



# **Pan-Africa Component**

## **SEB Modeling Guidance Materials**

### **Indicators for an Integrated Cost Benefit Analysis (SEB assessment)**

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## 1. Introduction

This report is aimed at providing guidance for the analysis of the socio economic benefits (SEB) of climate policy, as well as the identification and assessment of adaptation options.

Specifically, it presents the steps required for the effective identification and use of indicators to support a sectoral and integrated analysis of SEB. Some of the steps presented are more relevant to climate vulnerability assessment, while others are more useful for adaptation and policy formulation/assessment. Given that the opportunities arising from adaptation are dependent on the (current and upcoming) issues originating from climate change, these steps can be applied sequentially. Finally, these steps lead to the implementation of an integrated Cost Benefit Analysis (CBA), where social, economic and environmental impacts –as well as policy outcomes- are considered. Differently from Multi Criteria Analysis, this integrated CBA includes the economic valuation of environmental consequences.

Concerning the structure of this report, firstly, a general overview of cost-benefit analysis techniques is provided (see Text Box 1). Further, Section 2 seeks to provide a broad methodological framework, highlighting the need for an integrated assessment of economic, social and environmental indicators. Section 3 proposes indicators for the CBA. Section 4 focuses on a more detailed description of the various analytical stages of the exercise, seeking to provide guidance on each step of the methodological approach proposed, from the identification of key indicators to the use of relevant data and information along the decision-making process. Section 5 introduces Causal Loop Diagrams, system maps that can be very informative for the initial steps of the modeling process. Section 6 lists policy options that can be used for climate adaptation, to prevent and adapt to climate impacts. Finally, section 7 provides an overview of simulation models that are generally used to carry out an assessment of the impacts of climate change, and are hence also useful for the assessment of SEB of climate information.

## 2. Identification and use of indicators for SEB analysis

Indicators (McCool & Stankey, 2004), when used to effectively inform decision making, are designed to support the initial and final stages of the development planning process, namely issue identification (stage 1), strategy/policy formulation and assessment (stage 2), and strategy/policy monitoring and evaluation (stage 5) (UNEP, 2014). Decision-making (stage 3) is the point in time when a particular policy recommendation is adopted, based on the comparison of different policy options that were developed under stage 2. Finally, the role of indicators in policy implementation (stage 4), is mainly exercised through monitoring and evaluation (stage 5), when the actual impacts of development plans are monitored both during and after implementation.

### 2.1. Issue identification

Several indicators could be selected and analyzed in the issue identification phase of the planning process. In particular, emphasis should be put on those indicators that provide information on the stocks (e.g., forests, mineral reserves, public debt) and flows (e.g., annual deforestation, mineral extraction trends, annual deficit) that govern the behavior of the system. The combined analysis of trends is expected to highlight the multiple causes and effects of consumption and production, as well as the role played by past policies and investments in improving or worsening the situation.

UNEP (2014) identifies four main steps that should be followed for the selection and use of green economy indicators in the issue identification phase, namely: (1) identify potentially worrying trends; (2) assess the issue and its relation to the natural environment; (3) analyze more fully the underlying causes of the issue; (4) analyze more fully how the issue impacts society, the economy and the environment.

In developing countries, problems related to climate change, ecosystem management and natural capital depletion are increasingly impacting on socioeconomic performance, thereby challenging the achievement of key sustainable development objectives (Costantini & Monni, 2008). While problems like climate change and ecosystem management are already high in the agenda of decision makers, an integrated approach to the analysis of worrying trends is challenged by several factors related to the use of indicators, including (1) limited availability of historical data, especially on environmental indicators; (2) “silo” approach to the analysis of sectoral trends, impeding the identification of cross-sectoral causes and effects; and (3) limited adoption of integrated methodologies for the analysis of system’s structure and behavior, often leading to misinterpretation of problems and duplication of efforts. In this sense, the adoption of a rigorous but still flexible approach to the selection and analysis of indicators is expected to improve the effectiveness of the issue identification phase, and ensure that development plans are centered on the main causes and effects of unsustainable practices.

### 2.2. Policy formulation and assessment

The policy formulation and assessment phase involves the selection of relevant policy and investment interventions that are expected to address worrying trends and create the enabling conditions for a transition to sustainable development. The steps involved in the policy formulation phase include (UNEP, 2014): (1) identify policy objectives; (2) identify intervention options and output indicators. Once the strategy/policy options have been identified, their advantages and disadvantages should be assessed. The steps involved in the assessment of interventions include (UNEP, 2014): (3) estimate impacts across sectors; (4) analyze impacts on the overall well-being of the population; (5) analyze advantages and disadvantages and inform decision-making.

Many developing countries are already actively engaged in the formulation of climate adaptation and mitigation strategies, policies and action plans. These strategies are generally cross-sectoral, and aligned with the national development vision and sectoral development goals. However, although the systemic linkages between economic, social and environmental dynamics are being more frequently mentioned (although far from being fully understood and coherently presented) at the strategic/visionary level, several challenges are encountered in the implementation phase, when sectoral policies and investment decisions are still designed in silos, showing a reticence to deviate from “tried and tested” though unsustainable development pathways (Boschken, 2013).

SEB indicators could play a central role in overcoming these challenges, for two main reasons: (1) cross-sectoral collaboration would be strengthened, as the selection of indicators in the policy formulation and assessment phases require the engagement of multiple stakeholders at different levels (given that climate change has far reaching impacts); (2) policy targets and expected policy outcomes are assessed based on evidence from the analysis of these (M&E) indicators, thereby facilitating the agreement on key intervention options, and the establishment of accountability and monitoring frameworks.

### **2.3. Policy monitoring and evaluation**

The last stage of the policy cycle consists in the monitoring and evaluation of policy/strategy impacts. In this phase, the actual results obtained by green economy and sustainable development strategies are measured and evaluated in order to address potential gaps and unintended consequences, as well as to inform future development planning processes based on lessons learned.

The performance of the strategy/policy implemented has to be evaluated with respect to the problems identified at the beginning of the policy cycle, as well as the costs and cross-sectoral benefits identified in the formulation and assessment phase. As a result, three main steps should be followed in this phase (UNEP, 2014): (1) measure policy impacts in relation to the environmental issue; (2) measure policy performance and (3) analyze impacts across sectors and on the overall well-being of the population.

The monitoring and evaluation (M&E) phase is the most challenging phase of sustainable development planning in developing countries. The lack of coherent M&E systems and accountability frameworks, together with constraints related to data collection and difficulties in measuring certain impacts of sustainability projects, contribute to the weakening of monitoring processes, and thus undermine the whole development planning process (Agol, Latawiec, & Strassburg, 2014). In this sense, the step-by-step process proposed for the selection and use of green economy indicators at different stages of sustainable development planning is expected to facilitate monitoring and evaluation efforts as well.

### 3. CBA methodology

An integrated and systemic CBA methodology is proposed, made of three main analytical components: investment, avoided costs and added benefits. To better illustrate the applicability of this approach, the example of sustainability certification (to reduce negative impacts of human activity and improve adaptation and resilience) is presented throughout the report, for selected sectors.

- a) *Investment*: from a private sector perspective, investments refer to the monetary costs of implementing a decision, such as complying with sustainability standards, including, for example, annual certification fees, auditing and other management costs related to certification, as well as the costs for greening production (e.g. the purchase of machinery and the transformation of production processes and techniques, potential additional labor and training costs). From a public sector point of view, investments refer to the allocation and/or reallocation of financial resources with the aim to reach a stated policy target (e.g. create enabling conditions for the development of sustainable businesses in a given country).
- b) *Avoided costs*: the estimation of potential costs that could be avoided as result of the successful implementation of an investment/policy. In the case of sustainability principles and processes, these refer to the use of green production practices (as a result of sustainability certification) and may include direct savings deriving from a more efficient use of natural resources, as well as indirect avoided costs, e.g. health expenditure, avoided losses from environmental degradation, and avoided payments for the replacement of key ecosystem services (UNEP, 2012a).
- c) *Added benefits*: the monetary evaluation of economic, social and environmental benefits deriving from investment/policy implementation, focusing on short-, medium- and long-term impacts across sectors and actors. In the case of sustainability certification these include enhanced access to markets, or the availability of premium prices for certified products. These are all additional benefits that would not be accrued in a business as usual scenario.

This framework is proposed as a modular and customizable method for conducting a systemic analysis of sectoral and cross-sectoral vulnerabilities and opportunities. It starts with issue identification, to then move to the assessment of opportunities for intervention.

### **Text Box 1. Cost Benefit Analysis techniques**

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 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 common CBA techniques utilized, it is worth mentioning the payback period, net present value, and rate of return.

The **payback period** is the most basic of all cost-benefit analysis techniques. First, all costs associated with a specific strategy/project are quantified and aggregated. In particular, costs might include investment in fixed assets, labor and training costs, as well as the time lost for training or implementation. The total aggregated costs are then divided by the expected financial returns deriving from the implementation of the strategy/project. The result obtained corresponds to the indicative time needed for the investment to pay for itself.

The **Net Present Value (NPV)** analysis follows the same procedure as the payback period technique for the calculation of total costs and benefits associated with strategy/project implementation. In addition, the cost of capital associated with outside funds needed to start the strategy/project is estimated. Based on the comparison between present and estimated future value of financial costs and benefits (including estimation of future inflation trends), the net present value of a given strategy/project is calculated. If the final result is a negative value, the project is generally not considered as worthwhile, and thus rejected.

The **rate of return** technique is generally used to assess single or small investments. The formula consists of subtracting the total costs associated with the investment from the expected added benefits, and then to divide the obtained value by the investment required. The value obtained at the end of the analytical process is the percentage return on investment, which gives an idea of the profitability of the proposed strategy/project.

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. It is broader than a CBA and includes the analysis of non-monetary impacts, evaluated qualitatively, or ranked, for instance, on a scale from 1 to 5. An 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.



### 3.1. Investment

Table 1 provides a general overview of a set of possible indicators of investment, broadly subdivided into capital and operation & management costs, training costs, certification costs, and government costs. These indicators are selected for the example of sustainability certification, for agriculture, fisheries and aquaculture, and forestry. This set of indicators is neither exhaustive nor in its entirety applicable to all policies and sectoral analyses. It rather reflects a generic portfolio of indicators that can be flexibly customized (i.e. expanded or narrowed down) to the requirements and objectives of specific sectoral assessments.

**Table 1. Sectoral indicator samples for measuring investments in sustainability certification.**

Sector	Capital and Operation & Management Costs	Training Costs	Certification Costs	Government Costs
<b>Agriculture</b>	Cost of organic pesticides and fertilizers (US\$/kg; US\$/ha). Cost of water and energy efficient technology (US\$/ha) Operation & Management Costs (US\$/ha). Labor costs (US\$/ha) Energy costs (US\$/ha) Water costs (US\$/ha)	Training of farmers in sustainable agriculture technologies and processes (US\$/person). Training of law enforcement officials (US\$/person)	Application fee (US\$) Annual renewal fee (US\$/year) Assessment on annual production or sales fees (US\$/year) Inspection fees (US\$/year)	Incentives for the purchase of organic inputs (US\$/kg). Incentives for the purchase of organic agriculture technology (US\$/kg).
<b>Fisheries and aquaculture</b>	Cost of water- and energy-efficient technology (US\$/ha) Establishment/Expansion of Marine Protected Areas, including enforcement costs (US\$/year) Fuel costs (US\$/ton; US\$/year). Cost of sustainable fishing gear (US\$/ton; US\$/year). Operation & Management Costs (US\$/ha). Labor cost (US\$/person; US\$/year; US\$/ton).	Training of fishermen on sustainable fishing techniques (US\$/person). Training of law enforcement officials (US\$/person). Training on assessment of biological status of fish resources (US\$/person)	Annual fee (US\$/year) Royalties (% of value of consumer facing seafood products that are sold/purchased) Periodic assessment of biological status of fish resources (US\$/year).	Subsidies to fishermen for reducing fishing activities (US\$/person; US\$/year). Incentives for the purchase of equipment, e.g. fishing gear that minimizes the incidental take of non-target species (US\$/year)
<b>Forestry</b>	Establishment/Expansion of Forest Protected Areas, including enforcement costs (US\$/year) Costs associated with the respect of legal and customary rights of indigenous people (US\$/ha). Sustainable plantations (US\$/ha). Operation & Management Costs (US\$/ha). Labor cost (US\$/person; US\$/year; US\$/ton).	Training and supervision of forest workers (US\$/person). Training of law enforcement officials (US\$/person)	Initial and annual audit costs (US\$/ha) Compliance costs, e.g. retaining a percentage of trees to function for wildlife habitat, elaboration of forest management plan and forest inventory (US\$/ha; US\$/year)	Subsidy to family forest owners to support costs of certification audits (US\$/ha). Subsidies to local forest communities (US\$/year) Development and implementation of policies for Environmental, Social, & Economic Performance Criteria (US\$/year).

Main references: Afari-Sefa and Gockowski (2010); Macfadyen and Huntington (2007); MSC (2013); Nemes (2009); Owens (2008); Pazek and Rosman (2012); Schreiber (2006); UNEP (2013a).

### 3.2. Avoided costs

A key aspect that is often neglected when measuring the effectiveness of investments in sustainability is the cost saving deriving from such interventions. More specifically, improving the sustainability of a sector has the potential to: (1) reduce costs currently sustained by public and private actors as result of the current ineffective natural resources management and use, and (2) avoid potential future costs deriving from the depletion of natural capital and ecosystem degradation.

Consequently, an integrated analysis of the impacts of climate change adaptation interventions should include the estimation of potential (policy-induced) avoided costs, using historical and current data on environmental, social and economic performance. This analysis is particularly relevant from a green economy perspective, where social inclusiveness (i.e. the equitable distribution of costs and benefits across actors) is at the core of sustainable development.

Table 2 provides a general overview of sample indicators for measuring economic, social and environmental avoided costs originating from sustainability certification and greener production practices.

**Table 2. Sectoral indicator samples for measuring economic, social and environmental avoided costs originating from sustainability certification and greener production practices.**

Sector		Economic Avoided Costs	Social Avoided Costs	Environmental Avoided Costs
Agriculture	<i>Direct</i>	<u>Private</u> Reduced use of fertilizers and pesticides (US\$/year). Reduced water intensity (US\$/ton). <u>Public</u> Avoided costs of food subsidies, as result of increased food production and overall well being (US\$/year).	Reduced employment and income losses from soil degradation and abandonment (US\$/year)	Reduced GHG emissions and associated costs (tCO <sub>2</sub> e/year; US\$/year).
	<i>Indirect</i>	<u>Private</u> Reduced productivity losses from soil degradation (US\$/year). <u>Public</u> Reduced costs of ground water purification (US\$/year).	Reduced health costs due to malnutrition water pollution diseases (US\$/year) Reduced costs of urbanization from abandoned agricultural land, e.g. subsidies to urban poor (US\$/year)	Reduced costs of water pollution, e.g. from nitrogen concentration (ug/L; US\$/year).
Fisheries and aquaculture	<i>Direct</i>	<u>Private</u> Reduced profit losses from fish stock depletion (US\$/year). Reduced fuel consumption (US\$/year). <u>Public</u> Reduced losses from illegal fishing (US\$/year) Reduced costs of subsidies to unsustainable fishing activities (US\$/year).	Reduced income losses from fish stock depletion (US\$/year).	Reduced costs of marine ecosystem degradation (US\$/year). More sustainable fish stock management (replenishing of stocks etc.)
	<i>Indirect</i>	<u>Private</u> Reduced economic losses in other sectors, e.g. eco-tourism, as result of environmental degradation (US\$/year). <u>Public</u> Avoided costs of fish imports (US\$/year)	Reduced health costs due to malnutrition (US\$/year). Reduced costs of urbanization from abandoned coasts, e.g. subsidies to urban poor (US\$/year).	Reduced salinization of groundwater sources from improved marine ecosystem management, and related costs (mg/L; US\$/year).

