** the compliance of LR was evaluated considering a variation of the CRA market, including the possibility to transfer CRAs only to existing high priority areas, including to reforestation areas.

In all the three scenarios the target of 2.3 million hectares (total deficit area) was considered. Planning units were identified and prioritized to total 2.3 million hectares of LRs.

Results of the analysis

The baseline scenario showed the highest potential economic loss, with a total opportunity cost reaching to R$37 billion from reaching full LR compliance. Compared to the first scenario, the second and the third ones show a reduction in opportunity costs of 76 per cent and 53 per cent respectively. The second scenario resulted in lower costs, amounting to R$8.9 billion. The third scenario resulted instead in an opportunity cost of R$17.4 billion.

Regarding the establishment of the new LR, the first scenario had almost 57 per cent of the new LR concentrated between priority classes 2 and 4, while only 12 per cent of the new LR were located in areas of higher priority classes (from 5 to 8). This is because most land has been converted, and there is little potential to introduce LR in intact habitats. Scenarios 2 and 3 allowed for the access to a larger number of high priority classes with the introduction of CRAs. Scenario 2 was characterized by an increase in conservation effectiveness of 22 per cent, while Scenario 3 showed a consistent increase of 44 per cent.

Considering cost effectiveness, the first scenario presented a ratio of 7.45 high priority hectares/million R$ as shown in Figure 48. The second scenario showed a cost-effectiveness ratio of 37.81 high priority hectares/million R, while the third one presented a ratio of 85.46 hectares/million R$. This is an indication that the third scenario delivers a much larger amount of high priority hectares per million R$ of opportunity cost. In these areas the opportunity cost is lower than in areas with extensive agriculture production, and the priority class is higher.

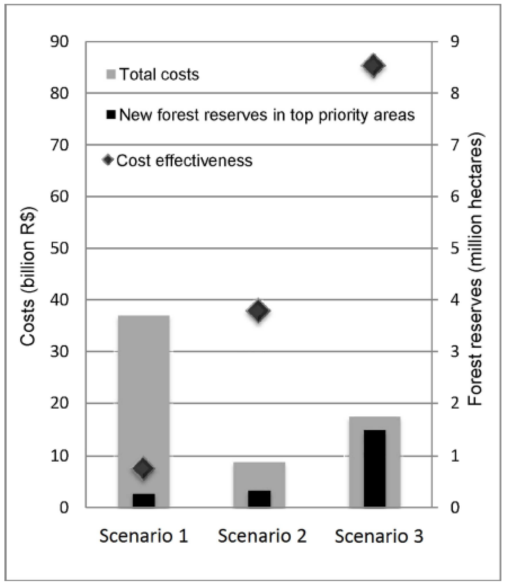

Figure 48: *Cost-effectiveness ratio by different scenarios (Bernasconi et al., 2016)*

In the second scenario, the areas identified using cost minimization optimization through Marxan are located in the central and western region of the state: in scenario 3 instead these are found in the central and northern areas, as shown in Figure 49. The two scenarios show only 16 per cent of coincidence, or overlap of the areas identified.

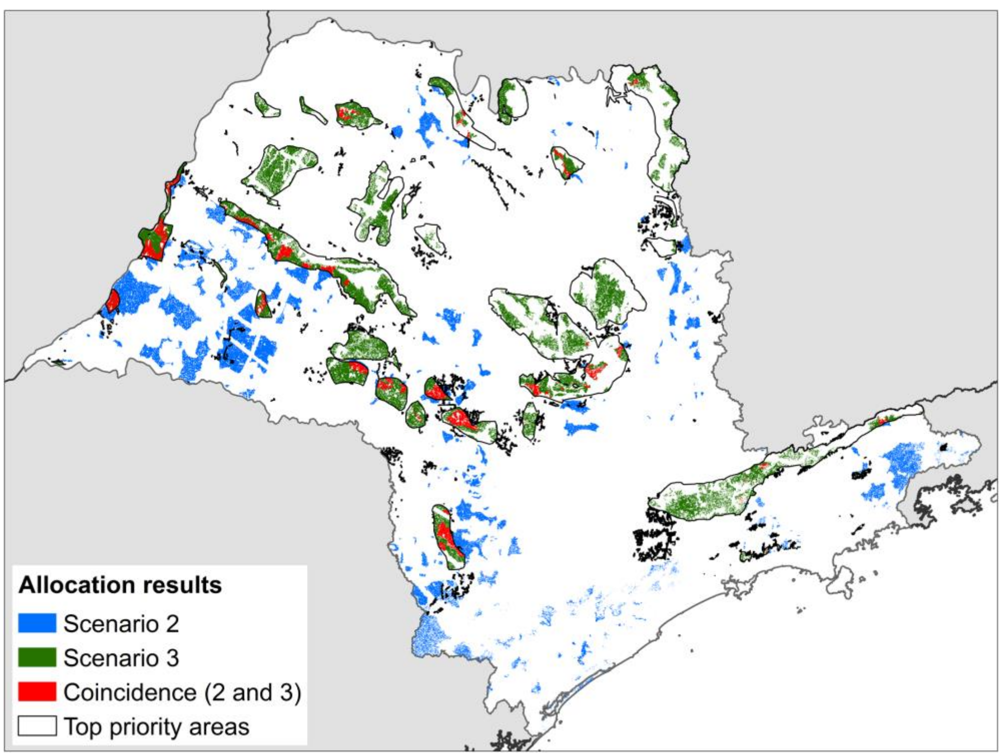

Figure 49: *Allocation of new Legal Reserves (LR) depending on different scenarios (Bernasconi et al., 2016)*

To compare the availability of alternatives, the results were summarized with a flexibility index, which is the number of selected planning units divided by the average selection frequency (>0) of all planning units. As a result, the flexibility index amounted to 805.3 and 872.7 for Scenario 2 and 3 respectively. In other words, Scenario 3 shows the larger set of available good alternatives when compared to Scenario 2.

The inclusion of trading within each biome reduces compliance costs by 76 per cent compared with the baseline of no trading. Although the inclusion of a new constraint targeting the Priority Areas almost doubled the cost (+95 per cent) compared with Scenario 2 of “free trade” constrained only by biome, it was still 50 per cent less costly than the baseline. The proposed scenario also showed substantially larger conservation gains relative to the increase in costs resulting in the most cost-effective option.

Box 5: *Potential contribution of SEEA-EEA to the case study Forest certificates for reducing deforestation in Brazil*

This study used the opportunity costs for forest conservation, calculated by using land value as a proxy. This could be replaced by the use of economic valuation of large set of ES relevant to the areas analysed (some will be more valuable than others, due to their higher ES provisioning). As a result, the analysis could be expanded with the use of condition and ES accounts, with the addition of monetary accounts. With this approach it may well be that the opportunity cost used as input in the model would change, and the optimization outcomes would change as a result.

Ecosystem extent	***Ecosystem condition***	***ES supply and use, physical***	***ES supply and use, monetary***
Required to better estimate the impact of land cover change on habitat quality and carbon sequestration. ***Indicators:*** - *Tropical lowland rainforests* - *Tropical montane rainforest* - *Tropical dry forests and shurbs* - *Plantations* - *Croplands* - *Pastures* - *Settlement land* - *Roads* - *Protected area*	Required to improve the calculation of ES provisioning and for the estimation of habitat quality. ***Indicators:*** - *Biomass of natural forest* - *Species abundance index* - *Living plant index* - *Nutrient concentrations (N)* - *Nutrient concentrations (P)* - *Habitat quality*	Required to expand the list of ES quantified, better parametrize the model. ***Indicators:*** - *Carbon retention* - *Soil retention* - *Crop provisioning* - *Timber provisioning* - *Water regulation* - *Water purification* - *Species appreciation services* - *Nursery population and habitat maintenance services*	Necessary to improve the estimation of land value and opportunity cost. ***Indicators****:* - *Value of carbon* - *Value of crop provisioning* - *Value of water supply and purification* - *Value of tourism activity*

4.4.5 Water pollution reduction in India and Sri Lanka

Policy context and overview of the issue

Beira Lake in Sri Lanka and Dal Lake in India are examples how natural infrastructure can tackle air and water pollution in urban areas. Natural infrastructure provides many services that can be valued, and often results in lower maintenance costs and higher climate resilience when compared to built infrastructure (IISD, 2019c).

Beira Lake is an artificial lake in Colombo that has an important role for social, cultural and religious activities. The lake is negatively impacted by human and industrial activities, and has been affected by urbanization, resulting in poor ecological conditions (IISD, 2019c). Beira Lake is surrounded by residential areas and economic activities, it receives wastewater from centralized and decentralized sewage systems and wastewater treatment facilities; however, this infrastructure is dated, the sewage system is undersized when compared with storm water runoff, and water circulation is minimal. The poor environmental conditions of the lake affect the ecosystem integrity of the lake, human health and economic activity (eg. leisure, tourism, property prices for existing and new real estate developments).

Dal Lake is an iconic natural lake located in the state of Jammu and Kashmir that is an important economic and cultural asset for Srinagar and the region. Growing pollution loads, excessive water extraction, as well as land grabbing and land conversion to agriculture and settlements, have led to a sharp decrease in water quality, loss of eutrophication, loss of fish stocks and recreational activities, including tourism (IISD, 2018a). The lake remains an important source of livelihood for the local population due to its environmental and infrastructure services. However, the declining size of the lake and of the water amount, coupled with the increase of pollutants, is severely limiting the potential contribution of the lake to the well-being of the population.

Modelling approach

The Sustainable Asset Valuation (SAVi) model was utilized, and customized to assess the performance of various intervention options to solve water pollution issues of Beira Lake and Dal Lake. While the models utilize similar building blocks (see Table 25), they were fully customized in order to 1) assess different drivers of change and dynamics and 2) to estimate different externalities and policy interventions. The analysis of investment outcomes was performed with an integrated System Dynamics model and with a project finance model (IISD, 2019c).