Sector		Economic Avoided Costs	Social Avoided Costs	Environmental Avoided Costs
Forestry	Direct	<u>Private</u> Reduced pesticides use (US\$/year). Reduced losses of timber and non-timber forest products (US\$/year). Reduced energy use (US\$/year). <u>Public</u> Avoided costs of reforestation programmes (US\$/year).	Avoided loss of habitat by forest dwellers (households/year). Reduced damages from floods and inundations on households (US\$/year).	Reduced deforestation (forest cover as % of total land). Reduced costs of desertification of forest area (Aridity Index, Rain concentration index.).
	Indirect	<u>Private</u> Reduced economic losses in other sectors, e.g. eco-tourism, as result of environmental degradation (US\$/year). <u>Public</u> Avoided costs of imports of timber and non-timber forest products (US\$/year).	Reduced costs of urbanization from abandoned forests, e.g. subsidies to urban poor (US\$/year). Reduced health costs from air pollution, floods etc. (number of hospitalized people/year).	Reduced costs of replacement of ecosystem services, e.g. watershed management (US\$/year).

Main references: European Commission et al. (2012); Pretty et al. (2005); Schreiber (2006); TEEB (2010); UNEP (2011).

### Text Box 3. The valuation of environmental and social costs

An integrated cost-benefit analysis should include the valuation of environmental and social (avoided) costs deriving from climate change adaptation interventions.

As indicated by WWF (2013) perhaps the clearest and most useful way to trace the relationships between ecosystem services, economic values and human well-being outcomes is to combine two frameworks. The first is total economic value (TEV), which is commonly applied by economists. The second is the ecosystem services-human well-being framework presented in the Millennium Ecosystem Assessment (MA, 2005), which is widely used by conservation planners and decision-makers.

The estimation of the TEV implies the analysis of the complete range of characteristics of ecosystems as integrated systems – resource stocks, flows of services, and the attributes of the ecosystem as a whole, include the following (Emerton, 2006):

- **Direct values:** raw materials and physical products that are used directly for production, consumption and sale.
- **Indirect values:** ecological functions that maintain and protect natural and human systems.
- **Option values:** the premium placed on maintaining ecosystems for future possible uses, some of which may not be known now.
- **Existence values:** the intrinsic value of ecosystems and their component parts, regardless of their current or future use possibilities.

Researchers apply different methods and techniques for the valuation of ecosystem services. These include, for example:

- **Household production costs:** the costs paid by households as result of the impact of environmental degradation. *Example: costs of cleaning or repairing due to pollution.*
- **Replacement costs:** the cost of replacing a service with a man-made system. *Example: cost of construction of reservoirs due to reduced natural watershed regulation.*
- **Dose-response:** how changing an environmental service affects the production costs of a product. *Example: the increase in food prices as result of reduced production due to soil erosion.*
- **Averting behavior:** expenditures to defend against negative effects of ecosystem degradation. *Example: cost of the building of preventive walls for possible floods.*
- **Travel cost method:** changes in the value of a recreational site or changes in the environmental quality of that site by using the amount of money and time people spend traveling there.

- **Hedonic pricing method:** based on the idea that people prefer and will pay more to live in areas with good environmental quality, or consume sustainably produced goods. *Example: the value of environmental quality is embedded in housing prices.*

### 3.3. Added benefits

Once the total investment and avoided costs (both public and private) have been estimated, the additional benefits potentially deriving from policy implementation should be properly assessed. In particular, economic, social and environmental benefits should be identified, and adequately measured by means of relevant indicators.

Table 3 provides a general overview of sample indicators for measuring economic, social and environmental benefits of sustainability certification. As for tables 1 and 2, the set of indicators is neither exhaustive nor applicable to all sectoral analyses in its entirety, but rather reflects a generic portfolio of indicators that can be flexibly customized to the requirements and objectives of specific sectoral assessments.

**Table 3. Sectoral indicator samples for measuring economic, social and environmental benefits of sustainability certification.**

Sector		Economic Benefits	Social Benefits	Environmental Benefits
Agriculture	Direct	<u>Private</u> Increased access to global BioTrade markets (% or US\$/year). Increased productivity (US\$/ha). Premium market price (%; US\$/year). <u>Public</u> Increased revenues from taxes on agribusiness as result of increased private profits (US\$/year).	Income generation for rural population (US\$/year).	Improved soil quality (% of degraded agricultural land).
	Indirect	<u>Private</u> Additional revenues from improved corporate reputation/customer loyalty (US\$/year). Increased revenues in other sectors, e.g. fisheries and forestry, as result of reduced environmental impact (US\$/year). <u>Public</u> Additional fiscal space to support the expansion of organic agriculture and BioTrade (US\$/year).	Poverty reduction (% poor population). Increased access to water (% of population). Improved nutritional levels (kcal/person/day).	Preservation of forest cover (forest cover as % of total land). Preservation of fish stocks as result of reduced water pollution (fish stock level/year). Improved air quality (Air Quality Index) from reduced emissions.
Fisheries and aquaculture	Direct	<u>Private</u> Increased access to global aquaculture markets (% or US\$/year). Premium market price (%; US\$/year). Increased profits from improved customer confidence (US\$/year) <u>Public</u> Increased revenues from fishery taxation as result of increased private profits (US\$/year).	Sustainable income of fishermen households (US\$/year).	Restoration of damaged marine ecosystems (US\$ per area, or % of restored marine ecosystems).
	Indirect	<u>Private</u> Additional revenues from improved corporate reputation/customer loyalty (US\$/year).	Improved nutritional levels (kcal/person/day)	Improved conservation of coastal ecosystems (% of degraded coastal ecosystems).

Sector		Economic Benefits	Social Benefits	Environmental Benefits
		<p>Increased revenues in other sectors, e.g. eco-tourism, as result of reduced environmental impact (US\$/year).</p> <p><u>Public</u></p> <p>Additional fiscal space to support the expansion of sustainable aquaculture (US\$/year).</p>	<p>Fishermen income from alternative activities (US\$/year)</p>	
Forestry	<i>Direct</i>	<p><u>Private</u></p> <p>Increased access to global BioTrade markets (% or US\$/year).</p> <p>Increased productivity (US\$/ha).</p> <p>Premium market price (%; US\$/year).</p> <p><u>Public</u></p> <p>Increased revenues from taxes on forestry as result of increased private profits (US\$/year).</p> <p>Revenue from selling forest credits (US\$/year).</p>	<p>Increased income of local forest communities (US\$/year).</p>	<p>Increase in forest cover from sustainable plantation (forest cover as % of total land).</p>
	<i>Indirect</i>	<p><u>Private</u></p> <p>Additional revenues from improved corporate reputation/customer loyalty (US\$/year).</p> <p>Increased revenues in other sectors, e.g. eco-tourism, agriculture etc., as result of reduced environmental impact (US\$/year).</p> <p><u>Public</u></p> <p>Additional fiscal space to support and promote sustainable forest management (US\$/year).</p>	<p>Increased access of forest dwellers to traditional forest products (%).</p>	<p>Improved air quality (Air Quality Index).</p> <p>Preservation of biodiversity (GEF biodiversity index).</p>

Main references: Blackman and Rivera (2010); Nemes (2009); Owens (2008); Pretty et al. (2005); Schreiber (2006); UNEP (2013a).

#### **4. Step-by-step guide to conduct sustainability-related CBAs**

While Section 3 outlines a broad methodological framework to assess costs and benefits of climate change adaptation interventions, this section provides a step-by-step guidance for identifying indicators that can support the implementation of an integrated CBA, especially highlighting vulnerability and opportunities arising from adaptation.

Based on the Methodology outlined in Section 3, six steps are proposed for the selection, categorization and comparative analysis of relevant indicators (see Table 4). As indispensable starting point for the process (i.e. the “Step 0”), a clear and concise research question (revolving around vulnerability) needs to be defined, which informs the analytical narrative and determines the scope and angle of the CBA.

**Table 4. Key steps, objectives, actions and challenges for carrying out a sustainability-related Cost-Benefit Analysis.**

Steps	Objective	Actions	Potential challenge
1- <u>Identify relevant indicators</u>	To identify a comprehensive range of transparent, reliable and measurable indicators of issues, costs and benefits (i.e. investments, added benefits and avoided costs) that should be used to assess the profitability of adhering to sustainability certification.	<ul style="list-style-type: none"> <li>- Identify indicators of (1) issues, (2) investment, (3) added benefits (economic, social and environmental) and (4) avoided costs (economic, social and environmental).</li> <li>- Analyze relevant case studies to better inform the indicators identification process.</li> </ul>	Data availability issues preventing researchers from identifying indicators that respect the four basic criteria of (1) policy relevance; (2) analytical soundness; (3) measurability; and (4) usefulness in communication.
2- <u>Customization of the framework methodology</u>	To assess the need for indicators in more detail, with an approach tailored to the specific sector and context analyzed, as well as the progress already made in increasing resilience.	<ul style="list-style-type: none"> <li>- Select indicators to assess current level of resilience.</li> <li>- Select indicators of transition costs, avoided costs and added benefits directly related to the sectoral context.</li> <li>- Provide a brief justification of the choice of indicators.</li> </ul>	Data availability, and inconsistency between indicators selected and current set being used at the national level.
3- <u>Collect available data</u>	To collect data on relevant indicators in order to inform the cost benefit analysis.	<ul style="list-style-type: none"> <li>- Collect sector-specific data from relevant sources at the national level (if needed also regional and global level). Collect data and relevant information from sector-specific case studies.</li> </ul>	Limited national, local and (especially) private sector data on sales, profits, productivity etc.
4- <u>Classify data based on specific analytical needs</u>	To categorize the information in a way that facilitates the implementation of a sustainability-related CBA, following the methodology proposed in Section 3 of this study.	<ul style="list-style-type: none"> <li>- Group data on investments, avoided costs and added benefits for each policy intervention and across all interventions at the sectoral level.</li> <li>-</li> </ul>	The monetary valuation of environmental and social benefits and avoided costs might represent a challenging task, especially in the case of limited data availability.
5- <u>Analyze the data adopting an integrated and systemic approach</u>	To plug categorized data into the indicator framework in order to conduct the assessment of costs and benefits of sustainability certification.	<ul style="list-style-type: none"> <li>- Analyze the data and select the most suitable cost-benefit analysis technique (e.g., net present value, payback period, rate of return).</li> <li>- Carry out a cost-benefit analysis by comparing investments with added benefits and avoided costs.</li> <li>- Assess the results of different scenarios, adopting a systemic perspective.</li> <li>- Compare the outcome of different scenarios (e.g. outcome of one or more investment scenarios against a business as usual (i.e. “no action”) scenario).</li> </ul>	Unrealistic and poorly documented scenario assumptions may challenge the credibility of the analysis.
6- <u>Evaluate CBA results and inform the decision-making process</u>	To inform the preparation of sectoral TNC action plans with the outcome of CBA analysis.	<ul style="list-style-type: none"> <li>- Evaluate the results of the analysis through a multi-stakeholder process.</li> <li>- Outline potential impacts of policy implementation across actors, in the sector of analysis.</li> </ul>	Stressing the importance of medium and long-term sustainability gains is often a difficult task for researchers.

## 4.1 Step 1: Identify relevant indicators

### **Objective**

To identify a comprehensive range of transparent, reliable and measurable indicators of costs and benefits (i.e. investments, added benefits and avoided costs) that should be used to assess the profitability of adhering to sustainability certification.

### **Actions required**

- a. Identify key indicators for investment, including, among others, (1) capital and operation & management costs, e.g. for the purchase of machinery; (2) training costs, e.g. for monitoring compliance with certification requirements and for the maintenance of machinery and infrastructure; (3) costs of certification, including fees (registration and periodic fees) and costs of auditing and inspection fees; (4) Incentives provided by the government, e.g. subsidies or other incentive payments for certification, which would reduce the total costs incurred by the private sector.
- b. Select indicators of added benefits, including direct and indirect economic, social and environmental benefits potentially deriving from the shift to sustainable production and trade, and the creation of green supply chains. Indicators of economic benefits are sector-dependent and might include, for example: increased access to national and international markets (e.g. higher sales) and the availability of a premium price for certified products (leading to higher profitability). Furthermore, social benefits (primarily from a public sector perspective) should be estimated using indicators for employment creation, income generation, and improvement in the well being of employees and local communities. Concerning private companies, possible gains in reputation, labor productivity, and a better attachment of employees to corporate values and corporate goals and targets should be considered. Finally, indicators of additional environmental benefits could include an improved ecosystem balance (e.g. through the analysis of ecosystem goods and services) and natural capital preservation and regeneration (e.g. through the analysis of natural resource stocks and flows). These can also be monetized making use of existing studies and ongoing research in this field (e.g. global initiatives for the valuation of natural capital and ecosystem services, such as The Economics of Ecosystems and Biodiversity (TEEB), the System of Environmental-Economic Accounting (SEEA), and others).
- c. Quantify avoided costs resulting from sustainability certification and greener production processes. For example, indicators of natural resource (or production input) prices, as well as the consumption of these resources, should be monitored to estimate potential savings from improved resource efficiency (e.g. savings from reduced water and energy consumption, reduced costs of waste treatment and disposal). Also, the avoided social costs of unsustainable practices could be estimated, including for example reduced health expenditure (e.g. from pollution related diseases). Finally, the avoided costs of environmental degradation should be quantified and included in the integrated CBA process. Indicators of natural capital loss and costs of replacement of ecosystem services are essential to evaluate the broader benefits of sustainability investments, especially concerning large-scale projects and investments.



## 4.2 Step 2: Customization of the framework methodology to the specific sector case

### **Objective**

To assess the need for indicators in more detail, with an approach tailored to the specific sector, certification programme and context analyzed, as well as the progress already made in greening production.

### **Actions required**

Researchers should assess whether (1) producers in a given sector already comply with the sustainability principles, criteria and standards defined by the organization issuing the certificate (Case A), or (2) additional interventions are needed to transform production and trade in order to comply with these requirements (Case B). The selection of indicators for Case B should include specific data on additional costs and benefits of shifting to sustainable production and trade processes and procedures. On the other hand, Case A only requires an analysis of advantages and disadvantages directly related to the sustainability certification process (mostly for the monitoring and evaluation of the interventions already implemented). The specific actions for Case A and Case B are listed below.

- ***Case A. Producers/companies that already comply with certification requirements***
  - a. Estimate the costs of certification, including for example: (1) application fees; (2) annual fees; (3) inspection fees; (4) costs of monitoring compliance with certification requirements (e.g. some sustainability criteria require periodic laboratory tests, which should be conducted by certified laboratories).
  - b. Evaluate the advantages of becoming certified using indicators of economic profitability and access to trade, such as: (1) the availability of premium prices for eco-labeled products; (2) access to international markets from which the company would be otherwise excluded; (3) reputational benefits; (4) increased business opportunities deriving from the participation to international sustainability fairs, conferences etc.
  - c. Measure/compare the costs and advantages of trade in certified products against a business-as-usual (i.e. “no action”) scenario and/or for different certification investment scenarios, thus altering the level of investment and assessing the change in outcome.
- ***Case B. Producers/companies that do not comply with certification requirements***
  - a. Select and measure indicators of market potential. In particular, the market potential should be assessed considering opportunities and costs related to the identification of certified suppliers, creation of linkages, partnerships and networks, monitoring and auditing of potential partners.
  - b. Select indicators of investment related to sustainability certification. The costs of compliance with sustainability principles, technical standards and common procedures should be analyzed using a broad set of business-specific indicators. In particular, the analysis should focus on possible additional costs or barriers related to: (1) knowledge gaps associated with an analysis of the value placed on learning in the specific country/sector context addressed; (2) access to credit for primary producers; (3) technology gaps, among others. Finally, additional costs might derive from the adherence to social sustainability principles, such as higher costs for ensuring employee welfare and benefits to local communities. On top of these, more conventional investment indicators should be selected and analyzed (e.g. for certification as well as for greening the production process).
  - c. Select indicators of the benefits of sustainability certification, such as: (1) reduced amount of inputs used in the production process due to improved resource efficiency; (2) increased

productivity; (3) long-term availability of natural resources and avoided cost of natural capital depletion; (4) additional social benefits accruing to employees, local communities and the company as result of complying with sustainability standards (e.g. minimized health costs from improved working conditions; attachment to company values etc.).E

- d. Evaluate additional costs of sustainable trade, such as: (1) additional marketing costs for competing on global markets for sustainable products; (2) costs deriving from trade barriers (e.g. tariff and non-tariff barriers) in certain markets; (3) additional transportation and overall logistics costs due to the expansion of exporting activities.
- e. Select indicators of added benefits and avoided costs of sustainable trade, which might include, depending on the business context analyzed: (1) revenues from premium prices on sustainably produced products; (2) access to international markets for sustainable products; (3) reduced costs from optimization of transportation and logistics; (4) increased revenues from expanding demand for sustainably produced products, etc.