Table 25: *SAVi models used in both analyses (IISD, 2019c; IISD, 2018a)*

Beira Lake	**SAVi Water Balance Model**: to understand biophysical dynamics in a lake
	SAVi Wastewater Model: to assess both capacity and cost of upgrading wastewater treatment plants and facilities
Dal Lake	**SAVi Water Balance Model**: to understand biophysical dynamics in a lake
	SAVi Wastewater Model: to evaluate the use of various technologies for water treatment
	SAVi Energy Model: to assess the impacts of the installation of solar panels that can provide electricity to sewage treatment plants and pumping stations
	SAVi Natural Infrastructure Model: to evaluate the outcomes of the construction of an artificial wetland, or the rehabilitation of the lake
	SAVi Roads Model: to forecast the impacts of a new road that has been planned and would result in further land conversion

Figure 50 presents the simplified system map (Causal Loop Diagram, CLD) created with a multi-stakeholder approach and co-creation modelling techniques used in Srinagar, with direct contribution from various stakeholders, including the Tourism Directorate and the Lake and Waterways Development Authority (LAWDA), in addition to representatives from academia and civil society. The diagram shows the interconnections that exist between water quality, human health and economic activity. It also highlights how an increase in population leads to environmental pressures via wastewater generation, land conversion and unsustainable land-use practices. The diagram highlights the complexity of the system analysed, with several reinforcing and balancing factors determining the performance of the system. Specifically, it shows that the growth in economic activities that are enabled by the services provided by the lake has been one of the primary causes for the degradation experiences in the last decades.

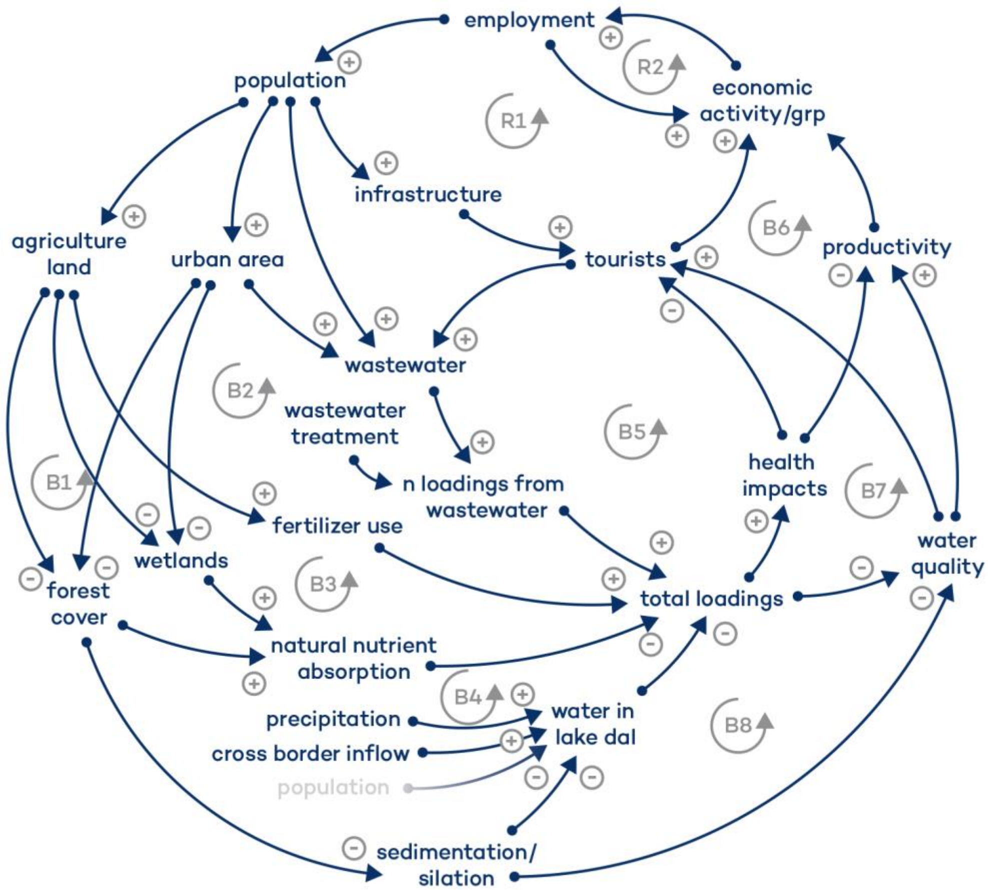

Figure 50: Simplified CLD – Dal Lake (IISD, 2018a)

4.4.5.1 Sri Lanka - Beira Lake

Scenarios, and related assumptions

The SAVi assessment considered four scenarios for Beira Lake:

- **Scenario 1:** Business-as-usual (BAU). This scenario assumes a continuation of current trends, such as the absence of lake dredging or the amount of wastewater treated.
- **Scenario 2:** Wastewater treatment upgrades. This scenario assumes investments in upgrading wastewater treatment facilities between 2020 and 2025. The aim of this scenario is to reduce nutrient loadings.
- **Scenario 3:** Dredging of lake deposits. This scenario assumes that in 2021 a single operation of dredging will be carried out to reduce the volume of phosphorus deposit.
- **Scenario 4:** A combination of scenarios 2 and 3.

Results of the analysis

Table 26 shows the cumulative required investment and resulting benefits per scenario between 2020 and 2025, relative to BAU (in US$).

Since the BAU scenario does not assume investments for restoring the Beira Lake, water quality is expected to further deteriorate over time. Therefore, in Scenario 1 the economic value of properties surrounding the lake will decrease by almost US$173,000.

Scenario 2 would solve the problems of eutrophication and algae blooms, and water clarity will increase due to the reduction in phosphorus and nitrogen loadings (Figure 51). Therefore, the property value around Beira Lake will increase by more than US$14 million by 2025. Moreover, recreational activities will be encouraged by water quality improvements, thereby generating US$10 million in additional spending between 2020 and 2025. Overall, the cost-benefit ratio suggests that the benefits are almost 40 times greater than the initial costs of wastewater treatment upgrades.

Scenario 3 assumes a one-time dredging of the lake and will only slightly increase water clarity. This is due to the high volume of loadings that reach the lake every year, which will offset short term gains in waste quality within a couple of years. Although the valued benefits of this scenario are twice as high as the costs, dredging the lake will not restore the ecosystem of the lake and thus it will not produce long-lasting positive impacts on property value and recreation.

Scenario 4 will significantly increase water clarity, by combining dredging and reduction in loadings. This scenario will increase property value more markedly, by more than US$43 million by the end of 2025 compared to the BAU scenario. Furthermore, recreational spending will provide around US$19.4 million between 2020 and 2025.

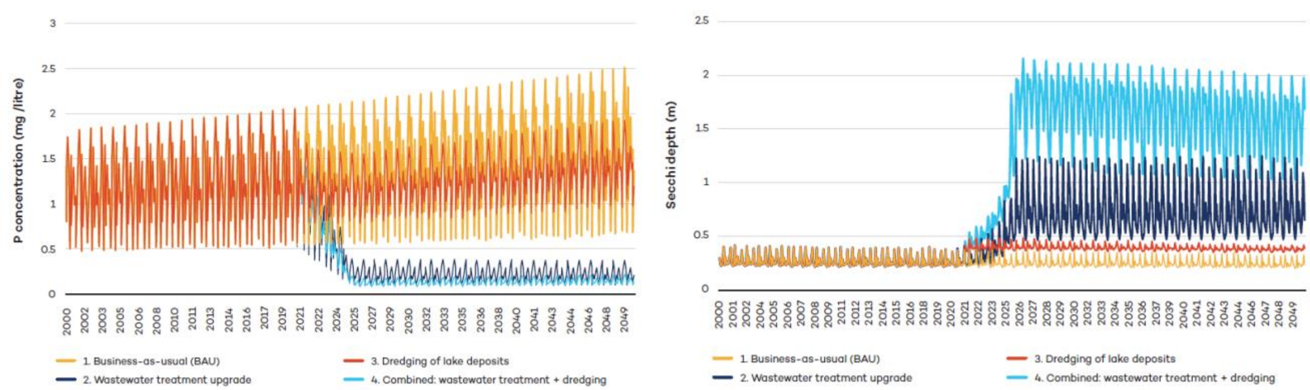

Figure 51: *Phosphorous concentration (left) and Secchi depth (water clarity) (right) under the four scenarios analysed (IISD, 2019c)*

Table 26: *Cost-benefit analysis for different scenarios, Beira Lake – Sri Lanka (IISD, 2019c)*

Costs and benefits (in USD, discounted)	Scenarios			
	1. Business-as-usual (BAU)	**2. Wastewater treatment upgrades**	**3. Dredging of lake deposits**	**4. Combined: wastewater treatment and dredging**
Costs				
Costs for wastewater treatment upgrades				
Nitrogen removal technology	\	479,314	\	479,314
Phosphorus removal technology	\	140,718	\	140,718
Cost of sediment removal	\	\	5,712,616	5,712,616
Total cost (2020 to 2025)	****	**620,032**	**5,712,616**	**6,332,648**

Costs and benefits (in USD, discounted)	Scenarios			
	1. Business-as-usual (BAU)	**2. Wastewater treatment upgrades**	**3. Dredging of lake deposits**	**4. Combined: wastewater treatment and dredging**
Benefits				
Property value net change by end of 2025*	(172,770)	14,266,034	5,098,886	43,221,392
Additional spending for recreation by local population	\	656,674	433,114	1,240,463
Additional spending for recreation by tourists	\	9,676,134	6,427,039	18,373,396
Total benefits (by end of 2025)	**(172,770)**	**24,598,842**	**11,959,039**	**62,835,251**
Net results	**(172,770)**	**23,978,810**	**6,246,424**	**56,502,603**
Benefit to cost ratio	**N/A**	**39.67**	**2.09**	**9.92**

**The calculated property value net changes do not account for the market-driven, organic appreciation of property values around South-West Beira Lake over time. For example, the negative value in the BAU scenario indicates solely the negative impact of deteriorated water clarity on property values.*

4.4.5.2 India – Dal Lake

Scenarios, and related assumptions

The SAVi assessment for Dal Lake considered a total of 11 scenarios, which are grouped into a baseline and four alternative scenarios:

- The Business-as-usual (BAU) scenario assumes a continuation of historical trends.
- Grey infrastructure interventions: implementation of different treatment options for selected polluters, such as houseboats or periphery population. It also considers the net impacts of utilizing solar PV for sewage treatment.
- Hybrid interventions: conventional sewage treatment is supported by artificial wetlands. In this set of scenarios, the impact of wetlands on nitrogen concentration in the lake is considered.
- Relocation of lake dwellers: relocation of dwellers, who are compensated and provided with new opportunities for developing their livelihoods.
- Road construction: road construction crossing Dal Lake. It also considers additional storm water loadings from pervious surfaces.

Results of the analysis

The baseline scenario shows that in the absence of investments for water treatment the lake would face ecological collapse by 2060. Eutrophication will increase due to population growth and insufficient sewage treatment, as well as reduced water in the lake. Both factors increase the concentration of pollutants and negatively impacting fishing and recreational activities.

All grey treatment scenarios show that the expansion of the sewage network and wastewater treatment capacity and the use of PV for wastewater treatment plants can obtain the highest reduction of nitrogen concentration by 2060. If the scenario also includes the creation of an artificial wetland, the water quality of Dal Lake would improve even further. In this case, the revenues from the tourism and fishery sectors would increase by 173 per cent and 170 per cent respectively, when compared to the baseline scenario.

Figure 52 summarizes the impact of each intervention option and scenario on nitrogen concentration and net economic benefits. The estimation of net benefits considers capital and operation and maintenance costs, as well as increased revenues from fishing and tourism and the social cost of carbon from increased carbon sequestration. The figure shows that, on the one hand, road construction will worsen the situation, the improved treatment of houseboats would be largely ineffective and, on the opposite hand, investing in artificial wetland, increased wastewater treatment and use of solar PV generates the highest net benefit and the larger reduction in nitrogen concentration.

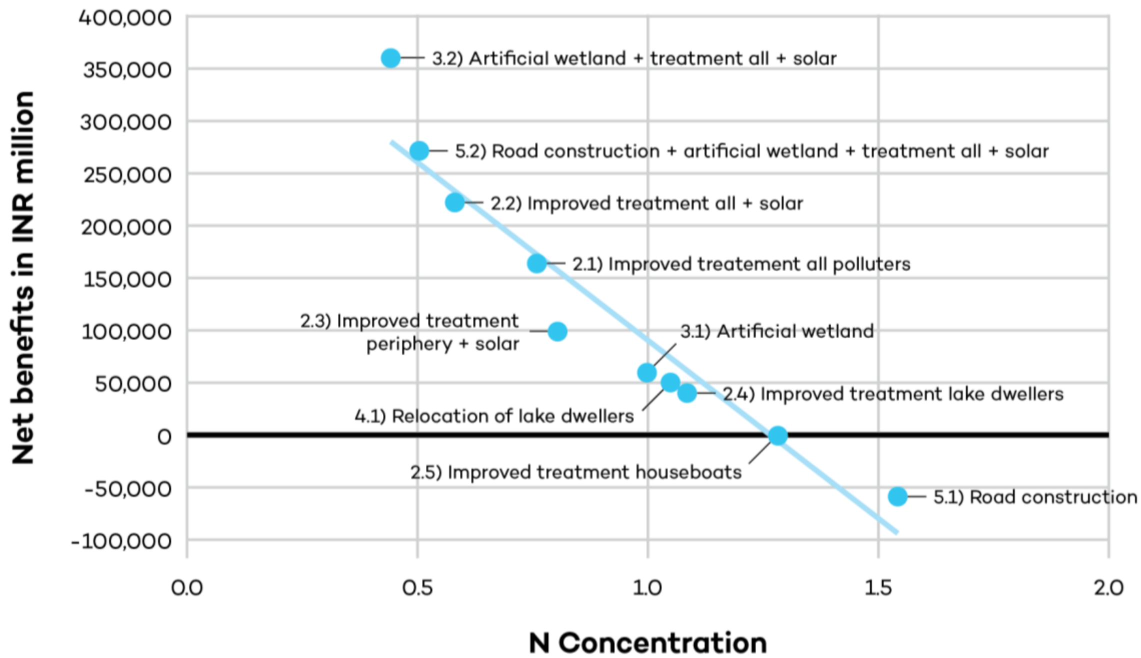

Figure 52: *Comparing net benefits and Nitrogen concentration for different intervention options, Dal Lake – India (IISD, 2018a)*

***Box 6:** Potential contribution of SEEA-EA to the case study Water pollution reduction in India and Sri Lanka*

The analysis performed considers a few ecosystem services, but their estimation is based on existing publications, not on accounts. The model is developed takes into account spatial information and estimates ecosystem service provisioning and related outcomes (eg. impacts of water pollution). The models and analysis would be strengthened by adding better formulations for ES that are location specific, based on a spatial and hydrological assessment. This would add more and more precise ES valuation and improve the economic assessment of the various intervention options analysed.

Ecosystem extent	***Ecosystem condition***	***ES supply and use, physical***	***ES supply and use, monetary***

Extent accounts would support model parametrization and calibration for this local assessment. ***Indicators:*** - *Public open green space* - *Public open blue space* - *Other public open space* - *Area allocated to streets* - *Private open space* - *Building footprint and other infrastructure* - *Roads*	Required to improve the calculation of ES provisioning. ***Indicators:*** - *Suspended matter (TSS)* - *Chlorophyll A* - *pH* - *Nutrient concentrations (N)* - *Nutrient concentrations (P)* - *Dissolved oxygen* - *Temperature* - *Biological Oxygen Demand (BOD)* - *Bacterial coliforms* - *Water-related species populations richness/abundance*	Required to expand the list of ES quantified, possibly with InVEST or other models. ***Indicators:*** - *Water regulation* - *Water purification (tonnes of waterbourne pollutants removed)* - *Carbon retention*	Necessary to better assess the economic viability of the policy options considered. ***Indicators:*** - *Value of water supply and purification* - *Value of tourism activity*

4.4.6 Deforestation and development planning in Rwanda

Policy context and overview of the issue

In 2011, Rwanda's Government set the ambitious goal to restore two million hectares of the country's forest cover under the Bonn Challenge, a global goal to bring 150 million hectares of degraded and deforested landscapes into restoration by 2020, launched by the Government of Germany and IUCN (BMU et al., 2016). This goal permeated into the country's legislation, development policies and Green Growth Strategy. The country had an interest in aggressively enhancing forest natural capital for the critical ecosystem services it delivers to all Rwandans.

In 2014 Rwanda was covered by around one-third of its surface by forests, of which less than 40 per cent consisted of natural forest, while more than 60 per cent of forest plantations. Most of the natural forests were confined to only four protected areas. Products from Rwandese forests, such as fuelwood, are the most relevant source of energy for more than 85 per cent of the total population; only 5 per cent of Rwandans have stable access to electricity. Moreover, charcoal and fuelwood as well as other nature-based products are a significant source of income in Rwanda; it has been estimated that the total wood energy sector amounted to around 3.4 per cent of the national GDP. On the other hand, while providing revenues and supporting rural livelihoods, the extraction of forest products is an important driver of deforestation in the country.

The Government's response to energy demand, deforestation and low productivity forest plantations was outlined in a series of legislative and policy developments that were used as the foundation for the inclusion of forests in the Economic Development and Poverty Reduction Strategy (EDPRS II), Rwanda's Vision 2020, and Rwanda's Green Growth Climate Resilient Strategy. The EDPRS II set the target of increasing forest cover from 28.8 per cent to 30 per cent of the country by 2018. For fuelwood, the target was designed to reduce consumption from 86 per cent to 50 per cent by 2020. In addition, Rwanda's Green Growth Strategy outlined lines of action for increasing sustainable forestry and agroforestry for the provision of ecosystem services including timber and energy provisioning services to meet current and future demand. Agroforestry systems would comprise an important component of this commitment (MINIRENA, 2014).

Rwanda recently began the implementation of SEEA accounts, specifically, land and water accounts. Through a collaboration funded by the Science for Nature and People Partnership, the Integrated Economic-Environmental Modelling (IEEM) model was developed, a macroeconomic Computable General Equilibrium (CGE) model that incorporates land use and SEEA accounts. Specifically, the IEEM Platform was linked with ecosystem services modelling (IEEM+ESM) to better understand and analyse green growth strategies on the relationship between land-use dynamics and green growth in Rwanda.

Modelling approach

The Integrated Economic-Environmental Modelling (IEEM) is a coupled CGE and land-use model that supports the integration of SEEA EA data in economic assessments (Banerjee et al, 2016a).

The IEEM Platform integrates non-material, regulating and cultural and aesthetic ecosystem services by linking IEEM with spatial ES modelling (IEEM+ESM) (Banerjee et al., 2020). The bridge between the two modelling frameworks is made possible through a Land Use Land Cover change (LULC) modelling module. There are various LULC change models that may be used including the *Conversion of Land Use and its Effects (CLUE)* modelling framework (Verburg et al., 1999; Verburg et al., 2008; Verburg & Overmars, 2009).

The LULC change model is used to spatially allocate IEEM demand for land across a high-resolution spatial grid to produce LULC projections for a baseline and policy scenarios. These spatial data sets are used as the basis for ecosystem services model runs with tools such as the Natural Capital Project's InVEST suite of models (Sharp et al., 2018) or the Artificial Intelligence for Ecosystem Services (ARIES) tools (Villa et al., 2014).

The main variable of change in the ecosystem services modelling are the new LULC maps for each scenario, though for some ecosystem services, some climate variables or changes in land management practices may be included.

The main inputs of the model are the System of National Accounts (SNA) and the Social Accounting Matrix (SAM), as well as the national land cover map. Additional data inputs are required for modelling specific ecosystem services.

The main outputs of the model are macroeconomic performance indicators, eg. GDP, value added by sector, government revenues and expenditures, disposable income, private consumption and savings. The model also forecasts land cover changes, and future provisioning of ecosystem services.

Figure 53 shows the modelling workflow of the IEEM+ESM platform, specifically for the generation of future land cover maps.