### **Potential challenges**

The identification of costs and benefits indicators for a specific case study analysis requires a detailed study of the context in which production and trade take place. However, researchers might find it difficult to receive information from producers, investors and other key actors along the value chain. Also, the selection of indicators of environmental and social benefits and avoided costs deriving from sustainability certification should be done considering the specificities of the context (e.g. natural resources stocks, environmental trends, employment level, average income), which may be unknown to local actors.

### **4.3 Step 3: Collect available data**

#### **Objective**

To collect data on relevant indicators in order to inform the cost benefit analysis.

#### **Actions required**

- a. Consult a variety of data sources (e.g. ranging from surveys to national databases). Priority should be given to field data, possibly directly obtained from the producers (or industry representatives/associations) that are interested in exploring sustainability certification.
- b. In case national and local data are not sufficient to carry out the CBA, consult international databases. Some relevant examples include, among others:
  - OECD industry and trade statistics.
  - World Bank's World Development Indicators (WDI).
  - Eurostat databases on industry and trade trends.
  - WHO's International Trade Statistics.
  - Trade statistics of the International Trade Centre (including specific tools such as the Standards Map, focused on sustainability certification trends at the global level).
- c. Conduct a review of sector-specific case studies that might provide additional information on costs and benefits of sustainability certification. When country specific data are not available, the analysis of studies conducted in similar country contexts and sectors could be of use to fill in gaps. The assessment and comparison of different case studies is particularly relevant to facilitate the estimation of expected benefits and costs potentially deriving from sustainability certification in the medium- to long-term. This is especially due to the fact that sustainability impacts may require time to become visible, and measurable.

#### 4.4 Step 4: Classify data based on specific analytical needs

##### **Objective**

To categorize the information in a way that facilitates the implementation of a sustainability-related CBA, following the methodology proposed in Section 2 of this study.

##### **Actions required**

- a. Group data on investments needed to comply with specific certification requirements. Data categories under this group may include: (1) Capital and Operation & Management costs; (2) Training costs; (3) Certification costs; (4) Government costs.
- b. Group data on potential added benefits of shifting to sustainability certification. Data categories under this group should include: (1) Direct and indirect economic benefits; (2) Direct and indirect social benefits; (3) Direct and indirect environmental benefits.
- c. Group data on potential avoided costs of adhering to sustainability certification. Data categories under this group should include: (1) Direct and indirect economic avoided costs; (2) Direct and indirect social avoided costs; (3) Direct and indirect environmental avoided costs.

##### **Potential challenges**

When grouping collected data into a coherent assessment framework, researchers should make sure that data are expressed in monetary terms, so as to allow the estimation of expected returns on sustainability certification investments. While conventional indicators of economic costs and benefits are generally expressed in monetary terms (or easily convertible), the valuation of environmental and social benefits and avoided costs might require further elaboration, including the adoption of internationally agreed approaches and methods (e.g. TEEB, SEEA), for which specific technical skills are needed.

#### 4.5 Step 5: Analyze the data adopting an integrated and systemic approach

##### **Objective**

To plug categorized data into the indicator framework in order to conduct the assessment of costs and benefits of sustainability certification.

##### **Actions required**

- a. Analyze the data and select the most suitable cost-benefit analysis technique. Depending on the research question, the data available, and the specific sector addressed, the analyst should decide on the most suitable CBA technique to assess the profitability of sustainability certification. Several techniques are available, including net present value, payback period, rate of return, among others (see Text Box 1).
- b. Carry out a cost-benefit analysis by comparing investments with added benefits and avoided costs. In this phase, the researcher should sum up the costs of sustainability certification and compare them with the sum of added benefits and avoided costs potentially deriving from certification programmes. The assessment will have to take into account uncertainty (e.g. market access). For this reason, various scenarios could be created (e.g. a no premium price scenario to be compared with a 30% premium price scenario) to assess potential threshold and minimum requirements for achieving a positive economic return on investment.

- c. Assess the results of different scenarios, adopting a systemic perspective. In this phase, checking for consistency across data from different sources is essential to evaluate the coherence of the analysis. This is important also to assess a variety of cross-sectoral indicators, which are often not available in a single, integrated database (e.g. by means of triangulation techniques). In particular, given the cross-sectoral nature of a sustainability-related CBA, observed trends should be evaluated using a systemic approach, which takes into consideration the dynamic interplay between economic, social and environmental variables. For example, environmental indicators showing a positive trend in soil quality could be linked to the overall increase in the productivity of sustainably certified agricultural land, in turn leading to higher income levels and company profits. Trends for these variables should be carefully evaluated to determine the presence of behavioral patterns that would reflect the existence of causal relations and, possibly, hidden costs and benefits (e.g. synergies) resulting from sustainability certification.
- d. Compare the outcome of different scenarios. Once the costs and benefits under each scenario have been quantified and assessed, the comparison between different scenarios should be done in order to identify the most profitable options in the short, medium and longer-term.

#### **4.6 Step 6: Evaluate CBA results and inform the decision-making process**

##### **Objective**

To ensure that CBA outcomes are taken into consideration in public and private decision-making processes on sustainability certification.

##### **Actions required**

- a. Evaluate the results of the analysis through a multi-stakeholder process. Given the complexity and significance of the CBA evaluation phase, the outcomes of the analysis should be validated through a multi-stakeholder process in order to take into account different perspectives of key actors along the value chain.
- b. Outline potential impacts of certification across actors, in the sector analyzed. The outcomes of the multi-stakeholder validation process should be clearly communicated in the final analysis. In particular, the potential impacts of sustainability certification on key actors should be explained taking into account the different perspectives, including the companies/producers collaborating along the supply chain, their employees, as well as local communities and the public sector.
- c. Evaluate the overall profitability of adhering to the selected certification scheme (including economic, social and environmental gains). Once stakeholder inputs and recommendations are integrated in the CBA, the final results of the analysis can be communicated, including precise recommendations for future action. Based on the outcome of the CBA, informed decisions can be derived by producers and companies interested in sustainability certification. The evaluation of CBA results should be done considering the various combinations of assumptions, both with regard to business strategy and market responses.

## 5. Causal Loop Diagrams

### 5.1. Definition

A causal loop diagram (CLD) is a map of the system analyzed, or, better, a way to explore and represent the interconnections between the key indicators in the analyzed sector or system.

A more accurate definition is that a CLD is an integrated map (because it represents different system dimensions) of the dynamic interplay (because it explores the circular relations or feedbacks) between the key elements – the main indicators – that constitute a given system.

By highlighting the drivers and impacts of the issue to be addressed and by mapping the causal relationships between the key indicators, CLDs support a systemic decision-making process aimed at designing solutions that last.

The creation of a CLD has several purposes: First, it combines the team's ideas, knowledge, and opinions. Second, it highlights the boundaries of the analysis. Third, it allows all the stakeholders to achieve basic-to-advanced knowledge of the analyzed issues' systemic properties.

Having a shared understanding is crucial for solving problems that influence several sectors or areas of influence (e.g., departments in a multinational company), which are normal in complex systems. Since the process involves broad stakeholder participation all the parties involved need a shared understanding of the factors that generate the problem and those that could lead to a solution to effectively implement successful private-public partnerships. As such, the solution should not be imposed on the system, but should emerge from it. In other words, interventions should be designed to make the system start working in our favor, to solve the problem, rather than generating it.

In this context, the role of feedbacks is crucial. It is often the very system we have created that generates the problem, due to external interference, or to a faulty design, which is showing its limitations as the system grows in size and complexity. In other words, the causes of a problem are often found within the feedback structures of the system. The indicators are not sufficient to identify these causes and explain the events that led to the creation of the problem.

We are too often prone to analyze the current state of the system, or to extend our investigation to a linear chain of causes and effects, which does not link back to itself, thus limiting our understanding of open loops and linear thinking.

Causal loop diagrams include variables and arrows (called causal links), with the latter linking the variables together with a sign (either + or -) on each link indicating a positive or negative causal relation (see Table 5):

- A causal link from variable A to variable B is positive if a change in A produces a change in B in the same direction.
- A causal link from variable A to variable B is negative if a change in A produces a change in B in the opposite direction.

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

**Table 5. Causal relations and polarity**

Circular causal relations between variables form causal, or feedback, loops. “Feedback is a process whereby an initial cause ripples through a chain of causation ultimately to re-affect itself” (Roberts et al., 1983).

*The energy policy that has been in place in Saudi Arabia in recent years is a good example of a feedback loop that can be found in real life. In order to distribute the exceptional profits of the country’s oil exports, the government decided to subsidize the domestic gasoline prices to a greater extent when world oil prices increased (Bradsher, 2008). This mechanism helped maintain the country’s social cohesion. On the other hand, this intervention generated a series of side effects: the lower the domestic price of gasoline, the higher the domestic consumption; when domestic consumption increased, all else being equal, exports, as well as profits, decreased. In order to mitigate this negative effect, Saudi Aramco, the national oil company of Saudi Arabia, had to increase its domestic refining capacity to avoid paying a premium price to foreign refiners, which normally refine exported crude oil, and to maximize the domestic production’s profitability.*

This example shows a negative feedback loop: the current high profits lead to a decrease in future profits due to the increasing domestic demand. Such loops tend towards a goal or equilibrium, balancing the forces in the system (Forrester, 1961).

A feedback can also be positive when an intervention in the system triggers other changes that amplify the effect of that intervention, thus reinforcing it (Forrester, 1961).

*This happens with an oil field’s production before it reaches a plateau phase: the higher the investment in the production capacity, the higher the production. Likewise, the higher the production, the higher the revenues and, therefore, the investments in the production capacity and production. Further, in the plateau and decline phases of the production, the balancing loops -driven by depletion- will dominate.*

## 5.2. Key features

Strengths	Weaknesses
<ul style="list-style-type: none"> <li>Facilitate a multi-stakeholder approach to problem-solving;</li> <li>Help highlight the causal relations between the indicators;</li> <li>Support the analysis of the system behavior and its reaction to external interventions.</li> </ul>	<ul style="list-style-type: none"> <li>Effectiveness is strictly linked to the process quality;</li> <li>Wrong or partial CLDs may lead to ineffective (or even harmful) interventions;</li> <li>Best used if combined with quantitative tools (e.g. simulation models).</li> </ul>

**Table 6. Strengths and weaknesses of CLDs**

### Strengths

CLDs highlight the drivers and impacts of the issue to be addressed and map the causal relations between the key indicators.

By explicitly identifying the feedback loops, CLDs shed light on the main internal mechanisms that led to the problem and also allow projections to be made regarding the system's possible future trajectories in reaction to any implemented decision.

They help identify entry points for interventions, evaluate their effectiveness, as well as the synergies and potential side effects.

They help avoid "blaming" for failure and promote the identification of systemic solutions by clarifying that the causes of a problem are found within the feedback structures of the system and are not due to uncontrollable external events. An external event is not even a problem as such, but the way the system reacts to this event is.

### Weaknesses

The effectiveness of a CLD is directly related to the quality of the work and the knowledge that goes into developing the diagram. Multi-stakeholder perspectives should be incorporated and cross-sectoral knowledge is essential to correctly identify the causes of the problem and design effective interventions.

The boundaries of the system and the relationships between the key variables have to be correctly identified. Errors in creating the diagram may lead to the implementation of policies that do not generate the desired effects, and may even backfire.

The estimation of the strength of causal relations, even if these are correctly identified, cannot be guaranteed as the causal diagram is a qualitative tool. It is therefore advisable to use a causal diagram together with a similar integrated and dynamic causal descriptive mathematical simulation model.

### **5.3. Associated decision-making steps**

CLDs support the decision-making process in several ways and provide valuable input during each step.

More specifically, in the agenda-setting phase, CLDs allow for identifying the causal chain that identifies the problem to be solved. The CLD can therefore show decision-makers problems that may have been overlooked. We too often focus our attention on an event (i.e., the manifestation of a problem) rather than on the problem. By explicitly showing the causal relations and feedback loops, a CLD allows the mechanisms that led to the creation of the problem to be identified, which leads to a far more accurate problem identification effort.

In the policy formulation and assessment phases, CLDs allow for identifying the key entry point for interventions. With CLDs, it is possible to identify the weakest link in the system and to target key feedback loops that (when strengthened or neutralized) will generate positive change. Further, CLDs allow decision-makers to follow the causal chain and to identify all the changes generated in the system. This also allows them to identify the system responses to the implemented interventions.

In the policy evaluation phase, CLDs help evaluate the interventions' performance. This takes place on two levels: (1) short vs. long-term impacts and responses and (2) direct and indirect impacts and responses. The system reacts to the interventions implemented, possibly generating

synergies, but perhaps also creating side effects and elements of policy resistance, which make the intervention ineffective.

#### 5.4. Implementation steps

As mentioned above, a CLD will only be as good as the knowledge and work put into it. On the other hand, a few additional steps have to be followed to design a useful and effective causal diagram.

The basic knowledge needed to build a CLD includes the concept of polarity (i.e., the sign of the causal relation between two variables, whether positive or negative), and the concept of feedback (reinforcing or balancing), as mentioned above. The following are the practical steps that should be followed:

- Start with the key indicator identified as representing the problem and add it to your diagram (which is blank at this stage).
- Add the causes of the problem, one by one, linking them to the first variable considered and determine the polarity of the causal relation.
- Continue identifying and adding the cause of the cause, and so forth.

In the process, the diagram will grow and other variables will influence some of the variables identified as causes of the problem. These circular relations are the feedback loops (representing closed-loop thinking), which are also the key functioning mechanisms of the analyzed system. Thinking in terms of feedbacks is crucial in the development of CLDs and requires a multi stakeholder approach.

More specifically, the following recommendations should be followed to create a good causal diagram (Sterman, 2000):

- Use nouns or noun phrases to represent the elements rather than verbs. That is, the links (arrows) represent the actions in a causal loop diagram and not the elements. For example, use “cost” and not “increasing cost” as an element.
- Generally it is clearer if you use an element name in a positive sense. For example, use “growth” rather than “contraction.”
- A difference between the actual and perceived states of a process can often be important to explain patterns of behavior. In many cases, there is a lag (delay) before the actual state is perceived. For example, when there is a change in actual product quality, it usually takes a while before customers perceive this change.
- There are often differences between short-term and long-term consequences of actions and these may need to be distinguished with different loops.
- Keep the diagram as simple as possible, subject to the earlier points. The purpose of the diagram is not to describe every detail of the management process, or the system, but to show those aspects of the feedback structure that lead to the observed problem. In other words: model the problem, not the system.

Finally, once the creation of the diagram is complete, the analysis can begin. Normally the starting point is the first variable added to the diagram, or the key problem to be solved. It is good practice to “read” the diagram to understand the extent to which simultaneous factors influence the causes of the problem. Further, reading the diagram helps check on its consistency and validity and also identifies the overall system pattern and the main feedback loops responsible for it.