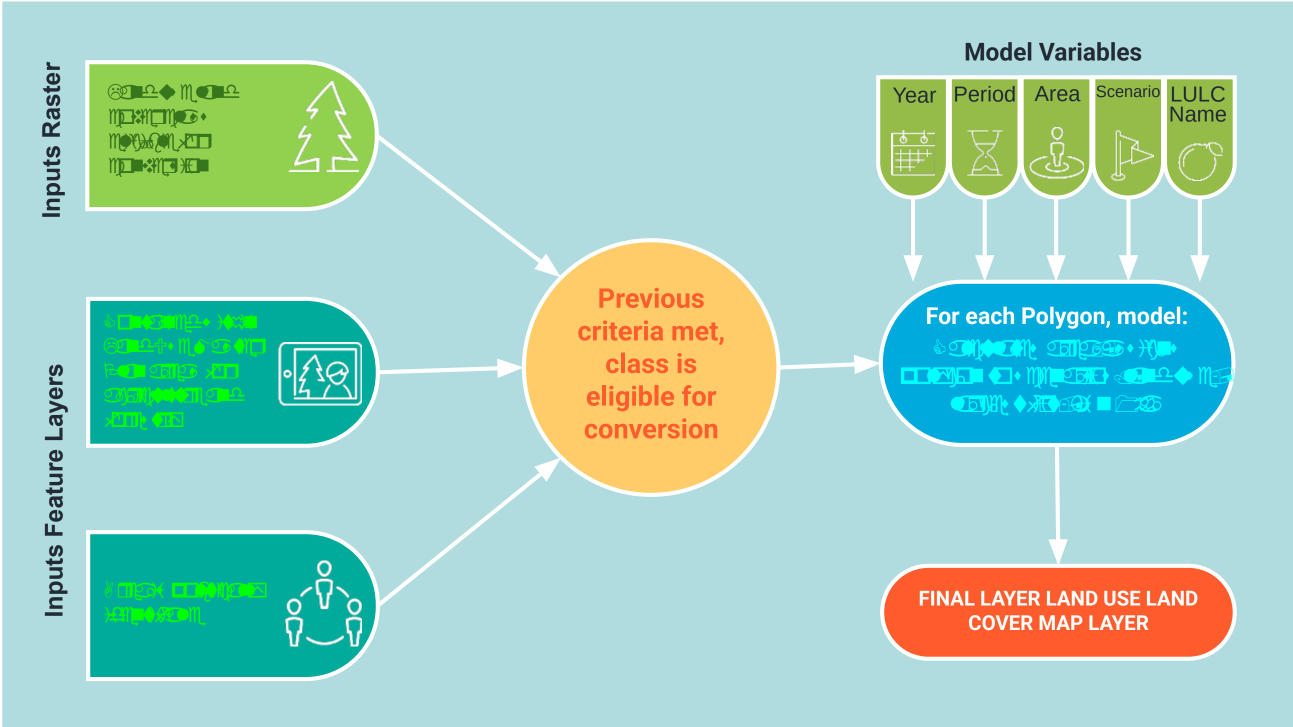

Figure 53: *Modelling workflow (Banerjee, et al., 2020)*

Scenarios, and related assumptions

The policies proposed by the Government of Rwanda were used to design scenarios to evaluate with IEEM+ESM. The BASE scenario simulates a balanced growth path with the economy and land use following past trends from 2014 to 2035. It is the reference scenario to which all other scenarios were compared. Table 27 provides an overview of each scenario simulated.

***Table 27**: Description of scenarios analyzed in IIEM (Banerjee et al., 2020)*

Name	Description
BASE	• Based on business as usual trends
FOR1	• Forest plantation area is increased by 110,400 hectares to 2035 • Total investment cost is US$285,581,699 (US$20,398,693 annually). • Land endowment is fixed; therefore, forest plantation expansion causes a reduction in land for agriculture
FOR2	• Forest plantations increased by 110,400 hectares between 2018 and 2035 • Cost of the policy is US$285,581,699 • Land endowment is not fixed, so forest plantations can expand without reducing availability of agricultural land.
FUEL	• Efficient cook stoves and kilns reduce woody biomass used by 25 per cent • Rural household labour productivity is increased by 0.125 per cent due to less work hours lost to acute respiratory diseases, eye disease and burns.
IRRIG	• 85,473ha of farmland currently cultivated without irrigation or with irrigation infrastructure in disrepair are brought into irrigated agricultural production. Irrigation will increase yields and crop values given quality improvements and seasonality of irrigated crops.
FERT	• Increase in area and quantity of fertilizer applied to all cropland to 45 kg/ha/yr
COMBI1	• Joint implementation of FOR1, FUEL, IRRIG, and FERT
COMBI2	• Same as COMBI1 but does not account for urban expansion

Results of the analysis

Starting with indicators of carbon sequestration and economic performance (Table 28), the best performer is the COMBI scenario. In this case there is an expansion of forest plantation (FOR1 and FOR2), but possible constraints to growth due to competition for land are more than offset by reducing the reliance on fuelwood (FUEL) and increased land productivity (IRRIG and FERT). Further, the FUEL scenario reduces energy costs, leading to higher disposable income, and increases labour productivity. The IRRIG and FERT scenarios increase land productivity instead, leading to higher value addition and investment. All these factors contribute to higher economic growth in the COMBI scenario. A scenario where production and value added are kept in alignment with the BAU scenario, and agriculture land declines in favour of forestland was not tested.

Table 28: *Impacts of different scenarios analyzed by the IEEM+ESM platform: difference relative to the baseline scenario in 2035, in million US$ (Banerjee et al., 2020).*

	FOR1	FOR2	FUEL	IRRIG	FERT	COMBI
Absorption	*(25)*	*92*	*490*	*185*	*2,653*	*3,312*
Private Consumption	*(5)*	*79*	*479*	*141*	*2,121*	*2,744*
Fixed Investment	*(20)*	*12*	*11*	*44*	*532*	*567*
Exports	*72*	*47*	*165*	*43*	*596*	*886*
Imports	*19*	*22*	*94*	*13*	*467*	*607*
GDP	*28*	*116*	*561*	*215*	*2,781*	*3,591*
Genuine Savings	*(34)*	*11*	*27*	*73*	*713*	*763*

Continuing with results on wealth, Genuine Savings[19], all scenarios are wealth-enhancing with the exception of FOR1 due to competition for land and how this impacts household savings. Nonetheless, in decomposing Genuine Savings, the FOR scenarios have a positive impact on its natural capital stock component. In the case of the IRRIG and FERT scenarios, there is a reduction in forest natural capital stocks, which has a negative impact on Genuine Savings. On the other hand, the foreign investment financing in these scenarios contributes positively to Genuine Savings by enhancing output and incomes. Overall, land-use impacts in IRRIG are small while in FERT, the large increase in agricultural productivity frees up land to be reallocated to livestock. FERT has the largest impact on Genuine Savings, increasing it by US$713 million while COMBI1 boosts Genuine Savings by US$763 million (Banerjee et al., 2020).

Summarizing, in terms of evaluating Green Growth, the FERT and COMBI scenarios are the greatest "winners" for Rwanda from the perspective of economic growth. However, from an ecosystem services perspective, the FOR and COMBI scenarios, which help reverse a 25-year trend of forest loss in Rwanda, provide the greatest gains in ecosystem services. Of these, the FOR scenarios yield reductions in nutrient

[19] Genuine saving adjusts SNA saving by deducting the value of depletion of the underlying resource asset and pollution damages, and considers current educational spending as an increase in saving, since this spending may be considered to be an investment in human capital (rather than consumption, as in the traditional national accounts).

export while when combined with fertilization in the COMBI scenarios, the net effect is an increase in nutrient export, though to a lesser degree than the FERT scenario.

It should be noted that the results mentioned above do not consider a full economic valuation of ecosystem services. For instance, the avoided cost emerging in the COMBI scenario from higher carbon storage (eg. possibly linked to the introduction of a carbon tax or a carbon border adjustment policy, or simply the cost to meet national emission reduction targets) or nitrogen export (eg. via avoided impact from reforestation on water purification costs). These costs or added benefits that do not have a monetary value are currently not included in the economic analysis but do represent societal costs. Thus, while IEEM can make these “hidden costs” more visible, feedbacks between ecosystem service supply and the economy must be considered if the full cost of alternative policies and investments to achieve green growth are to be taken into account (Banerjee et al., 2020). Including these economic valuations call for the further refinement of the modelling approach, eg. via the use of daily or monthly climate data, and the use of various climate projections (CMIP5) from different global circulation models.

***Box 7**: Potential contribution of SEEA-EEA to the case study Deforestation and development planning in Rwanda*

The modelling approach considers the relationship existing between economic activity and land use. Ecosystem condition and ES accounts could be added, leading to the economic valuation of ecosystem services (either model-based or estimated with ES monetary accounts). Some of these ES are modelled, but not valued monetarily because of the absence of a market price. With the availability of the economic valuation of ES, these economic values could be used as input in the GCE model. This would improve the economic assessment, possibly considering other economic losses resulting from the loss of ecosystem services (beyond land), and approximating an assessment of the societal value of intervention options.

Ecosystem extent	***Ecosystem condition***	***ES supply and use, physical***	***ES supply and use, monetary***	***Thematic accounts***
Required to better estimate the impact of land cover change on ecosystem services. ***Indicators***: - *Temperate tropical lowland rainforests* - *Temperate tropical montane rainforest* - *Temperate tropical dry forests and shrubs* - *Plantations* - *Croplands* - *Pastures* - *Settlement land* - *Roads*	Required to improve the calculation of ES provisioning and for the estimation of habitat quality. ***Indicators***: - *Biomass of natural forest* - *Species abundance index* - *Living plant index* - *Nutrient concentrations (N)* - *Nutrient concentrations (P)* - *Habitat quality*	Required to expand the list of ES quantified with InVEST, better parametrize the model. ***Indicators***: - *Carbon retention* - *Soil retention* - *Crop provisioning* - *Timber provisioning* - *Water regulation* - *Water purification* - *Species appreciation services* - *Nursery population and habitat maintenance services*	Necessary to assess the economic impact of ES provisioning, and the viability of proposed policy options. ***Indicators***: - *Value of carbon* - *Value of crop provisioning* - *Value of water supply and purification* - *Value of tourism activity*	Relevant for the assessment of ES that affect economic activity (eg. water)

4.4.7 Integrated planning for ecosystem conservation in the Heart of Borneo

Policy context and overview of the issue

The Heart of Borneo (HoB) is a region of 22 million hectares of tropical forest that covers approximately 30 per cent of the land area of the island of Borneo. It is the largest remaining transboundary tropical forest expanse of Southeast Asia and it crosses three countries: Indonesia (Kalimantan provinces), Brunei Darussalam, and Malaysia (Sabah and Sarawak provinces). The region, which hosts 6 per cent of global biodiversity and the headwaters of 14 of the 20 major rivers of the island, provides various forest ecosystem services that are essential for the livelihoods of local communities.

The ecosystems of the HoB are threatened by the overexploitation of natural resources; in particular, mining activities, palm oil plantations, and the industries of pulp, paper, and timber, led to rapid forest degradation and deforestation. Population growth and the impacts of climate change are also compromising the delivery of essential ecosystem services to the 11 million people of the island of Borneo.

In this context, the HoB initiative was formalized in 2007 by a joint declaration of the governments of the three countries that share this region. The aim of the initiative is to protect the livelihoods of the people who rely on local ecosystem services, and the work performed intends to inform policy and decision makers on sustainable management of forests and other land-uses. The modelling work presented in the next sections was created to support the reconfirmation of the HoB declaration by the governments of Indonesia, Brunei Darussalam and Malaysia at the Rio+20 conference in 2012.

Modelling approach

The modelling approach used by the HoB initiatives includes both qualitative and quantitative methods, which were used to analyse the dynamics in the Indonesian HoB area only due to lack of data for Brunei Darussalam and Malaysia.

The first step consisted of kick-off workshops and green economy dialogues with government, experts, and other stakeholders, to support the formulation of spatial development scenarios and modelling work, using qualitative methods. Next, three quantitative models were developed and linked to one another to evaluate the impacts of those spatial scenarios and form the “HoB modelling framework”:

- IDRISI Land Change Modeler – LCM
- Integrated Valuation of Ecosystem Services and Trade Offs - InVEST
- System Dynamics macroeconomic model, integrating social, economic and environmental dynamics.