There are a few methods to determine whether a feedback loop reinforces or balances. The two most commonly used are:

- Reading the CLD: starting with the assumption that the first variable in the loop will increase when the loop is followed, (1) we end up with the same result as the initial assumption (i.e., that the variable increases) and the feedback loop reinforces; (2) we end up contradicting the initial assumption (i.e., that the variable decreases) and the feedback loop is balanced, or opposes change.
- Counting plus and minus signs: (1) reinforcing loops have an even number of negative links (zero is also even); (2) balancing loops have an uneven number of negative links.

## 6. Policy Options

To be most effective, adaptation must proceed at several levels simultaneously. Adaptation is in fundamental ways inherently “local” - the direct impacts of climate change are felt locally, and response measures must be tailored to local circumstances. However, for these efforts to be robust -or, in many cases, even possible- they must be guided and supported by national policies and strategies. For some countries, these, in turn, need to be facilitated through international measures.

Collectively, these efforts must meet a wide range of interrelated needs. Briefly, these include (Burton et al., 2006)<sup>1</sup>:

- **Information:** Effective strategies must rest on the best available data on the nature and severity of likely impacts over different timeframes in given geographical contexts, and on the cost and efficacy of possible response measures.
- **Capacity:** An overriding priority is strengthening capacities in the technical and planning disciplines most relevant to understanding potential climate impacts and devising response strategies.
- **Financial Resources:** Most countries will require resources to improve capacity, undertake specific adaptation measures, and cope with impacts as they occur.
- **Institutions:** While adaptation must be integrated across existing institutions, focal points are needed at the national and international levels to garner expertise, develop and coordinate comprehensive strategies, and advocate for broad-based planning and action.
- **Technology:** As in climate mitigation, adaptation success depends in part on access to -and, in some areas, development of- technologies suited to the specific needs and circumstances of different countries.

In considering how best to address these needs, the international community faces a host of difficult issues stemming from the underlying characteristics of climate risk, the institutional contexts for adaptation decision-making and action, and inherent limits on available resources,

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<sup>1</sup> Burton, I., E. Diringer, J. Smith (2006). Adaptation To Climate Change: International Policy Options. Pew Center on Global Climate Change.

all compounded by politically sensitive questions of responsibility and equity. These issues include (Burton et al., 2006)<sup>2</sup>:

- The appropriate balance between “reactive” and “proactive” approaches;
- The proper coupling of specific adaptations and stronger adaptive capacity;
- The difficulty of distinguishing climate change impacts from those due to natural climate variability; and
- Adaptation’s intersection with a broad range of other policy areas and priorities.

As is true on the mitigation side of the climate equation, an effective adaptation response requires a wide array of measures and strategies. Three broad approaches for intervention are generally being considered at the international level:

- **Adaptation under the UNFCCC:** Strengthening mechanisms and support for proactive adaptation under the Convention by facilitating comprehensive national strategies and committing reliable funding for high-priority implementation projects.
- **Integration with development:** Factoring adaptation into development assistance through measures such as mandatory climate risk assessments for projects financed by multilateral and bilateral lenders.
- **Climate “insurance”:** Committing funds to support climate relief or insurance-type approaches in vulnerable countries for losses resulting from both climate change and climate variability.

Each of these approaches, pursued independently, could contribute to national-level efforts to reduce or cope with climate risks. Together, these three strategies also could be seen as complementary elements of a comprehensive international effort: the first, supporting proactive planning and high-priority implementation; the second, promoting integration with the broader development agenda; and the third, providing a safety net to ameliorate unavoidable impacts.

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<sup>2</sup> Ibid.

## 7. Review of simulation models

### 7.1. Overview of methodologies and models

Various methodologies can be utilized to effectively support policy formulation and assessment (identification of problems, and then policy options that would have the desired impact, also of the magnitude desired, on the system) and evaluation (simulation of selected intervention options against real events). In this respect, it is worth mentioning that the methodologies presented in this section are most commonly used when the analysis is done “ex ante”, or before the actual implementation of the interventions (issue identification and agenda setting, and policy formulation and assessment), but they can also be used to carry out “ex post” (policy monitoring and evaluation) analysis:

- *Ex-ante* modeling methodologies can generate “what if” projections on scenarios with no action, and on the expected (and unexpected) impacts of proposed policy options on a variety of key indicators. In addition, various methodologies can assist in the cost-benefit and multi-criteria analysis, and subsequent prioritization of policy options.
- *Ex-post* modeling methodologies can support impact evaluation by improving the understanding of the relations existing among key variables in the system and by comparing the projected performance with initial conditions and historical data. This can be done by considering individual interventions or a policy package. Improvements to the model and updated projections allow decision-makers to refine targets and objectives, building on synergies and positive spillovers across sectors.

### 7.2. Review of methodologies

The review of methodologies starts with a brief introduction of their strengths and weaknesses to continue with a comparative analysis of their contribution to the policymaking process, respective complementarity with other approaches and accessibility, or multi-stakeholder participation, in the process of model creation.

#### 7.2.1 Data frameworks

##### *Indicators*

An indicator is an instrument that provides an indication, generally used to describe and/or give an order of magnitude to a given condition. Indicators provide information on the historical and current state of a given system, and are particularly useful to highlight trends that can shed light on causal relations among the elements composing the system and in analyzing whether progress is made in reaching a given policy target.

When used in the context of policymaking, indicators are useful instruments to inform decision-making (UNEP, 2012). Using inventory data and/or surveys, indicators can be grouped in four main categories (1) indicators for issue identification and agenda setting; (2) indicators for policy formulation; (3) indicators for policy assessment and (4) indicators for policy Monitoring and Evaluation.

##### *Input - Output*

Input-Output (I-O) frameworks depict inter-industry relationships within an economy or across economies, estimating how output from one sector may become an input to another sector. Inputs and outputs can be measured in economic (e.g., the monetary value of trade) and physical terms (e.g., material flows and emissions, or employment).

In a typical I-O matrix, columns would represent inputs to a sector, while rows would represent outputs from a given sector. This approach is frequently used to estimate impacts of investments and policies on the value chain of specific products and industries.

#### *Social Accounting Matrix*

A Social Accounting Matrix (SAM) is an accounting framework that captures the transactions and transfers between the main actors in the economy. As a result, for any given year, the SAM provides information on the monetary flows that have taken place between, for instance, the government and households, ensuring that all inflows equal the sum of the outflows. The focus on households makes the SAM “social”, and makes it an adequate backbone for Computable General Equilibrium (CGE) and other macroeconomic models to carry out analysis that spans across the whole economy.

#### *Geographic Information System*

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

GIS applications use geographically disaggregated data presented in maps. Technically there is no restriction in the type of data that can be included in GIS tools, which often incorporate social, economic and environmental indicators. On the other hand, there could be a scaling problem when the coupling of spatially disaggregated data is not possible (e.g., when attempting to couple detailed local GIS information with economic data that may only be available at the national level).

### 7.2.2 Modeling approaches

#### *Econometrics*

Econometrics measures the relation between two or more variables, running statistical analysis of historical data and finding correlation between specific selected variables. Econometric exercises include three stages – specification, estimation, and forecasting. The structure of the system is specified by a set of equations, describing both physical relations and behavior, and their strength is defined by estimating the correlation among variables (such as elasticities: coefficients relating changes in one variable to changes in another) using historical data. Forecasts are obtained by simulating changes in exogenous input parameters that are then used to calculate a number of variables forming the structure of the model (e.g., population and economic growth).

The most important limitations of econometrics are related to the assumptions characterizing the most commonly used economic theories: full rationality of human behavior, availability of perfect information and market equilibrium. When looking at the results produced by econometric models, issues arise with the validation of projections (that cannot backtrack historical data) and with the reliability of forecasts that are only based on historical developments and on exogenous assumptions.

#### *Optimization*

The use of optimization in policymaking generates “a statement of the best way to accomplish some goal” (Sterman, 1988). Optimization leads to models that are normative, or prescriptive, and provide information on what to do to make the best of a given situation (the actual one). In order to optimize a given situation, these models use three main inputs: (1) the goals to be met (i.e., objective function, such as minimizing the cost of energy supply), (2) the areas of interventions and (3) the constraints to be satisfied.

Optimization is also used to estimate the impact of external shocks (e.g., policies), such as in the case of CGE models. Here optimization is primarily used to solve the mathematics underlying the model. The assumption is that agents are maximizing welfare (profits or consumption), and the model is solved by finding the price vector that optimizes overall welfare as a representation of how the economy might be thought of as functioning.

The challenges related to optimization models include the correct definition of an objective function, the extensive use of linearity, the limited representation of feedback and dynamics. Such models usually do not provide forecasts, but some of them, such as CGE models (Coady, 2006) as well as MARKAL (Fishbone et al., 1983; Loulou et al., 2004) and MESSAGE (IIASA, 2001, 2002) in the energy sector, provide snapshots of the optimum state of the system with specific time intervals. Such models use exogenous population and economic growth rates, among other exogenous variables.

### *System Dynamics*

System Dynamics is a methodology used to create models that are descriptive, and focuses on the identification of causal relations influencing the creation and evolution of the issues being investigated. System Dynamics models are in fact most commonly used as “what if” tools that provide information on what would happen in case a policy is implemented at a specific point in time and within a specific context.

System Dynamics aims at understanding what the main drivers for the behavior 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 analyzed. Potential limitations of simulation models include the correct definition of system’s boundaries and a realistic identification of the causal relations characterizing the functioning of systems being analyzed (e.g., relating to the use of causality rather than correlation).

### 7.2.3 Comparative assessment

A comparative assessment of the methodologies analyzed in this study is provided in Table 7. This table does not aim at identifying what is the best methodology, but to review their main strengths and weaknesses, how they contribute to the policymaking process, as well as their complementarity and accessibility. The choice of the best methodology and model to use depends on a variety of additional criteria.

With regard to data frameworks, and concerning the policy process, while the use of indicators can support each phase, I-O and SAM can primarily support policy formulation and assessment, by testing the impact of policies. GIS tools instead can be used to identify problems (by observing trends), support policy formulation (by testing the extent to which a policy, often regulation, would impact land use, among others) as well as policy M&E (by monitoring the evolution of the system over time). Concerning complementarity, indicators, SAM and GIS could be relatively easily incorporated in other types of assessments (provided that data are coherently disaggregated), while the specificity of I-O tables (especially concerning employment and material flows), makes them particularly useful for detailed studies but of more difficult incorporation in other analyses. Regarding accessibility, indicators and GIS are likely to capture the interest of a larger set of stakeholders, mostly due to their cross-sectoral coverage.

With regard to modeling approaches, System Dynamics provides a degree of flexibility that makes it useful and relevant for all policymaking stages. While this does not mean that a single model may be relevant throughout the policy cycle, the methodology allows for the creation of a suite of

models that can effectively inform decision makers. Further, econometrics can most effectively contribute to issue identification (by projecting trends based on historical observed behavior), and optimization is better suited for policy formulation and assessment (especially by setting targets and providing information on the best system setup to reach them). Concerning complementarity, elements of econometrics and optimization (especially if used in simulation mode, for solving the underlying mathematics of models) can be easily utilized in several models used for green economy assessments. System Dynamics facilitates the incorporation of knowledge in a single framework of analysis, and can also be coupled with other approaches (e.g., econometrics and optimization, and more increasingly GIS as well). Regarding accessibility, econometrics and optimization generally target a focused target audience, which would change depending on the scope of the analysis (e.g., energy, economic planning). The use of a systemic approach to develop System Dynamics models makes it instead better suited to broaden the range of stakeholders involved in the modeling process and planning. This is primarily due to the ease of incorporating cross-sectoral factors in the model (e.g., energy-economy-environment nexus).

Methodology	Main strengths	Main weaknesses	Problem identification	Policy formulation	Policy assessment	Policy M&E	Complementarity	Accessibility - participation
<b>Static</b>								
<b>Indicators</b>	Support the entire policy cycle, quantify trends.	Require harmonization; primarily limited to (quantitatively) measurable variables.	✓	✓	✓	✓	✓	✓
<b>Input-Output</b>	Represent value chain impacts, and ripple effects across sectors.	Data intensive; material flows not generally available.	✓	✓	✓			
<b>Social Accounting Matrix</b>	Estimates economic flows across the main economic actors.	Covers exclusively monetary flows; lacks feedbacks.		✓	✓		✓	
<b>Geographic Information System</b>	Captures local trends, based on geographical maps; fully accounts for natural resources and ecosystem services.	Data intensive; may miss economic dimensions; uneven data resolution may pose challenges.	✓	✓		✓	✓	✓
<b>Dynamic (Projections)</b>								
<b>Econometrics</b>	Entirely based on historical trends; quick implementation.	Lacks the explicit representation of feedbacks and does not capture possible emerging dynamics.	✓		✓		✓	✓
<b>Optimization</b>	Supports the estimation of targets, understanding key limits of the system.	Provides and "end" with little insights on the "means". Not viable for highly dynamic and cross-sectoral systems.		✓	✓			✓
<b>System Dynamics</b>	Focuses on structure to drive behavior; horizontal sectoral representation; knowledge integrator (ad hoc).	Highly reliant on knowledge available in other fields; relatively long implementation time for national models.	✓	✓	✓	✓	✓	✓

Table 7. Review of methodologies; contribution to the policy process, complementarity and stakeholder participation.

### 7.3. Review of models

The review of models focuses on the comparative assessment of their respective key contributions to a green economy assessment. More details on the main characteristics of these models are available in UNEP (2014).

A comparative assessment of the models is provided in Table 8. More specifically, I-O models can provide a high level of sectoral disaggregation and generate results analyzed across the value chain of selected products and technologies, tracking employment, material and/or emission flows. Regional I-O models extend this analysis to trade among countries. These models can capture economic and human capital, sustainable consumption and production (SCP) and competitiveness, as well as support investment analysis.

Energy and other system engineering models specifically focus on one or two sectors and can track manufactured capital (even if expressed in physical terms, as built up capital), climate change mitigation options (e.g., in the case of energy) and potentially also climate change adaptation (e.g., in the case of water). These models can support both investment and policy analysis (especially regulation).

GIS-based models (e.g., LCM) and InVEST, being spatially disaggregated and focusing on land use changes, specialize in natural capital and are able to capture ecological scarcities and environmental risks. These tools can also support the analysis of human well-being, with access to resources and vulnerability to climate change, being capable of analyzing impacts, mitigation (especially sinks, through land use) and adaptation options. Spatial models are generally better suited to analyze policy impacts (e.g., regulation), rather than green economy investments.

CGE models cover the economic sphere of sustainable development, accounting for manufactured capital, competitiveness and social equity (e.g., through the estimation of income distribution). Human capital can also be estimated, despite methodological constraints, regarding employment, skills, as well as salary and wages. CGE models can effectively support both investment and (fiscal and monetary) policy analysis.

When coupled with system engineering models, CGEs can more effectively incorporate natural capital (primarily by representing natural resource stock and flows) and ecological scarcities. This allows a fuller estimation of competitiveness, also including SCP and the analysis of capital misallocation (now possible due to the cross-sectoral nature of the model, capable of estimating ecological scarcities). Further, by adding natural resources, the model would be able to analyze climate change mitigation and adaptation options, and make use of spatial information to potentially incorporate impacts as well.

System Dynamic models, both sectoral and integrated, can endogenously represent economic, human and natural capital. The strength of the model and the level of detail of the analysis depend on the identification and understanding of the key drivers of the system, and on the availability of inputs from more detailed employment and natural capital assessments. By accounting for natural resource stocks and flows, ecological scarcities can be estimated, with resulting environmental risks and vulnerabilities (incorporated using results of an InVEST analysis, for instance). At the economic level, given the typical high level of aggregation of System Dynamic models, SCP could be simulated and analyzed from a macro perspective, tracking consumption of the most relevant inputs to production (especially natural resources). Further, competitiveness and capital misallocation would be endogenously estimated, providing insights on the key -past, present and



future- drivers of economic growth. Concerning social dimensions, while social equity would be estimated through income distribution, the calculation of human well-being could use indicators from a variety of sectors, including environmental ones. As in the case of CGEs with system engineering modules, climate change impacts could be incorporated if science is available, and the model could simulate and support the evaluation of mitigation and adaptation options using cross-sectoral indicators (including direct, indirect and induced impacts). Finally, System Dynamics models can be used to carry out both green economy investment and policy analysis.

This section reviewed some of the various criteria for choosing the best model to use, criteria which relate primarily to the problem to be analyzed, the stage of the policymaking process to influence and the constraints relating to timing, budget and human resources (e.g., local knowledge of modeling techniques and time availability).

**Text box: Climate models and Downscaling**

Global climate models (GCMs) are very important to study the current climate and to obtain projections on the future climate using different anthropogenic emission scenarios. The most important advantage from using GCM outputs is the physical consistency between variables. However, they are not adequate for climate regional studies, to support impact studies and for studies on adaptation strategies to climate changes. The generation of high resolution climate scenarios is needed for these goals. The need for regional scenarios of climate change for impacts studies has been felt for years and has resulted in the development of different methodologies for deriving such information. These methodologies are known as “downscaling” and the interest towards them is also confirmed by the existence of different national and international initiatives. Downscaling techniques have been designed to bridge the gap between the information that the climate modelling community can currently provide and those requested by the impacts research community. The downscaling can be performed in two different ways: statistical or dynamical downscaling. In the report “Development of a DRR Strategic Framework and Action Plan for Mauritius”, a Regional Climate Model (RCM) is used to provide a dynamical downscaling of the GCM. This technique consists of using outputs from GCM simulations to provide initial and boundary conditions for high-resolution RCM simulations, without feedback from the RCM to the driving GCM. This technique derives finer resolution climate information from coarser resolution data. RCM provides output only for a limited domain at a finer spatial resolution (GoM, 2012)

		Representation of key pillars (and capitals) of sustainable development									Analysis of Climate Change			GE Intervention Analysis		
		Economic dimension			Social dimension			Environmental dimension								
Model	Scope of the analysis	Economic capital	SCP	Competitiveness	Capital misallocation	Human capital	Human well being	Social equity	Natural capital	Ecological scarcities	Environmental risks	CC impacts	CC mitigation	CC adaptation	Investment analysis	Policy Analysis
Input-Output (I-O)	Macro, with high level of sectoral disaggregation, for monetary and physical flows	✓	✓	✓		✓									✓	
Energy and other System Engineering models	Sectoral analysis, with high level of detail	✓											✓	✓	✓	✓
Geographical Information System (GIS) and InVest	Highly geographically disaggregated, with analysis ranging from local to national						*		✓	✓	✓	✓	✓	✓		✓
Computable General Equilibrium (CGE)	Macro, with sectoral disaggregation	✓		✓		*	✓	✓							✓	✓
CGE and System Engineering (energy and natural resources)	Macro, with sectoral detail.	✓	✓	✓	✓	*		✓	*	✓		*	✓	✓	✓	✓
System Dynamics (SD) models (e.g., T21)	Macro, with the possibility to add sectoral detail with social, economic and environmental variables	✓	*	✓	✓	✓	*	✓	*	✓	*	*	✓	✓	✓	✓

Table 8. Review of models. The \* indicates the possibility to include basic variables and to address the criteria more extensively with the availability of information generated by other models.

### 7.3.1 Fisheries

Advancements in the area of Earth System modeling are increasingly linking climate, ecosystems and socio-economics dynamics. However, the global view of climate impacts on fish and fisheries is patchy and still emerging. Validating higher trophic level outputs, and social, economic and behavioral mechanisms is still difficult, given the limited amount of comparable data. Shelf models are starting to be developed, but there are technical issues to be resolved on the boundary conditions between shelf models and global models, particularly in continental shelves and upwelling areas (where fishery productivity is greatest) (Kellerman, 2010).

New approaches are needed to assess the risks associated with different management strategies in the fishery sector. These approaches must be capable of tracking the complex nature of management systems. In many countries, fisheries are managed through a complex suite of interrelated regulations that are designed to build sustainable fisheries within an ecosystem context. Two different risk assessment approaches have emerged. Several analysts have attempted to identify indicators that track changes in ecosystem status to assess the performance of management strategies within an ecosystem context. Proposed indicators include measures of fish sustainability, habitat quality, biodiversity, and socio-economic factors. On a separate but related research track, analysts have attempted to develop projection models that would allow managers to evaluate the implications of their actions within an ecosystem context. Management strategy evaluation (MSE) models were introduced to address this need. With the growing recognition of the potential impacts of climate change on marine oceans, fishery scientists have developed MSE models that incorporate climate forcing. Because of the desire to trace the sources of uncertainty within the projection, MSEs typically model a limited number of fisheries. The index and MSE approaches seldom project management scenarios that address multispecies, multisector, multiobjective fisheries management within an ecosystem context. Although efforts are underway to develop fully coupled end-to-end models, these models require a data-rich environment, where coupled ocean circulation models are available (Zhang, 2011).

### 7.3.2 Biodiversity

Various types of modelling tools exist for predicting impacts of climate change on biodiversity and/or ecosystem services. Scale, data and resource needs, and knowledge gaps may affect the type of model most appropriate. When considering the climate portion of models, for example, Coupled Atmosphere-Ocean General Circulation Models (AOGCMs), used for global and continental predictions, typically operate on coarse resolutions (150-300 km) whereas broad categories of downscaling include: High-resolution “time-slice” Atmosphere General Circulation Models (AGCMs); Variable resolution AOGCMs (VarGCMs); Nested Regional Climate Models (RCMs); and statistical downscaling (SD) methods. Each regionalization method is being used in an increasingly wider range of applications however major source of uncertainty are cloud feedbacks, cryospheric processes, extreme and tropical precipitation patterns and southern ocean dynamics. Such climate models can be combined with biological or ecological information as bioclimatic models. The Intergovernmental Panel on Climate Change, in its Third Assessment Report, defines bioclimatic models as, models “...used to determine the strength of association between suites of biotic and abiotic variables and species distributions. These associations can then be used to predict responses to environmental change, including climatic change.” (UNEP, 2012)

The most pressing issue is to quantitatively assess the prospects for biological diversity in the face of global climate change. Although several methods exist to draw inferences, starting with existing paleontological or recent data, experiments, observations, and meta-analyses (e.g., Lepetz et al. 2009), ecological modelling is the most commonly used tool for predictive studies. Progress in this

field is characterised by both an extremely high pace and a plurality of approaches. In particular, there are three main approaches to projecting species loss, concentrating either on (1) future changes in species range or (2) species extinction or (3) changes in species abundance. However, all three modelling approaches have so far largely focused on one axis of response (change in space), largely overlooking the importance of the other aspects. In addition, they seldom account for the mechanisms of these responses (plasticity and evolution).

### 7.3.3 Health

The main types of models used to forecast future climatic influences on infectious diseases include statistical, process-based, and landscape-based models. Statistical models require, first, the derivation of a statistical (empirical) relationship between the current geographic distribution of the disease and the current location-specific climate conditions. This describes the climatic influence on the actual distribution of the disease, given prevailing levels of human intervention (disease control, environmental management, etc.). By then applying this statistical equation to future climate scenarios, the actual distribution of the disease in future is estimated, assuming unchanged levels of human intervention within any particular climatic zone. These models have been applied to climate change impacts on malaria, dengue fever and, within the USA, encephalitis (WHO, 2016).

Process-based (mathematical) models use equations that express the scientifically documented relationship between climatic variables and biological parameters -e.g. vector breeding, survival, and biting rates, and parasite incubation rates. In their simplest form, such models express, via a set of equations, how a given configuration of climate variables would affect vector and parasite biology and, therefore, disease transmission. Such models address the question: "If climatic conditions alone change, how would this change the potential transmission of the disease?" Using more complex "horizontal integration", the conditioning effects of human interventions and social contexts can also be incorporated (WHO, 2016).

Since climate also acts by influencing habitats, landscape-based modeling is also useful. This entails combining the climate-based models described above with the rapidly-developing use of spatial analytical methods, to study the effects of both climatic and other environmental factors (e.g. different vegetation types -often measured, in the model development stage, by ground-based or remote sensors). This type of modelling has been applied to estimate how future climate-induced changes in ground cover and surface water in Africa would affect mosquitoes and tsetse flies and, hence, malaria and African sleeping sickness (WHO, 2016).

Historical studies demonstrate the usefulness of long-term historical or current datasets in predicting present and future patterns of disease. They also suggest that it is possible to construct an Early Warning System (EWS) based on overall associations of climate variables with disease incidence, without necessarily relying on complete knowledge of the effects of climate on all components of the disease transmission cycle. The health sector is now in a much stronger position to explore the utility of EWS. Firstly, standardization of disease diagnosis and networked computerized reporting potentially allow accurate and rapid monitoring of disease incidence (although undermined by patchy and often deteriorating surveillance systems in many parts of the world). Secondly, a wide variety of environmental monitoring data from satellite and ground-based systems are easily accessible at no or low cost, facilitating the investigation of potential links to climate. Thirdly, advances in statistical and epidemiological modelling allow apparent associations to be tested explicitly, rather than relying on visual inspection (WHO, 2004).

Despite the renewed interest in EWS within the health sector, there has been little operational activity to date. This contrasts with other sectors: most notably, a large amount of research and

development effort has been focused on the development of famine early warning systems (FEWS) following widespread famine in Africa in the early 1980s. FEWS operate at various geographical levels, with food availability being predicted using risk indicators such as market export prices, pest infestations, war and conflict, nutritional indices and climate and vegetation variables. The Food and Agriculture Organization of the United Nations (FAO) has established the Africa Real Time Environmental Monitoring Information System (ARTEMIS) which uses Meteosat remotely sensed images to monitor crop seasons and rainfall. These can be used to assess environmental conditions during the current growing season relative to previous years (WHO, 2004).

#### 7.3.4 Infrastructure

Advances in climate prediction offer the potential to enable a strategic regional and national approach to planning and preparedness for energy infrastructure: predictive models are achieving a level of completeness and complexity that begins to capture climate evolution at regional scale in response to the complex coupling between atmosphere, ocean, land-mass, ecology, etc. Advances in interdependent infrastructure simulation—including probabilistic risk assessment and multi- infrastructure design optimization—offer the potential to utilize climate modeling and simulation outputs to create a multi-scale, risk-aware, time-extended simulation and optimization environment for both exploring and directing infrastructure adaptation models. Integration and automation of interdependent infrastructure and natural systems simulation enables the rapid exploration of the resilience and probabilistic risk assessment of local-scale infrastructure to a wide range of complex threats ranging sea level rise, hurricanes, extreme rainfall, inland flooding, and severe ice storms. Advancements in optimization techniques such as new relaxations and heuristic methods are making optimal designs of large-scale interdependent infrastructure networks computationally tractable (Los Alamos National Laboratory, 2016).

Bringing these two components together can lead to a level of accuracy in understanding potential climate–infrastructure impacts that is needed for effective planning in the context of infrastructure investments and resilience to extreme events. However, to achieve this integration of climate predictions and infrastructure assessment and design requires addressing several challenges (Los Alamos National Laboratory, 2016):

- Outputs from climate predictions are not directly usable in risk assessments of infrastructure impacts. Models do not currently predict all of the relevant interface variables that drive infrastructure design. For those that are predicted, they are often not available on useful time scales or expressed in an appropriate structure, e.g. predictions of seasonal mean regional temperature versus predictions of distributions or extreme of daily temperatures.
- Integrated formulations of large-scale infrastructure optimization and simulation models do not yet account for the wide disparities of spatial and temporal scales needed to simultaneously represent both local resilience to extreme episodic events and regional-scale adaption and economic efficiency over long time scales.
- Stakeholders (particularly federal stakeholders) cross many organizations, resulting in no focused federal program.

Numerical simulations are the most reliable way to produce credible process-based projections of the future climate. However, even state-of-the-art simulations inevitably contain biases and are so computationally expensive as to hinder comprehensive uncertainty analysis. These limit the direct usefulness of Earth system models for infrastructure vulnerability and adaptation

assessments. One path forward is a fast “emulation” approach that combines observational data and multi-fidelity simulation output to link climate variability and extreme weather dynamics, providing probabilistic risk information to infrastructure simulations. This new “risk projection model” would represent a convergence between numerical-physical Earth system modeling and the statistical-empirical catastrophe risk (“cat-risk”) modeling more common to the insurance industry (Los Alamos National Laboratory, 2016).

The same limitations also exist in integrated assessment models of coupled natural-human-engineered systems. In particular, adaptation dynamics at the level of individual infrastructure assets is embedded in a larger system of national infrastructure and resource availability; at the same time, infrastructure hardening and siting decisions feed back to this larger scale. There are close links between infrastructure and the natural Earth system, such as ecosystems buffering population centers from storms, and urban development disturbing ecosystems and land surface processes. The result is a high-complexity, multiscale, nonlinear system with threshold behavior as failures cascade through interdependent systems. This already-complex system may become further embedded within nested multiscale optimization loops when human decision making is represented. This calls for emulation of not only infrastructure dynamics at multiple scales, but of adaptation policies and their feedbacks to other system components. Policies should be robust with respect to both present-day uncertainty and the possibility of new information arriving over time (Los Alamos National Laboratory, 2016).

There are potential links to information science and technology beyond emulation, uncertainty quantification, and optimization. For example, one approach to high-fidelity Earth system modeling advocates a “seamless prediction” program, where a numerical model is expected to be useful both in a short-term weather prediction and long-term climate projection setting. The same approach could be taken an operational forecasting or a probabilistic risk projection setting. For example, a cat-risk type model that forecasts the exposure of infrastructure assets to hurricane intensification based on climate projections could also be expected to perform well as an operational hurricane statistical forecast model. This would lend credibility and historical validity to its longer-term projections. Machine learning techniques could be used to identify new nonlinear features/signatures useful for prediction, or even to provide statistical models that can be used in place of numerical models for highly efficient data assimilation and forecasting of both climate and weather and infrastructure response (Los Alamos National Laboratory, 2016).

### 7.3.5 Models for the analysis of ecosystem services

The modeling and mapping of ecosystem services are important elements in a decision-making process that aims to improve recognition and application of services. Spatial prioritization is also considered an important step in conservation planning. With spatial and quantitative information, land use decisions could incorporate areas with the best trade-offs and win-wins between services, biodiversity conservation and economic activities. Those are very important tools for decision-making, especially in conflict regions, where the economic activities affect the natural surroundings. In the following subsections, a review for three main modeling tools for analysing agricultural activities, water availability, and degradation of ecosystem services is presented.

#### *CROPWAT*

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. 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.

As a starting point, and only to be used when local data are not available, CROPWAT includes standard crop and soil data. When local data are available, these data files can be easily modified or new ones can be created. Likewise, if local climatic data are not available, these can be obtained for over 5,000 stations worldwide from CLIMWAT, the associated climatic database. The development of irrigation schedules in CROPWAT is based on a daily soil-water balance using various user-defined options for water supply and irrigation management conditions. Scheme water supply is calculated according to the cropping pattern defined by the user, which can include up to 20 crops.

Calculations of the crop water requirements and irrigation requirements are carried out with inputs of climatic, crop and soil data. For the estimation of crop water requirements (CWR) the model requires:

- Reference Crop Evapotranspiration (Eto) values measured or calculated using the FAO Penman-Montieth equation based on decade/monthly climatic data: minimum and maximum air temperature, relative humidity, sunshine duration and windspeed;
- Rainfall data (daily/decade/monthly data); monthly rainfall is divided into a number of rain storm each month;
- A Cropping Pattern consisting of the planting date, crop coefficient data files (including Kc values, stage days, root depth, depletion fraction) and the area planted (0-100% of the total area); a set of typical crop coefficient data files are provided in the program.

In addition, for Irrigation Scheduling the model requires information on:

- Soil type: total available soil moisture, maximum rooting depth, initial soil moisture depletion (% of total available moisture);
- Scheduling Criteria: several options can be selected regarding the calculation of application timing and application depth (e.g. 80 mm every 14 days, or irrigate to return the soil back to field capacity when all the easily available moisture has been used).