LCM is a quantitative scenario generation modelling tool that forecasts future land-cover changes. LCM was used to develop the scenarios considered in the HoB initiative, based on land-cover changes recorded in Kalimantan from 2000 to 2009. The modelling was limited to changes in natural forests extent due to the complexity of land-cover changes. Anthropogenic and biophysical drivers of land-cover changes were included in the modelling work, such as roads, settlements, slope, and fires. Concessions for mining, palm oil, and forestry were also considered.

Land-cover and land-use maps were then imported as main inputs into *InVEST*, allowing for the assessment of the provision of key ecosystem services. *InVEST* models were used to evaluate and value the impact of each scenario on water supply, water purification through nutrient retention, and sediment retention.

To complete the modelling framework, a macroeconomic System Dynamics (SD) model was utilized. The Casual Loop Diagram (CLD), which represents the basis of the model, was developed during a kick-off workshop with stakeholders (Van Paddenburg et al., 2012). The CLD, was used as a starting point to develop the SD mathematical model, which was initially based on Millennium Institute's T21 model (Millennium Institute, 2005). This model was heavily customized to the Indonesian context, and was particularly expanded to better represent natural capital. The *SD* model includes the ecosystem services mentioned above and was calibrated using land cover data from LCM and ecosystem service data from the *InVEST* analysis (Figure 54).

The three models generated cross-sectoral spatial scenarios addressing environmental and socioeconomic issues in a single framework.

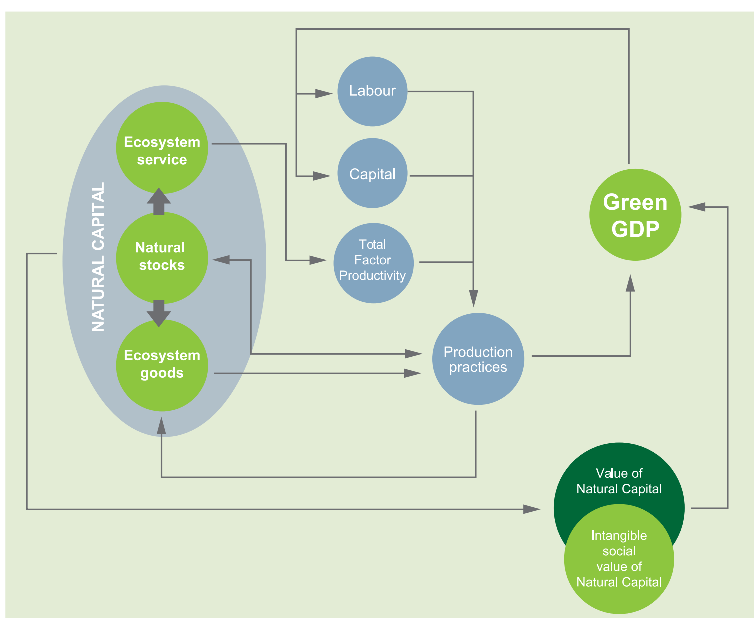

Figure 54: *Conceptual overview of the nature-economy system in an economy that values natural capital (Van Paddenburg et al., 2012)*

Scenarios, and related assumptions

Two main scenarios were simulated and analysed in the HoB study, with detail assumptions presented in Figure 55:

- Business-as-usual (BAU): this scenario does not consider sustainable practices and includes developments under forestry, mining, and palm oil concessions.
- Green Economy (GE): this scenario includes interventions related to certified palm oil, timber and mining concessions, protection of forest land by allowing for the expansion of palm oil on degraded land only, and including investments in renewable energy and biodiversity-based industries.

Theme	Business as Usual (BAU)	Green Economy (GE)
Spatial planning	Limited enforcement or reconciliation of land use plans leads to deforestation and forest degradation	Coherent land use plans including the creation of a category for degraded land, expanding community forests and implementation of watershed protection
Protected areas	Poorly managed protected areas lead to loss of biodiversity and fragmentation of natural habitats	Effective protection of natural habitats with improved connectivity among protected areas
Forestry	Widespread conventional logging and plantation within High Conservation Value Forest (HCVF) Areas with inactive forestry concessions result in degradation due to lack of management	Reduced impact logging, international certification of sustainable forest management, plantations limited to highly degraded or deforested areas that are not HCVF Concession management is improved. Inactive forestry land is protected to reduce degradation. Forest restoration concessions are implemented within natural forest areas following logging
Palm oil plantation	Oil palm expansion is permitted in natural forest areas and HCVF No improvement in oil plantation management	Oil palm plantations do not expand in any area of natural forest. Land swaps for permits granted within natural forest, to ensure expansion on degraded land only Roundtable for Sustainable Palm Oil (RSPO) ensures that management practices are improved, including improved fertilizer and pesticide application management
Mining	Mining causes forest degradation within concessions and air and water pollution	Mining follows international good practice guidelines, with improved waste management treatment reducing impacts on air and water quality
Agriculture	No improvement in agricultural practices, increasing reliance on chemical fertilizers, use of monocultures results in greater vulnerability to pests and diseases	Sustainable agriculture practices maintain and restore soil quality, use of chemical fertilizers is reduced, larger biodiversity gene bank provides wild varieties that may be hybridized to ensure greater resilience to pest and diseases
Energy	Energy consumption grows, reducing exports and increasing the cost of energy use Power is mostly generated from coal and other fossil fuels, limiting exports and generating GHG emissions	Increased energy efficiency reduces domestic consumption (especially of fossil fuels), renewable energy use expands, costs and impacts of fossil fuel consumption are reduced Investments in non-hydro renewable energy power plants are implemented to decentralize power generation and to reduce consumption of coal for electricity supply and lower GHG emissions
Biodiversity-based enterprises	Limited infrastructure and support to advance biodiversity-based products such as NTFP and agro-forestry	Sustainable biodiversity products from legal community forests (NTFP and agro-forestry), bioprospecting and biotechnology supports soil quality, minimizes erosion and sedimentation and secures forest carbon by reducing pressure to convert forests
Innovative green sectors	Limited infrastructure and support to advance innovative green sectors	New business models build local economies, e.g. using 'waste products' from waste produced by current HoB industries

Figure 55: *Assumptions used for the creation of the BAU and GE scenarios (Van Paddenburg et al., 2012)*

Results of the analysis

Figure 56 provides a graphical representation of the main differences between the BAU (left) and GE (right) scenarios.

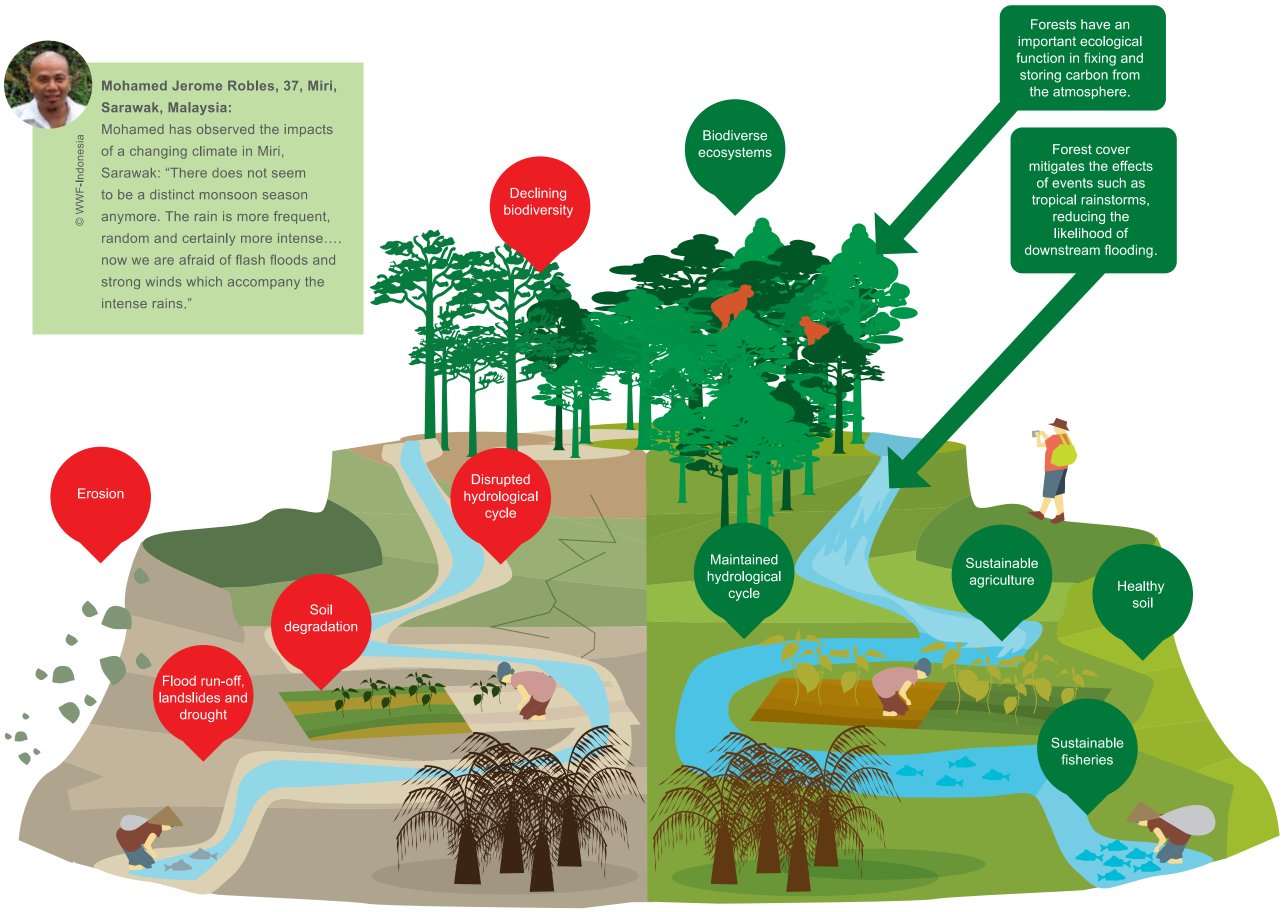

Figure 56: *Graphical representation of results of the BAU (left0 and GE (right) scenarios. The GE scenario shows avoided costs and the emergence of added benefits, providing resilient growth in the future without impacting negatively on the environment (Van Paddenburg et al., 2012).*

Regarding economic outcomes, GE projections indicate that GDP will grow more rapidly than in the BAU scenario. Growth under the GE scenario was evaluated using a conventional and green formulation for the estimation of GDP, as shown in Figure 57 and Figure 58. Green GDP includes the value of natural capital, which also accounts for the use of natural resources that are both renewable and non-renewable for the generation of value added. Thus, while GDP is higher in the GE scenario than in the BAU case for both GDP and Green GDP, the difference is more marked when considering the latter.