As for the output, CROPWAT calculates the results as tables or plotted in graphs. The time step of the results can be any convenient time step: daily, weekly, decade or monthly. The output parameters for each crop in the cropping pattern are:

- reference crop evapotranspiration (mm/period);
- crop Kc: average values of crop coefficient for each time step;
- effective rain (mm/period): the amount of water that enters the soil;
- crop water requirements (mm/period);
- irrigation requirements (mm/period);
- total available moisture (mm);
- readily available moisture (mm);
- actual crop evapotranspiration (mm);
- ratio of actual crop evapotranspiration to the maximum crop evapotranspiration (%);
- daily soil moisture deficit (mm);
- irrigation interval (days) & irrigation depth applied (mm);

- lost irrigation (mm): irrigation water that is not stored in the soil (i.e. either surface runoff or percolation);
- estimated yields reduction due to crop stress.

An example of the application of CROPWAT in Africa is represented by the case study conducted in Benin in 2015 (Bouraima, 2015). This case study estimated the crop reference and actual evapotranspiration, and the irrigation water requirement of *Oryza sativa* in Benin's sub-basin of Niger River of west Africa. The long recorded climatic data, crop and soil data from 1942 to 2012 were computed with CROPWAT. The Penman-Monteith method was used to estimate evapotranspiration. Crop coefficients from the phenomenological stages of rice were applied to adjust and estimate the actual evapotranspiration through a water balance of the irrigation water requirements (Bouraima, 2015). The irrigation projects were then scheduled for water use efficiency based on the study's findings.

### SWAT

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 predict the impact of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying soils, land use and management conditions over long periods 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.

SWAT uses a two-level disaggregation scheme; a preliminary sub-basin identification is carried out based on topographic criteria, followed by further discretization using land use and soil type considerations. Areas with the same soil type and land use form a Hydrologic Response Unit (HRU), a basic computational unit assumed to be homogeneous in hydrologic response to land cover change. SWAT divides a watershed into hydrological response units (HRUs) based on unique land cover, soil type, and slope. HRUs are a set of discontinuous land masses that are spatially located in the watershed but their responses are not tied to any particular field (Melesse, 2016). To satisfy its objectives, the model has the following characteristics:

- It is physically based. Rather than incorporating regression equations to describe the relationship between input and output variables, SWAT requires specific information about weather, soil properties, topography, vegetation, and land management practices occurring in the watershed. The physical processes associated with water movement, sediment movement, crop growth, nutrient cycling, etc. are directly modeled by SWAT using this input data.
- It uses readily available inputs. While SWAT can be used to study more specialized processes such as bacteria transport, the minimum data required to make a run are commonly available from government agencies.
- It is computationally efficient. Simulation of very large basins or a variety of management strategies can be performed without excessive investment of time or money.
- It enables users to study long-term impacts. Many of the problems currently addressed by users involve the gradual buildup of pollutants and the impact on downstream water



bodies. To study these types of problems, results are needed from runs with output spanning several decades.

### *InVEST*

The Integrated Valuation of Environmental Services and Trade Offs (InVEST) is a family of models developed by the Natural Capital Project that quantifies and maps the values of environmental services. 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 (Sharp, 2015).

InVEST models are spatially explicit, using a combination of maps and tables as information sources and producing maps as outputs. InVEST returns results in either both biophysical terms (e.g., tons of carbon sequestered) and/or economic terms (e.g., net present value of that sequestered carbon). The spatial resolution of analyses is also fairly flexible and can be conducted with globally available data if no local datasets exist, allowing users to address questions at the local, regional or global scale (Sharp, 2015).

The InVEST toolset includes models for quantifying, mapping, and valuing the benefits provided by terrestrial, freshwater and marine systems. InVEST can be used to achieve and/or inform the following:

- Identify areas of current ES provision in the landscapes and to evaluate their values in biophysical and monetary metrics;
- Model future changes in ES provision based on planned infrastructure development;
- Quantify, map and where feasible value key ecosystem services in order to inform and help stakeholders and policy makers during the land use planning process;
- Inform the development of financing mechanism options to offset the upfront costs of constructing sustainable transport infrastructure.

InVEST uses a three-step modelling process. First, the ecological production function, or the supply side of ecosystem services, is modeled. These models require biological, physical, geological, and other kinds of inputs, and draw heavily on existing knowledge. The outputs from this step of modeling are in biophysical units and represent the level of each ecological process supported by each part of the landscape. The second step of modeling determines the use of ecosystem services. This step incorporates socio-economic, management, and other kinds of data on demand for ecosystem services with information on supply. Use of an ecosystem service is the level of supply in an area actually demanded by people for the service of interest. It is only by combining supply and demand to determine use that we quantify the level of outputs of ecosystem services. In addition to mapping and quantifying the supply and use of ecosystem services, InVEST also has the capacity to estimate their value.

## 8. SEB Modelling Framework

Identifying and quantifying the impacts of weather information on national and subnational socio-economic performance involves creating a modelling framework for the assessment of past, present and future impacts of action and inaction. The following key activities are envisaged.

### 8.1. Collect data

#### *Main activities*

- *Data collection for the indicators selected (see initial data request file)*
- *Assessment of data consistency and data gaps*
- *Interpretation of data based on source, complementarity with international (e.g. SDGs) and national (e.g. medium term development plans) indicator frameworks*
- *Review of existing national and sectoral development plans (to assess the adequacy of the tool to support policy formulation and evaluation)*

The construction of the model is done transparently. All the steps, including the definition of a conceptual framework, the selection/production of indicators, the classification, the normalization and weighting approaches, as well as their potential combination to build synthetic indices will be thoroughly documented and each step will be validated with regional and country stakeholders. Data gaps as well as degree of divergence across countries will be assessed. Alternative indicators illustrating comparable patterns will be identified for each category so that a variety of alternatives including both quantitative and qualitative indicators, are provided.

### 8.2. Develop an underlying simulation model

#### *Main activities*

- *Create Causal Loop Diagram (CLD) with the UNECA and country teams, as well as relevant stakeholders (general CLD and a customized one for each country)*
- *Identify policies to be included in the model*
- *Identify indicators to be included in the model, review literature on relevant sectoral coverage and equations*
- *Create System Dynamics model (e.g. GEM customization)*
- *Structural model validation*
- *Simulate scenarios and analyze results of a series of different policy packages*
- *Behavioral model validation*
- *Writing of technical report (including model documentation)*

The model is developed using Systems Thinking and System Dynamics (using Vensim, a freely available software). These methodologies are used as knowledge integrators, to allow users to introduce, simulate and assess the outcomes of policies (not targets). A dynamic model (e.g. the Green Economy Model –GEM-) <sup>3</sup> is created, using building blocks that are common across countries (e.g. population, land use, and energy supply technologies) but with extensive country customization at the sectoral level to capture the peculiarities of local contexts (e.g. what drives

<sup>3</sup> Bassi, A.M. (2015). Moving towards integrated policy formulation and evaluation: the Green Economy Model (GEM). Environmental and Climate Technologies, Volume 16, Issue 1.

land use change and energy consumption at the local level). This supports the analysis of scenarios of inaction as well as of *policy formulation and assessment*, which makes this type of approach more attractive to decision makers (e.g. in comparison with the use of optimization models). The use of this approach ensures a longer lifetime for the tool and its effective use at the country level (e.g. it goes well beyond cross-country comparisons).

Several examples exist for the use of System Dynamics for this type of task, and in all cases this methodology is used to integrate existing knowledge, data and sectoral models in a single framework of analysis. A key advantage of the approach proposed is the use of Systems Thinking as a tool to integrate knowledge across disciplines, through a multi-stakeholder approach. The advantages of customization at the country level, starting with causal mapping sessions (that would involve both GGGI staff and relevant stakeholders) have been described in the book *Tackling Complexity*<sup>4</sup> and documented in several papers and reports. Organizations like the OECD (Development Center)<sup>5</sup>, IISD<sup>6</sup>, IRENA<sup>7</sup>, UNDP<sup>8</sup>, UNEP<sup>9</sup> and WWF<sup>10</sup>, as well as several governments have made use of this approach, with the creation of customized models for green economy assessments and national development planning.

More specifically, the approach used: a) extends and advances the policy analysis carried out with other tools by accounting for the dynamic complexity embedded in the systems studied; and b) facilitates the investigation and understanding of the relations existing between natural capital, society and the economy. The inclusion of cross-sectoral relations supports a wider analysis of the implication of alternative policies for the availability of weather information and related action taken across sectors and actors, and the long-term perspective proposed (with simulations reaching up to 2050) allows for the identification of potential side effects and sustainability of different strategies.

This approach uses the System Dynamics (SD) methodology<sup>11</sup> as its foundation, serving primarily as a knowledge integrator. SD is a form of computer simulation modelling designed to facilitate a comprehensive approach to development planning in the medium to long term. A key characteristic of SD is that it allows to integrate the three spheres of sustainable development in its analytical process. SD operates by simulating differential equations, represented through stocks and flows, and comparing historical data for a period of at least one decade with simulation results. In other words, the model starts simulating in the past (to aid structural and behavioral validation) and continues projecting into the future (semi-continuous simulation). The purpose of such models is not to make precise predictions of the future; rather, they are a tool for exploring causality (and how different variables are interconnected with each other) and simulate

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<sup>4</sup> Probst, G. and A.M. Bassi (2014). "Tackling Complexity, A Systemic Approach for Decision Makers". Greenleaf Publishing, Sheffield, UK. ISBN 978-1-783530-81-6.

<sup>5</sup> E.g. in projects relating to Multi-Dimensional Country Reviews, see <http://www.oecd.org/dev/mdcr.htm>

<sup>6</sup> IISD (2015). "Green Public Procurement in China: Quantifying the Benefits". IISD, 2015.

<sup>7</sup> E. Taibi, P. Journeay-Kaler, A.M. Bassi (2014). "Renewable Energy Opportunities for Island Tourism". IRENA, 2014.

<sup>8</sup> Sukhdev P., K. Varma, A.M. Bassi, E. Allen and S. Mumbunan (2015). "Indonesia Green Economy Model (I-GEM)". UNDP Low Emission Capacity Building Programme, Jakarta, Indonesia.

<sup>9</sup> UNEP (2013). Green Economy Scoping Study: South African Green Economy Modelling Report (SAGEM) – Focus on Natural Resource Management, Agriculture, Transport and Energy Sectors".

<sup>10</sup> Van Paddenburg, A., Bassi, A.M., Buter, E., Cosslett C. & Dean, A. 2012. "Heart of Borneo: Investing in Nature for a Green Economy". WWF Heart of Borneo Global Initiative, Jakarta.

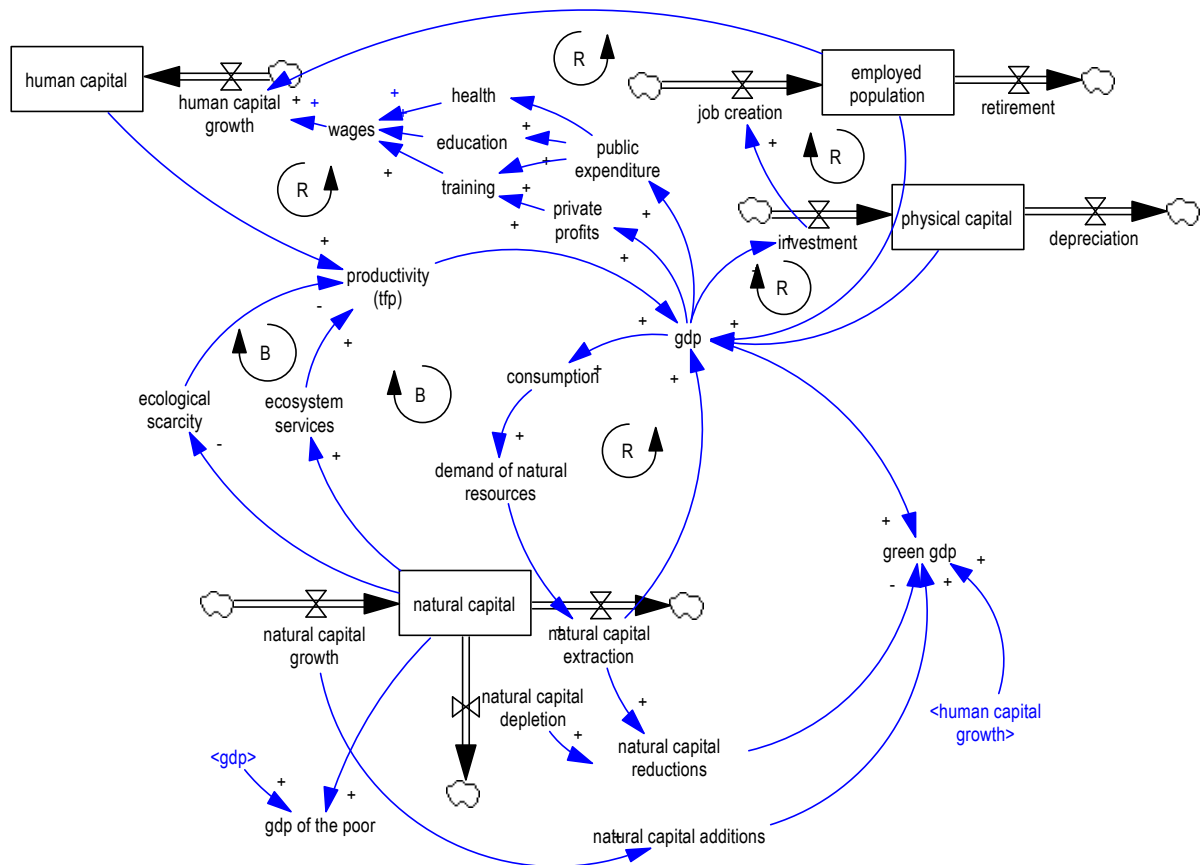
<sup>11</sup> Sterman, J. D. (2000). *Business Dynamics: Systems Thinking and Modelling for a Complex World*. Boston, Irwin/McGraw-Hill.

alternative policy scenarios in order to identify those policies which could improve conditions in the future and contribute to the achievement of desired goals and objectives.

The GEM will be used as a starting point for further customizations and improvements at the country level. It was designed explicitly to analyze green growth scenarios and was conceived through consultations with experts (e.g. Pavan Sukhdev of GIST, UNEP Goodwill Ambassador) and practitioners (e.g. decision makers and technicians of the government of Indonesia and Mauritius). Figure 1 presents the generalized underlying structure of GEM. This diagram shows how the key capitals are interconnected (social, human, built and natural), and contribute to shaping future trends across social, economic and environmental indicators. Specifically, feedback loops can be identified that are reinforcing (R) in all areas pertaining economic growth and social development. These are enabled by the availability of natural capital, which, if not properly managed, can constrain economic growth (hence the balancing loops -(B)- identified in the diagram). Policies can be implemented to promote sustainable consumption and production, decoupling economic growth from resource use (also through education and behavioral change), to mitigate the exploitation of natural capital and generate a stronger and more resilient green growth.

As a result, customized GEM country applications can be used to (1) test the effectiveness of individual policies and investments (by assessing their impact within and across sectors, and for social, economic and environmental indicators); (2) inform budgetary planning, by assessing the effectiveness of annual plans in delivering green and inclusive growth; (3) support the formulation and analysis of development plans that span across sectors and target medium to longer term goals.

The main outputs of GEM, and of the SEB analysis carried out with it, include the investment required to implement the intervention desired, added benefits and avoided costs. Among the benefits, indicators include sectoral value added (as driven by natural resources stocks and flows, e.g. sustainable agriculture yield and production, with and without access to weather information), direct employment creation and relative income generated, e.g. additional employment in public transport or energy efficiency sectors. Avoided costs include savings from avoided consumption (e.g. water, through resource efficiency interventions), and potential avoided ecosystem restoration costs. These are compared with costs, and potential damages created by the business as usual case and by the policy implemented, to estimate the economy-wide annual cash flow, as well as the break-even point, and the return on investment.



**Figure 1: Causal Loop Diagram (CLD) representing the main variables and feedback loops of GEM applications.**

By generating systemic, broad and cross-sectoral scenarios over time that address environmental, economic, and social issues in a single coherent framework, the GEM simulates the main short, medium and longer-term impacts of investing in a greener economy. The most important contribution of this model is its systemic structure that includes endogenous links within and across the economic, social, and environmental sectors through a variety of feedback loops. Most existing models focus on one or two sectors and make exogenous assumptions about other sectors that affect and are affected by the sector under consideration. Using endogenous formulations instead improves consistency over time and across sectors, because changes in the main drivers of the system analyzed are reflected throughout the model and analysis through feedback loops. While detailed sectoral analysis is very important, it is not adequate to demonstrate the whole set of relations and feedback loops that properly represent the functioning of the real world and that have to be taken into account in making the necessary transitions to greener economic and social structures.

**Text box 1: Review of models for Green Growth Assessments<sup>12</sup>, also useful as a starting point for SEB analysis**

When analyzing Green Growth performance and potential, methodological approaches and models should allow to quantitatively project and evaluate trends (for issue identification), identify entry points for interventions and set targets (for policy formulation), assess ex-ante the potential impact across sectors and the effectiveness in solving stated problems (or exploiting opportunities) of selected interventions (for policy assessment), as well as monitor and evaluate the impact of the interventions chosen against a baseline scenario (for policy monitoring and evaluation ex-post assessment / analysis).

Various methodologies can be utilized to support policy formulation and assessment. These methodologies can be divided into two main categories: (1) data frameworks and (2) dynamic modelling approaches. Data frameworks are “static”, and can be used either in isolation or embedded in simulation models. The data frameworks most commonly used at the national level include (1) indicators; (2) Input-Output frameworks; (3) Social Accounting Matrix; and (4) Geographic Information System (GIS). Quantitative simulation models are developed following modelling approaches, which are their underlying mathematical theories and frameworks. These methodologies could be considered “dynamic” as they allow generating future projections and include (1) econometrics, running statistical analysis of historical data and finding correlation between specific selected variables; (2) optimization, prescriptive models providing information on what to do to make the best of a given situation; and (3) system dynamics (or simulation), used to create models that are descriptive, focuses on the identification of causal relations influencing the creation and evolution of the issues being investigated.

When comparing these modelling approaches it becomes evident that complementarities exist, and country customization is required. More specifically, Input-Output (I-O) models provide a high level of sectoral disaggregation across value chains of selected products and technologies. Energy and other system engineering (optimization) models specifically focus on one or two sectors and can track manufactured capital, climate change mitigation options and potentially also climate change adaptation (e.g., in the case of water)<sup>13</sup>. GIS-based models (e.g., InVEST<sup>14</sup>), being spatially disaggregated, specialize in natural capital and are able to capture ecological scarcities and environmental risks. Computable General Equilibrium (CGE) models (optimization) cover the economic sphere of sustainable development, accounting for manufactured capital, competitiveness and social equity (e.g., through the estimation of income distribution)<sup>15</sup>. Finally, System Dynamics models, both sectoral and integrated, can endogenously represent economic, human and natural capital.<sup>16</sup> and effectively integrate knowledge from across sectors and actors. The strength of the model and the level of detail of the analysis depend on the identification and understanding of the key drivers of the system, and on the availability of inputs from stakeholders. This approach focuses on “what if” scenarios, is multi-stakeholder and transparent (white box).

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<sup>12</sup> This text box is based on the following publications authored by members of the consortium: Bassi, A.M. (2015). Moving towards integrated policy formulation and evaluation: the Green Economy Model (GEM). Environmental and Climate Technologies, Volume 16, Issue 1; Mercure, J-F, H. Pollitt, A.M. Bassi, J.E. Viñuales, N.R. Edwards (2016). Modelling complex systems of heterogeneous agents to better design sustainability transitions policy. Global Environmental Change, Volume 37, March 2016, Pages 102–115; UNEP (2014), Using Models for Green Economy Policymaking; UNECA (2015), Integrated Assessment Tools and Methodologies for Inclusive Green Economy in Africa.

<sup>13</sup> Loulou, R., G. Goldstein, K. Noble (2004). Documentation for the MARKAL Family of Models. IEA Energy Technology Systems Analysis Programme.

<sup>14</sup> Tallis, H., T. Ricketts et al. (2012). InVEST 2.2.2 User's Guide: Integrated Valuation of Ecosystem Services and Tradeoffs. Stanford, The Natural Capital Project, Stanford University.

<sup>15</sup> Lofgren, H. and C. Diaz-Bonilla (2010). MAMS: An Economy-wide Model for Development Strategy Analysis. The World Bank. Washington DC, USA.

<sup>16</sup> Bassi, A.M. (2014). Using Simulation Models for Green Economy Policy Making: A Comparative Assessment. Review of Business and Economics Studies. Volume 2, Number 1, 2014.

### 8.3. Model validation

Models can be classified in many different ways and assessed according to different criteria, such as physical versus symbolic; dynamic versus static; deterministic versus stochastic, etc. As it relates to the notion of validity, a crucial distinction must be made between models that are “causal-descriptive” (i.e., theory-like or “white-box”) and models that are “correlational” (i.e., purely data-driven or “black-box”).

In correlational models, since there is no claim of causality in structure, what matters is the aggregate output behavior of the model; the model is assessed as valid if its output matches the “real” output within a specified range of accuracy, without any questioning of the validity of the individual relationships that exist in the model. This type of “output” validation can often be cast as a classical statistical testing problem. Models that are built primarily for forecasting purposes (such as time-series or regression models) belong to this category.

On the other hand, causal-descriptive models make statements about how real systems actually operate in some aspects. In this case, generating an “accurate” output behavior is not sufficient for model validity; what is crucial is the validity of the internal structure of the model. A causal-descriptive model, in presenting a “theory” about the real system, must not only reproduce or predict its behavior, but also explain how the behavior is generated, and possibly suggest ways of changing the existing behavior.

System dynamics models fall into the causal-descriptive category of models. Such models are built to assess the effectiveness of alternative policies or design strategies at improving the behavior of a given system. This is only possible, of course, if the model has an internal structure that adequately represents those aspects of the system that are relevant to the problem behavior at hand. In short, it is often said that a system dynamics model must generate the “right output behavior for the right reasons.”

This section discusses model parameterization (calibration), corroboration (validation and simulation), behavior pattern tests and computational reproducibility in the quality assurance plan for the project. The main purpose of these procedures is to ensure that the model is accurate and precise enough to meet the project needs.

In addition to these procedures, we will conduct an assessment of the confidence level for individual model inputs, which will provide an indication of the degree of uncertainty in the model results. We also will analyze the sensitivity of model results to the value of selected variables. The sensitivity analysis will consist of a large number of simulations in which upper and lower boundaries for selected variables will be defined ad hoc. The simulation software chooses values (one per simulation) within the boundaries via a user-defined probability distribution function (e.g., random uniform, random normal). The resulting simulations are summarized in output graphs that indicate the probability of obtaining certain results and allow us to analyze the impact (across sectors) of using different assumptions for the variables selected. The output graphs show how sensitive the model is to changes in the input parameters considered. If the variability of results is high throughout the model, particular attention should be used in defining input parameters.<sup>17</sup> If the variability is low (i.e., if the model is not sensitive to changes in a specific parameter), the input parameter is less relevant.

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<sup>17</sup> Ranges are evaluated on a variable by variable basis, depending on historical trends; high variations could be considered for variables showing more than a 10% difference between upper and lower boundary.

### 8.3.1. Model parameterization (calibration)

System dynamics models are based on the identification of causal relationships. The calibration of the model is therefore relevant to understanding the strength of the key causal relationships upon which the model is built and how they change over time based on key endogenous drivers of the system.

The calibration is carried out using features available in Vensim, the software platform used to create the model. Along with manual calibration, we will also perform automated model calibration (based on historical data) and optimization (based on specific present or future targets). Parameters will be estimated using historical data, either using raw data or carrying out econometric analysis, but also using existing sectoral relationships and evaluating their strength based on observed real world relations. Calibration will be considered complete when the margin of error (measured as an average point to point error) is within acceptable boundaries.

In addition, we will apply the following three different types of sensitivity analysis for the model: numerical, behavior mode, and policy sensitivity.

- Numerical sensitivity exists when a change in assumptions changes the numerical values of the results. For example, changing the strength of the word of mouth feedback in an innovation diffusion model will change the growth rate for the new product. All models exhibit numerical sensitivity.
- Behavior mode sensitivity exists when a change in assumptions changes the patterns of behavior generated by the model. For example, if plausible alternative assumptions changed the behavior of a model from smooth adjustment to oscillation or from s-shaped growth to overshoot and collapse, the model would exhibit behavior mode sensitivity.
- Policy sensitivity exists when a change in assumptions reverses the impacts or desirability of a proposed policy. If cutting prices boosted market share and profitability under one set of assumptions but led to ruinous price wars and bankruptcy under another, the model would exhibit policy sensitivity.

Both univariate and multivariate sensitivity analyses will be performed for the GEM model. Optimization methods will be used to confirm manual calibration and to evaluate whether the software, using calibrated feedback loops, would utilize parameters and policies within reasonable ranges. Optimization methods will also be employed to test whether plausible parameter combinations could generate implausible results or reverse policy outcomes.

### 8.3.2. Model corroboration (validation and simulation)

The ultimate objective of system dynamics model validation is to establish the validity of the structure of the model. Accuracy of the model's reproduction of real behavior is also evaluated, but this is meaningful only if we first have sufficient confidence in the structure of the model. Thus, we will test the validity of the model structure prior to testing its behavioral accuracy.

#### *DOCUMENTATION OF MODEL STRUCTURE*

A full documentation of the model will be prepared and shared, including the following elements:

- A technical documentation, listing the main sectors, the method used to create them, and the equations of key variables for each sector of the model;
- A full, technical documentation of the model with a high degree of detail on all the variables created, and their use within and across sectors, including output generated



from the software package System Dynamics Model Documentation and Assessment Tool (SDM-Doc).<sup>18</sup>

Further, all the results of the baseline simulation (for all variables in the model) will be exported in a user-friendly format (e.g., MS Excel, .dat or a tab delimited text file) to facilitate the review and analysis of results by third parties.

#### *DIRECT STRUCTURE TESTS*

Direct structure tests assess the validity of the model structure by direct comparison with knowledge about the structure of the real system. This involves assessing each relationship within the model individually and comparing it with available knowledge about the real system. Examples of direct structure tests include: (1) structure confirmation tests; (2) parameter confirmation tests; (3) direct extreme-conditions test; (4) dimensional consistency test (unit of measure check); (5) behavior sensitivity tests; and (6) phase-relationship tests. Direct structure tests can be classified as empirical or theoretical. Empirical structure tests involve comparing the model structure with information (quantitative or qualitative) obtained directly from the real system being modeled. Theoretical structure tests involve comparing the model structure with generalized knowledge about the system that exists in the literature.

The direct extreme-condition testing is a very important step in the validation of the GEM model. This will involve evaluating the validity of model equations under extreme conditions, by assessing the plausibility of the resulting values against the knowledge or anticipation of what would happen under a similar condition in real life.

Direct structure tests will be completed when (1) the structure does not lead to perpetual exponential growth or decay; (2) exogenous parameters are validated with peer reviewed studies or econometric estimation; (3) the model reflects real world phenomena when it comes to extreme-condition tests ; and (4) when all the key units are consistent.

#### *BEHAVIOR PATTERN TESTS*

The two categories of tests discussed above are designed to evaluate the validity of the model structure. Once these tests have established an adequate level of confidence in the validity of the GEM's structure, we will apply a third type of test designed to measure how accurately the model reproduces the major behavioral patterns exhibited by the real system. It is crucial to note that the emphasis is on pattern prediction (periods, frequencies, trends, phase lags, amplitudes, etc.) rather than point (event) prediction. Several tools are provided by Vensim to evaluate behavioral validity against historical data (as system dynamics models allow one to start the simulation in the past and validate the historical projection with data), such as minimum, maximum, mean, median, standard deviation. In conducting this type of test, we will apply the same criteria as we described in the model parameterization (calibration) section above.

There may be numerous loops and model revisions throughout the testing process. The tests are carried out in a logical sequence, and it makes sense to proceed to the next step only if we are able to establish sufficient confidence in the current step. In this way, we can make necessary model revisions (typically structural revisions, not ad hoc parameter changes).

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<sup>18</sup> SDM-Doc was created at Argonne National Laboratory and can be found at <http://tools.systemdynamics.org/sdm-doc/>

## 9. Introduction to the Pan African CIS SEB Analysis model

At the workshop in Addis Ababa, the Pan African CIS SEB Analysis model (PA CIS SEB) was introduced. The model, based on System Dynamics, allows for the integration of climate information into policy impact analysis across sectors. Simulation outcomes show the impacts of climate variability and extreme events on social, economic and environmental indicators. As a result, it allows to estimate the socio-economic benefits of weather information by simulating alternative scenario of action against a baseline.

### 9.1. Climate impacts

There are many ways in which the climate and weather impacts human systems, both directly and indirectly. Figure 2 provides an overview of the aggregate categories that were discussed during the workshop, and points out some of the impacts that temperature, precipitation and sea level rise can have on socio-economic indicators, as well as environmental ones.

The PA CIS SEB model that was introduced to the participants of the workshop currently includes temperature and precipitation. Future version of the model will include a variety of additional indicators.

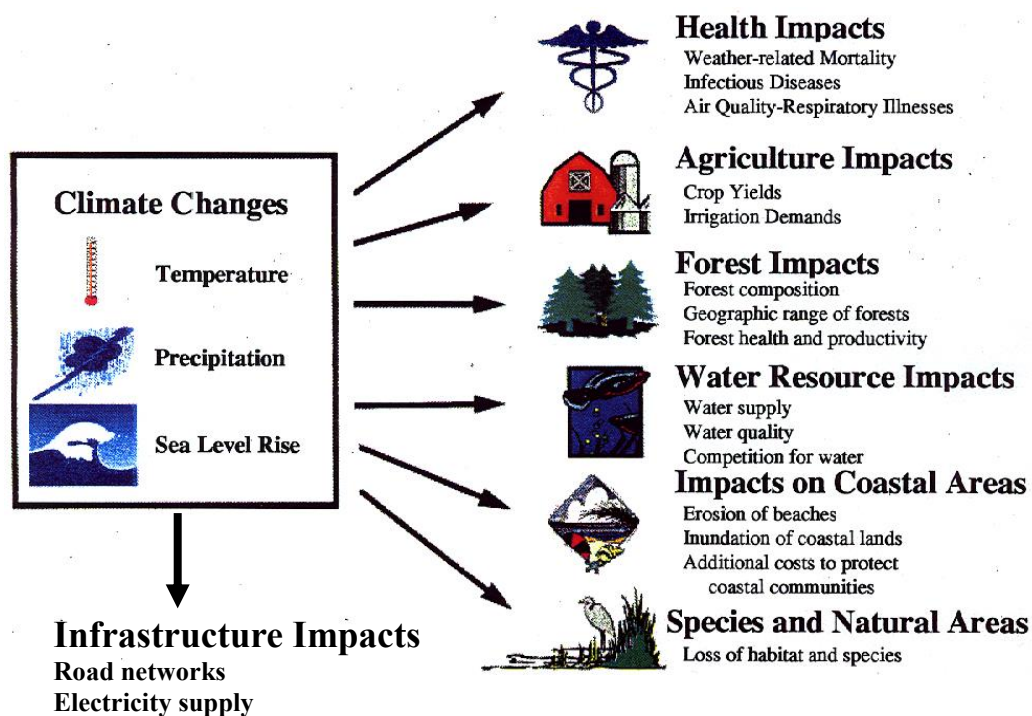


Figure 2 – Climate impacts on socio-environmental systems

### 9.1.1. Climate impacts included in the model

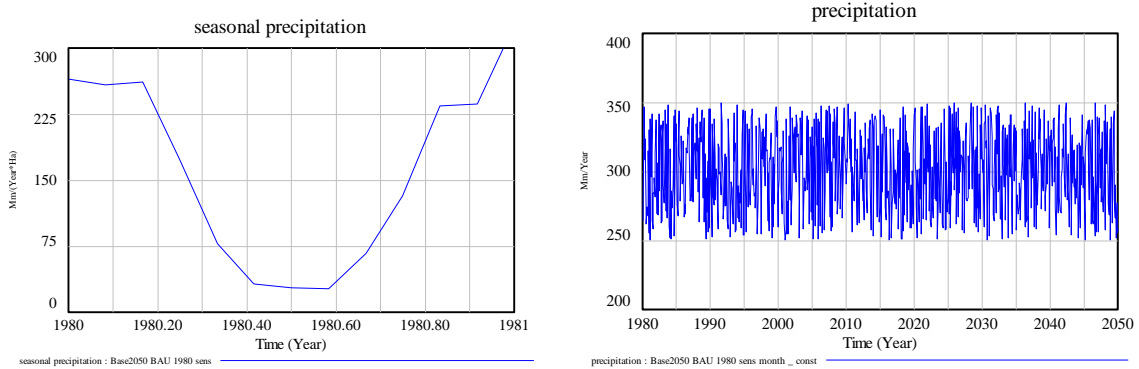
The PA CIS SEB model has the capacity to include and analyze most of the climate-related impacts that are featured in Figure 2. Table 9 summarizes the drivers and impacts that are currently included in the v1 of the model.