In addition to higher GDP, in the GE scenario rural poverty will decline. In fact, the GE scenario shows 5 per cent higher per capita rural income by 2030. Employment is also forecasted to be higher in the GE scenario, and GHG emission intensity will drop by 30 per cent on average between 2009 and 2030. Besides, forest loss in the GE scenario will be limited to 0.1 million ha between 2009 and 2020, while in the BAU scenario, this number will increase to 3.2 million ha. The conservation and improved management of natural capital in the GE scenario reduce costs thanks to the avoided reduction of ecosystem services and at the same time increase the revenues of the local population by generating more ecosystem goods, ultimately contributing to a more equitable path for Borneo.

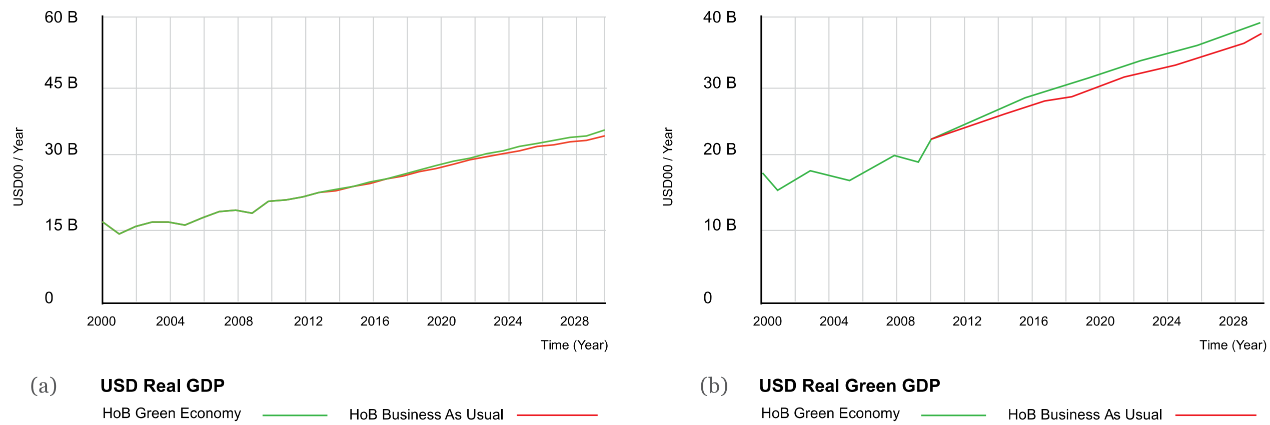

Figure 57: *GDP and green GDP in different scenarios (Van Paddenburg et al., 2012)*

The investment required in the GE scenario averages 1.2 per cent of GDP between 2010 and 2030, with investments related to natural capital conservation reaching roughly 0.6 per cent of GDP on average, but declining as progress is made. These investments include a wide range of interventions, such as REDD+ payments and clear mandates for palm oil certifications.

It is estimated that by 2030, green economy investments will generate US$1.70 per US$1 invested when using conventional GDP. This value increases to US$4.20 per US$1 invested when considering ecosystem services and their economic valuation in the formulation of Green GDP. Over time, as GDP grows, the net return will further increase as avoided costs and additional benefit accumulate.

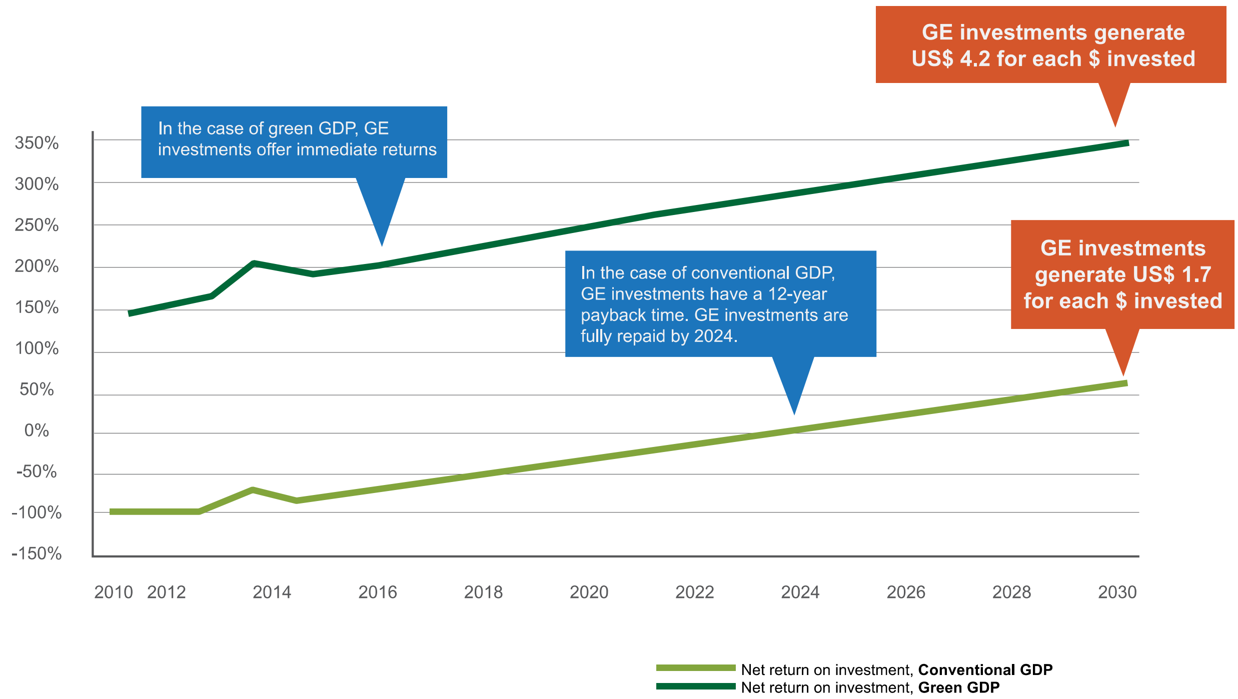

Figure 58: *Net return on investment in the GE scenario, using GDP and Green GDP (Van Paddenburg et al., 2012).*

Under the BAU scenario, the total value of natural capital will increase by an average of US$40 per capita, annually from 2011 to 2020, and it will start to decline by 2030 reaching a US$20 reduction per capita per year in 2050. On the other hand, in the GE scenario, the total value of natural capital will increase on average to US$90 per person each year between 2011 and 2030.

The estimated absolute value (as opposed to the per capita value presented above) of soil, forest, biodiversity, and carbon storage amounted somewhere between US$11,000 and US$35,000 per capita in 2011. Under the BAU scenario this value was expected to decrease by US$200-US$650 per capita per year. On the contrary, the GE scenario shows gains of US$50-US$100 per capita per year relative to BAU. In other words, investments in natural capital will increase future revenue and support a sustainable economic transformation.

Concerning emissions, the GE scenario is forecasted to absorb 1.2 billion tonnes of CO_2 more than the BAU scenario. This amount of stored carbon was estimated to be worth more than US$3.8 billion, using a carbon price of US$9.2 per tonne, the European Trading Scheme price point for carbon in 2011, at the time of writing of the report.

Regarding water, water availability in the dry season is forecasted to decrease by 5 per cent in the BAU scenario compared to the GE scenario. The costs required to build drinking water reservoirs to anticipate water scarcity are estimated at US$10 million in Kalimantan only. Water quality will also considerably improve in the GE scenario.

Furthermore, in the GE scenario export of nutrients would be 12 per cent lower per year when compared to the BAU scenario, allowing to save around US$1.9 million per year from nutrient removal (water treatment).

Finally, under the BAU scenario the number and severity of flood events will increase by 10 per cent relative to 2011, driven by deforestation and forest degradation, causing an average increase in annual damages to households of US$1.2 million. This problem would be avoided under the GE scenario.

Overall, results indicate that shifting to a green economy that values and invests in natural capital will sharply reduce the negative impacts of environmental degradation while supporting socioeconomic growth. The net impact is positive, showing the long-term sustainability of investments in natural capital.

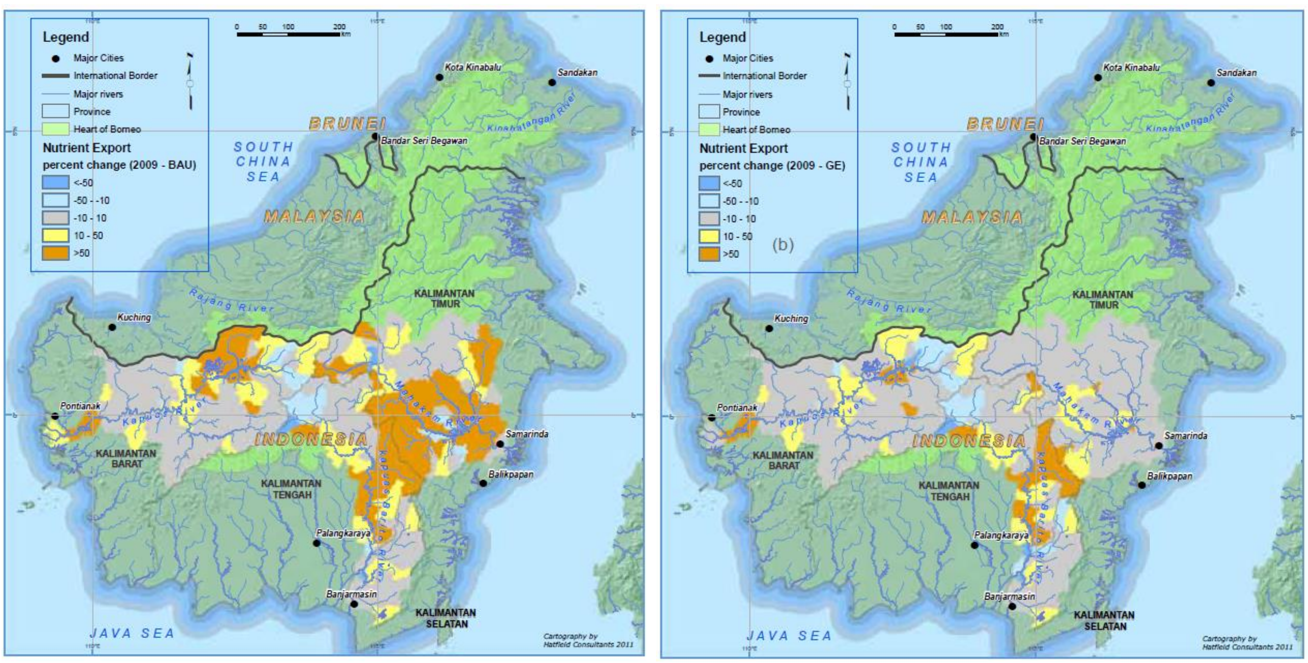

Figure 59: *Nutrient exports, percentage change between 2009 and BAU 2020 (left); percentage change between 2009 and GE 2020 (right) (Van Paddenburg et al., 2012)*

Box 8: *Potential contribution of SEEA-EEA to the case study Integrated planning for ecosystem conservation in the Heart of Borneo*

This modelling exercise uses spatial data for ecosystem extent and the provisioning of ecosystem services. Ecosystem condition accounts could be added, and analysed in more detail to refine the estimation of ES. In this exercise all ecosystem services are modelled, and could benefit from verification and validation of data. A similar approach could be used to strengthen the economic valuation of ecosystem services, which in the study is based on grey literature and not on local conditions.

Ecosystem extent	***Ecosystem condition***	***ES supply and use, physical***	***ES supply and use, monetary***	***Thematic accounts***
Required to better estimate the impact of land cover change on habitat quality and ecosystem services. ***Indicators****:* - *Tropical lowland rainforests* - *Tropical montane rainforest* - *Tropical dry forests and shrubs* - *Plantations* - *Tropical flooded forests and peat forests* - *Croplands* - *Pastures* - *Settlement land* - *Roads* - *Protected area*	Required to improve the calculation of ES provisioning, with local data ***Indicators****:* - *Biomass of natural forest* - *Species abundance index* - *Living plant index* - *Nutrient concentrations (N)* - *Nutrient concentrations (P)* - *Habitat quality*	Required to better parametrize the model. ***Indicators****:* - *Carbon retention* - *Soil retention* - *Crop provisioning* - *Timber provisioning* - *Water regulation* - *Water purification* - *Species appreciation services* - *Nursery population and habitat maintenance services*	Useful to expand the economic analysis performed, using local data. ***Indicators****:* - *Value of carbon* - *Value of crop provisioning* - *Value of water supply and purification* - *Value of NTFP (eg. rubber, medicinal herbs)* - *Value of tourism activity*	Land (especially peat), species and biodiversity, water and carbon accounts would improve the estimation of the value of the HoB, and the cost-benefit analysis of proposed policies. Selected species could be analyzed in more detail, such as orangutan, for a better assessment of habitat quality and potential for conservation and/or tourism development.

4.4.8 Contribution of SEEA EA to the strengthening of the case studies analysed

As indicated earlier, there are several ways in which SEEA EA can support and strengthen the analysis carried out with simulations models. TEEB can further contribute to the analysis of policy formulation and policy assessment. Table 29 presents a summary of these contributions for the seven case studies presented in this chapter.

Table 29: *Summary of the contributions that the use of SEEA EA can provide to the case studies analysed (Report authors)*

	Case	Ecosystem extent	Ecosystem condition	ES supply and use, physical	ES supply and use, monetary	Thematic accounts
1	**Low Carbon Development in Indonesia**	SEEA accounts have been used as input in this modelling exercise, but not at national level. Provincial level accounts were available, called SISNERLING. These were used to strengthen model formulations, improve parametrization and calibration (using data at provincial level), but not to the extent that would be possible with national accounts. Having extent, condition and ES can to better define and analyse carrying capacity (ES and ecological scarcity), making the assessment stronger.				
		National accounts would support model parametrization and calibration	Required to improve the calculation of ES provisioning	Required to strengthen the estimation of carrying capacity	Required to improve the link between carrying capacity and economic performance	Land (especially peat), species and biodiversity, water and carbon accounts could support policy assessment
2	**Agriculture expansion in the face of climate change in Tanzania**	The modelling work presented in this study makes use of spatial information, incorporating ecosystem extent. On the other hand, the analysis of ecosystem condition is limited to crop production and water availability. Refining and deepening ecosystem condition would provide more valid results. Expanding the list of ecosystem services, in addition, improves model formulations for crop production, water use, with validated accounts. It would then support expanding the cost-benefit analysis, with new economic valuation of ES.				
			Useful to better estimate ecosystem services, especially in relation of crop production and water	Required to expand the list of ES quantified, and to improve the calculation of ES provisioning	Necessary to better assess the economic viability of the project, from a societal perspective	Water accounts would be valuable to extend the analysis to the Rufiji delta (lowlands)

<table>
<tr><th></th><th>Case</th><th>Ecosystem extent</th><th>Ecosystem condition</th><th>ES supply and use, physical</th><th>ES supply and use, monetary</th><th>Thematic accounts</th></tr>
<tr><td rowspan="2">3</td><td rowspan="2">Biodiversity and tiger habitat conservation in Indonesia</td><td colspan="5">This modelling exercise considers land cover and various ecosystem services to determine habitat quality for tigers. Ecosystem condition accounts could strengthen the analysis, as would the addition of other ecosystem services that are relevant to tigers. In this respect the creation of a species account could support the analysis by linking ecosystem extent and condition accounts. Adding the economic valuation of ecosystem services may provide more incentives to keep habitat intact, by turning the assessment into an economic valuation related to specific policy options (eg. PES schemes). Both physical and monetary accounts ES accounts could demonstrate the many ancillary benefits of maintaining tiger habitat.</td></tr>
<tr><td></td><td>Required to improve the calculation of ES provisioning and for the estimation of habitat quality</td><td>Required to expand the list of ES quantified with InVEST, better parametrize the model</td><td>Necessary to better assess the economic viability of the policy options considered</td><td></td></tr>
<tr><td rowspan="2">4</td><td rowspan="2">Forest certificates for reducing deforestation in Brazil</td><td colspan="5">This study used the opportunity costs for forest conservation, calculated by using land value as a proxy. This could be replaced by the use of economic valuation of large set of ES relevant to the areas analysed (some will be more valuable than others, due to their higher ES provisioning). As a result, the analysis could be expanded with the use of condition and ES accounts, with the addition of monetary accounts. With this approach it may well be that the opportunity cost used as input in the model would change, and the optimization outcomes would change as a result.</td></tr>
<tr><td></td><td>Required to improve the calculation of ES provisioning and for the estimation of habitat quality</td><td>Required to expand the list of ES quantified with InVEST, better parametrize the model</td><td>Necessary to better assess the economic viability of the policy options considered</td><td></td></tr>
<tr><td rowspan="2">5</td><td rowspan="2">Water pollution reduction in India and Sri Lanka</td><td colspan="5">The analysis performed considers a few ecosystem services, but their estimation is based on existing publications, not on accounts. The model is developed takes into account spatial information and estimates ecosystem service provisioning and related outcomes (eg. impacts of water pollution). The models and analysis can be strengthened by adding better formulations for ES that are location specific, based on a spatial and hydrological assessment. This would add more precise ES valuation and improve the economic assessment of the various intervention options that have been analysed.</td></tr>
<tr><td>Extent accounts would support model parametrization and calibration for this local assessment</td><td>Required to improve the calculation of ES provisioning</td><td>Required to expand the list of ES quantified, possibly with InVEST or other models</td><td>Necessary to better assess the economic viability of the policy options considered</td><td></td></tr>
</table>

	Case	Ecosystem extent	Ecosystem condition	ES supply and use, physical	ES supply and use, monetary	Thematic accounts
6	**Deforestation and development planning in Rwanda**	The modelling approach considers the relationship existing between economic activity and land use. Ecosystem condition and ES accounts could be added, leading to the economic valuation of ecosystem services (either model-based or estimated with ES monetary accounts). Some of these ES are modelled, but not valued monetarily because of the absence of a market price. With the availability of the economic valuation of ES, these economic values could be used as input in the GCE model. This would improve the economic assessment, possibly considering other economic losses resulting from the loss of ecosystem services (beyond land), and approximating an assessment of the societal value of intervention options.				
			Required to improve the calculation of ES provisioning	Required to expand the list of ES quantified	Useful to better assess the potential impacts on economic performance at sectoral level	Relevant for the assessment of ES that affect economic activity (eg. water)
7	**Integrated planning for ecosystem conservation in the Heart of Borneo**	This modelling exercise uses spatial data for ecosystem extent and the provisioning of ecosystem services. Ecosystem condition accounts could be added, and analysed in more detail to refine the estimation of ES. In this exercise all ES provisioning are modelled, and could benefit from verification and validation from data. While the approach is already very comprehensive, the analysis could be refined and better validated using various ecosystem and ES accounts.				
			Required to improve the calculation of ES provisioning, with local data	Required to better parametrize the model	Useful to expand the economic analysis performed, using local data	Land (especially peat), species and biodiversity, water and carbon accounts could support policy assessment.

5 Summary analysis and recommendations

The SEEA EA was adopted by the 52nd United Nations Statistical Commission in March 2021. This new statistical framework will enable countries to measure their natural capital and understand the immense contributions of nature to our prosperity and the importance of protecting it. As an increasing number of countries embark on the implementation and piloting of the SEEA EA, new opportunities will emerge for the use of ecosystem accounts to support national and international policy making.

The adoption of the SEEA EA comes at a time when the world is facing unprecedented environmental crises. UNEP's *Making Peace with Nature* report outlines the features of three planetary crisis facing humanity – the climate change crisis, the biodiversity loss crisis and the pollution and waste crisis (UNEP, 2021). The related array of escalating and mutually reinforcing environmental risks threatens human well-being and the achievement of the Sustainable Development Goals. The report provides a scientific blueprint to tackle these emergencies, calling for a fundamental transformation of human's relationship with nature, including to address the failure of social, economic and financial systems to account for the essential benefits society gets from nature and to provide incentives to manage nature wisely.

Central to the required global response to these crises is the need to strengthen the science-policy interface as the basis for evidence-based policymaking, Specifically society, governments and businesses should include natural capital in decision-making to enable an assessment of "the costs and benefits of mitigating and adapting to climate change, loss of biodiversity and ecosystem degradation, land degradation, and air and water pollution at a range of spatial scales," (UNEP, 2021). The report calls for development of "analytical tools, including plausible futures models, using exploratory, target-seeking and policy-screening scenarios that account for the complex interlinkages between environment and development," (UNEP, 2021).

This report is a step towards answering this call by providing a resource for developers and users of SEEA EA accounts on how the use of the SEEA EA and the TEEB approach in scenario analysis models can provide policymakers with a better understanding of the interconnections existing between society, economy and the environment, and hence lead to better decisions.

This report is complementary to other global guidance documents that have been developed as part of the NCAVES project in the context of the SEEA EA implementation strategy to advance the global implementation of the SEEA EA and institutional capacity building. The *Guidelines for Biophysical Modelling for Ecosystem Accounting* provide an overview of how biophysical modelling can be applied to facilitate accounts compilation according to the SEEA EA framework (United Nations, 2021). The *Guidelines for Guidelines on Valuation of Ecosystem Services and Ecosystem Assets in the Context of the SEEA-EA* provides guidance on methods for the valuation of ecosystem services to facilitate compilation of monetary ecosystem accounts (United Nations, forthcoming). These guidelines and this report demonstrate applications of both physical and monetary accounts to policymaking.

In doing so, it is intimately related to the TEEB framework through which policy analysis can be better contextualized, supporting the integration of knowledge from different stakeholders and delivering value to several economic actors, sustainably and over time supporting policy action and improved effectiveness. The SEEA EA, by providing a standardized approach, consistent and coherent data provides for the further development of modelling approaches and creation of new models, all with the ultimate goal of informing policy decisions. The strength of the SEEA is that it provides knowledge and data to connect the environment with society and the economy, with a spatially explicit approach. This report has shown multiple possibilities to strength policy scenario analysis by using SEEA EA accounts, including : (1) models could use SEEA EA as data input, (2) models could be improved, (3) expanded or (4) equipped with spatial features.

The joint use of SEEA EA and TEEB therefore bridges several gaps: (i) between top down and bottom up scenario analysis; (ii) between the assessment of historical data and future projections; (iii) between science and policy. SEEA EA and TEEB can contribute to the development and refinement of various models and related policy assessments.

As the use of the SEEA EA in policymaking proliferates, keeping track of the evidence base will provide an important continued impetus for mainstreaming of the accounts into national and international policymaking. Future examples will continue to be made available on the SEEA Knowledge Base: https://seea.un.org/news/new-seea-knowledge-base.

As the environmental and economic contexts change, as the scientific knowledge on modelling advances, and as policy and analytical requirements evolve, the use of SEEA ecosystem accounts in policy scenario analysis will continue to be reviewed and updated to ensure its ongoing relevance. Strengthening the data capacity at the global and national level, further research and development, and the continued collaboration between the policy users, the modelling and statistical community are crucial in advancing this work.

A Annex: Overview of methods for solving equations

There are three main computational mathematical methods used for solving the equations of a model and generate forecasts: econometrics, optimization and simulation. It is important to be aware of how these three methods work in order to understand the extent to which different models, developed in different fields, can be interlinked or whether new integrated models should be developed to produce the assessment required.

The SEEA EA accounts can improve the analysis carried out with simulation models by providing the data needed to (1) better understand causality, especially in relation to ecosystem accounts and the relationship between extent, condition and ecosystem services, and hence support the expansion of the boundaries of the model and include more variables (1a) as well as improve the formulations used in the model thanks to the improved understanding of the dynamics of the system (1b), and to (ii) better represent the interconnection of society with the economy and the environment, with the addition of new system-wide feedback loops.

A.1. Econometrics

Econometrics is a methodology that measures the relationship between two or more variables, performing statistical analysis of historical data to determine correlations between specific selected variables. Econometric exercises include three stages – specification, estimation, and forecasting (Sterman, 1988). The structure of the system is specified by an equation or set of equations that closely approximate physical relations and behaviour. The validity of an econometric model is determined by how closely the equation represents correlation among variables using observed historical data. Causal relationships can sometimes be inferred when regression analysis is combined with prevailing theories and hypothesis tests using quasi-experimental methods. Forecasts are obtained by simulating changes in exogenous input parameters (eg. a given rate of change, per year or for a specific target year) that are then used to calculate a number of variables forming the structure of the model.

The quality and validity of projections is highly connected to the soundness of the theory used to define the structure of the model, and the robustness and validity of historical data. The results of econometric assessments are generally related to historical experience, and as such rely heavily upon time series data. As a result, they are poorly suited for the analysis of unprecedented events or policies that have never been applied before. Further, they may be ill-suited to dealing with systems as they approach a critical threshold or chaotic state, and this may be pertinent to the assessment of environmental-economic analyses.

The SEEA EA accounts can improve the analysis carried out with econometric models by providing the data needed to (i) expand the boundaries of the model and include more variables to control for a greater number of confounding factors, (ii) better estimate correlations across indicators, and (iii) better estimate trends over time.

A.2. Optimization

Optimization is a method that aims at identifying the best solution (with regard to some criteria) from some set of available alternatives. Optimization models, which generate "a statement of the best way to accomplish some goal" (Sterman, 1988), are normative or prescriptive models. These models provide information on what to do to make the best of a given situation (the actual one), given a shock introduced in the system.

In order to optimize a given situation, optimization models use three main inputs: (1) the goals to be met (ie. objective function), (2) the scope or range of interventions and (3) the constraints to be satisfied (Sterman, 1988). The output of an optimization model identifies the best or most efficient interventions that would allow reaching the goals (or to get as close as possible to it), while satisfying the constraints of the system (IIASA, 2012).

The challenges related to optimization models include the correct definition of the objective function, the ability to internalize or measure collateral effects (externalities), and the use of linearity, resulting in the lack of feedback and dynamics.

The SEEA EA accounts can improve the analysis carried out with optimization models by providing data that could be used to (i) expand the boundaries of the model and include more variables, and to (ii) improve the formulation of the objective function to endogenize externalities (eg. by including air quality and related economic valuation in the determination of economic performance).

A.3. Simulation (causal descriptive models and Agent Based Modelling)

Simulation is a method that uses a "what if" approach, based on descriptive models that focus on the identification of causal relations between variables. Its main pillars are feedback loops, delays and nonlinearity (also, in some cases, through the explicit representation of stocks and flows). Examples of simulation models are *System Dynamics (SD)* and *Agent Based Modelling (ABM)*.

Simulation models are aimed at understanding what the main drivers for the behaviour of the system are. This implies identifying properties of real systems, such as feedback loops, nonlinearity and delays, via the selection and representation of causal relations existing within the system analysed. The validation of simulation models takes place in different stages. A distinction from optimization and econometric methods is the direct comparison of projections with historical data, which simulation models can backtrack (behavioural validation), and the analysis of the extent to which the equations used in the model reflect the causality and processes observed in reality (structural validation) (Barlas, 1996). Potential limitations of simulation models include the correct definition of boundaries and a realistic identification of the causal relations characterizing the functioning of systems being analysed, which greatly depend on the knowledge of the system analysed and the skills of the modeller(s). Related to this, SD is a relatively new field, with a smaller number of courses being offered when compared to econometrics, or energy optimization. In this respect, a disadvantage of the field is that it supports modelling across disciplines as opposed to proposing a highly sophisticated method for a single field. As a result, for a long time there has been no “home” for SD in academia (courses are found in Master and PhD programmes on economics, business management, geography, and more). On the other hand, recently SD has been more and more recognized as a relevant method for Sustainability Science and applications to Green Economy, Green Growth, Circular Economy, Climate Adaptation and Low-Carbon Development are growing.

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7 Glossary

Baseline scenario: elaborated to define the trends against which to assess the performance of alternative scenarios (eg. population, food demand trends etc.). This is also known as business-as-usual, because it considers the likely future path without the implementation of policies under consideration.

Computable General Equilibrium (CGE) models: a class of economic models that represent the main economic flows within and across the key actors of the national economy. The model couples' equations to an economic database, using the System of National Accounts (SNA), the Social Accounting Matrix (SAM) and Input-Output (I-O) tables as pillars.

Development planning: a range of public and private planning and decision-making processes (eg. ranging from a national land-use plan to the annual budgetary process, and including infrastructure projects as well as sectoral policy formulation exercises) that typically involve trade-offs between competing demands for scarce resources and which have implications for nature.

Econometrics: a methodology that measures the relation between two or more variables, running statistical analysis of historical data and finding correlation between specific selected variables.

Feedback loop: "*feedback is a process whereby an initial cause ripples through a chain of causation ultimately to re-affect itself*" (Roberts et al., 1983).

Geographic Information System (GIS): a system designed to capture, store, manipulate, analyse, manage, and present all types of geographical data. In the simplest terms, GIS is the merging of cartography, statistical analysis and computer science technology.

Green economy: an economy that results in improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities (UNEP, 2011).

Indicator: an instrument that provides an indication, generally used to describe and/or give an order of magnitude to a given condition.

Methodology: the underlying body of knowledge for the creation of different types of simulation models. It includes theoretical foundations for the approach, and often encompasses both qualitative and quantitative analyses and instruments.

Model transparency: a transparent model is one for which equations are available and easily accessible and it is possible to directly relate structure to behaviour (ie. numerical results).

Model validation: the process of deciding whether the structure (ie. equations) and behaviour (ie. numerical results) are acceptable as descriptions of the underlying functioning mechanisms of the system and data.

Optimization: simulation that aims at identifying the best solution (with regard to some criteria) from some set of available alternatives.

Policy Cycle: the process of policymaking, including issue identification, policy formulation, policy assessment, decision-making, policy implementation and policy monitoring and evaluation.

Policy scenario: generated to determine how the performance of a system is affected by a proposed policy change (eg. investment in irrigation infrastructure).

Policy scenario analysis: an exercise that aims at informing decision-making and makes use of scenarios to assess the outcomes and effectiveness of various policy intervention options.

Scenarios: expectations about possible future events used to analyse potential responses to these new and upcoming developments. Scenario analysis is a speculative exercise in which several future development alternatives are identified, explained, and analysed for discussion on what may cause them and the consequences that these future paths may have on our system (eg. a country, or a business).

Simulation model: a model is simplification of reality, a representation of how the system works, and an analysis of (system) structure and data. A quantitative model is built using one or more specific methodologies, with their strengths and weaknesses.

Social Accounting Matrix (SAM): an accounting framework that captures the transactions and transfers between the main actors in the economy. A SAM normally includes firms, households, government and 'Rest of Economy'.

Spatial aggregation/disaggregation: aggregated simulation models provide a single value for any given variable simulated (eg. population and agricultural land). Spatial models instead generate results at the human scale and present them on a map, eg. indicating how population and agricultural land would be geographically distributed within the boundaries of the country.

Stock and flow variables: a *stock* variable represents accumulation and is measured at one specific time. A *flow* variable is the rate of change of the stock and is measured over an interval of time.

System Dynamics: a methodology to create descriptive models that focus on the identification of causal relations influencing the creation and evolution of the issues being investigated. Its main pillars are feedback loops, delays and nonlinearity through the explicit representation of stocks and flows.

Vertical/horizontal disaggregation of models: vertically disaggregated models represent a high degree of sectoral detail; horizontal models instead include several sectors and the linkages existing among them (with a lesser degree of detail for each of the sectors represented).