<b>Climate change</b>	
<i>Included</i>	<i>Potentially</i>
<ul style="list-style-type: none"> <li>• Temperature</li> <li>• Precipitation</li> </ul>	<ul style="list-style-type: none"> <li>• Sea level rise</li> </ul>
<b>Infrastructure impacts</b>	
<i>Included</i>	<i>Potentially</i>
<ul style="list-style-type: none"> <li>• Road networks</li> <li>• Electricity supply</li> </ul>	<ul style="list-style-type: none"> <li>• Education</li> <li>• Health care</li> </ul>
<b>Health impacts</b>	
<i>Included</i>	<i>Potentially</i>
<ul style="list-style-type: none"> <li>• Weather-related mortality</li> </ul>	<ul style="list-style-type: none"> <li>• Air quality – Respiratory diseases</li> </ul>
<b>Agriculture impacts</b>	
<i>Included</i>	<i>Potentially</i>
<ul style="list-style-type: none"> <li>• Crop yields</li> <li>• Irrigation demand</li> </ul>	<ul style="list-style-type: none"> <li>• Soil quality</li> <li>• Fertilizer application</li> </ul>
<b>Forest impacts</b>	
<i>Included</i>	<i>Potentially</i>
<ul style="list-style-type: none"> <li>• Total forest</li> </ul>	<ul style="list-style-type: none"> <li>• Forest composition</li> <li>• Geographic range of forests</li> <li>• Forest health and productivity</li> </ul>
<b>Water resource impacts</b>	
<i>Included</i>	<i>Potentially</i>
<ul style="list-style-type: none"> <li>• Water supply</li> <li>• Competition for water</li> </ul>	<ul style="list-style-type: none"> <li>• Water quality</li> </ul>
<b>Impacts on coastal areas</b>	
<i>Included</i>	<i>Potentially</i>
	<ul style="list-style-type: none"> <li>• Additional costs to protect coastal communities</li> </ul>
<b>Species and natural areas</b>	
<i>Included</i>	<i>Potentially</i>
	<ul style="list-style-type: none"> <li>• Loss of habitat and species</li> </ul>

Table 9 – Climate impacts integrated or potentially to be integrated into the WISER framework

### 9.1.2. Calibration of precipitation

The annual rainfall uses seasonality and a baseline meadium to longer term trend. The left graph in Figure 3 illustrates precipitation in the year 1980, to highlight assumptions on seasonality. The graph on the right of Figure 3 shows precipitation in the baseline scenario over the full range of the simulation (1980 – 2050).

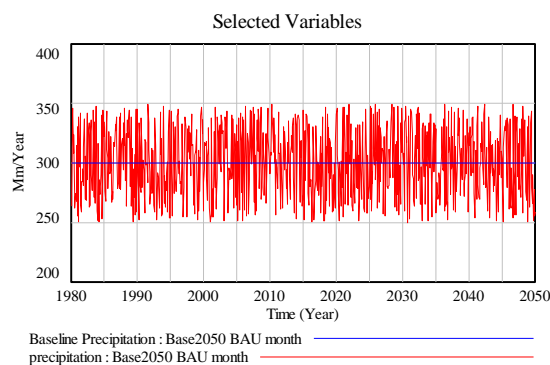


**Figure 3 – Seasonal precipitation and precipitation**

Capturing seasonality in precipitation is necessary to understand the dynamics i) of the sectors that are dependent on rain, and ii) the probability of adverse weather events (e.g. floods and droughts). As an example, the agriculture sector is heavily dependent on rainfall for growing crops, which implies that changes in the amount of seasonal rainfall or a shift in the rainy season can have detrimental consequences on production, especially if farmers are prepared for it.

#### *Climate variability and trends*

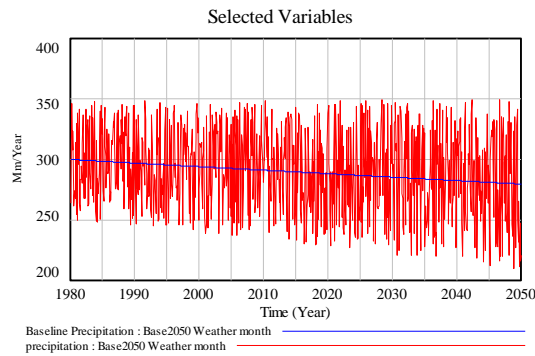
The model allows for the simulation of different scenarios. In the baseline scenario, the amount of rainfall is assumed to be constant through the simulation. Variability is introduced by a random factor (calibrated based on historical data) that either increases or decreases annual precipitation by a predefined amount, but the overall trend (the baseline) in precipitation remains constant. Figure 3 illustrates precipitation and trend in precipitation in the baseline scenario.



**Figure 4 – Precipitation in the baseline scenario**

Different assumptions on future precipitation can be accommodated in the model to explore the impacts of changing precipitation trends and patterns on socio-economic indicators.

Figure 5 illustrates the development of precipitation and seasonal precipitation in the *Weather* scenario assuming i) a declining trend in overall rainfall, and ii) a progressive increase in rainfall variability up to 2050.



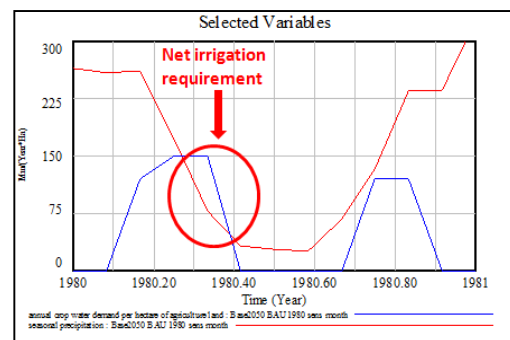
**Figure 5 – Precipitation in the Weather scenario**

Compared to Figure 4, the annual amount of rainfall (blue line) decreases over time and while the upper bound of precipitation is comparable to the baseline scenario (due to the assumed higher variability towards 2050), an increasing number of years with lower precipitation can be observed. The integration of different assumptions for precipitation, and also temperature, serves the purposes of i) evaluating the impact that a change in rainfall quantity and variability has on social indicators (e.g. loss of life, outmigration), ii) determining the future performance of the economy under different climatic conditions (e.g. decreased agriculture production, damage to infrastructure, interruptions in electricity generation), and iii) analyzing the environmental consequences of changes in climate (e.g. increased sedimentation due to floods, loss of fertile land, increased evapotranspiration due to changes in soil cover).

#### *Integration of crop water requirements*

To adequately account for the water demand from agriculture, the monthly crop gross water requirements per hectare are compared to the amount of monthly rainfall, as illustrated in Figure 5. The calculation is based on the assumption that, if the amount of rainfall in a given month exceeds the crop gross water requirements, there is no need for the farmers to irrigate. This assumption is very aggregate and will be refined in future iterations.

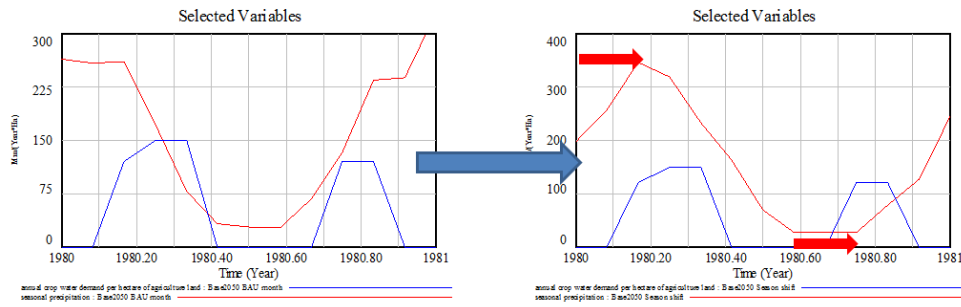
The total water demand for irrigation purposes is then calculated from the net irrigation requirements per hectare and the total amount of agriculture land.



**Figure 6 – Net irrigation requirements**

#### *Simulation of seasonal shifts*

A shift in the rainy season can have severe impacts on socio-economic development. The simulation of a seasonal shift, resulting in a change in annual rainfall patterns is displayed in Figure 7.



**Figure 7 – Simulation of a seasonal shift**

For illustration purposes, the seasonal shift is included from the beginning of the simulation (1980). The red line in Figure 7 represents the precipitation in the year 1980, while the blue line represents the gross irrigation requirement for crops in a given year. In the graph on the left the crop water requirements are aligned with the season and irrigation is only required during one month. With a shift in season, there are no irrigation requirements during the first growing period, while the second growing period falls into the dry season and crop growth needs to be maintained through irrigation. It is worth noting that the total irrigation requirements after the seasonal shift are higher than in the baseline scenario.

## 9.2. Sectoral dynamics and climate impacts

This section provides an overview of the key variables and feedback loops of the main sectors of the **PA CIS SEB model**, and illustrates how the impacts of adverse weather events are included in the model. Two scenarios are simulated: the baseline, or business as usual (BAU) scenario, and the Weather scenario. In the business as usual scenario seasonal precipitation and the underlying trend in precipitation are unchanged over time (see Figure 4). The Weather scenario assumes an increasing variability in precipitation, combined with a decreasing trend in annual precipitation (see Figure 5).

### 9.2.1. Agriculture

#### *Key variables and dynamics*

The key variables that are used in the agriculture sector are displayed in the causal loop diagram (CLD) in Figure 8. Land conversion for agriculture is driven by a balancing loop that reduces the gap in agriculture land, which is the difference between the current amount of agriculture land and the desired amount of agriculture land. Desired agriculture land depends on total population and desired agriculture land per capita. If the current amount of agriculture land reaches the desired level, no more land conversion takes place.

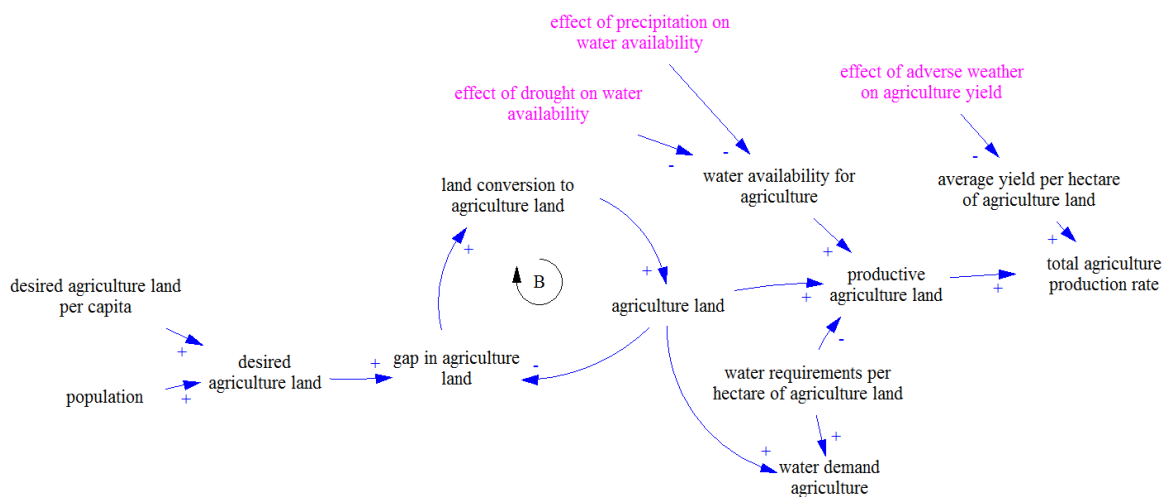


Figure 8 – CLD Agriculture

The amount of productive agriculture land depends on the water requirements per hectare of agriculture land and the water availability. The total water demand from agriculture is estimated as total agriculture land multiplied by water requirements per hectare. Water availability for agriculture is affected by precipitation and droughts (which, when a predefined threshold is exceeded, reduce the amount of water available for agriculture and consequently the amount of productive agriculture land).

Total agriculture production depends on the amount of productive agriculture land and the average yield per hectare of agriculture land. The average yield per hectare of agriculture land is affected by adverse weather based on the assumption that the productivity of agriculture land is reduced if there is flooding (too much rain) or a drought.

#### *Climate impacts on agriculture*

First order impacts that are identified in the agriculture sector concern total agriculture land and the yield of agriculture land. The decreasing trend in baseline precipitation causes less floods over time, which reduces i) the amount of agriculture land lost, and ii) the number of people that leave

the area. More people and a constant amount of agriculture land per capita cause agriculture land in the Weather scenario to be higher than in the BAU scenario. In addition, the agriculture yield benefits from the reduced number of floods and the productivity of agriculture land is higher than in the baseline scenario. Figure 9 compares total agriculture land and the yield of agriculture land from the Weather scenario (blue line) to the BAU scenario (red line).

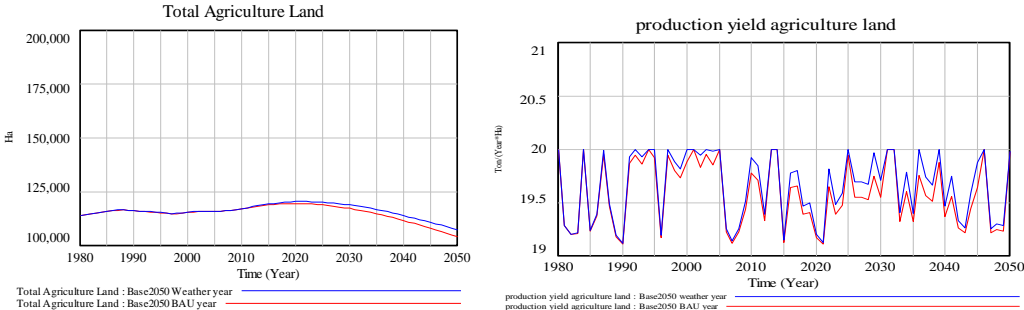


Figure 9 – Agriculture land and yield per hectare

As a consequence of higher agriculture land and a higher yield, the agriculture production in the Weather scenario is higher than in the BAU scenario. Figure 10 compares agriculture production in the Weather scenario to the production in the BAU scenario. These simulations indicates that a decreasing trend in precipitation would be beneficial for agriculture production. At the same time, it stresses the need to properly assess the critical thresholds for floods and droughts in order to ensure that the model behavior is consistent with the functioning of the system in the real world.

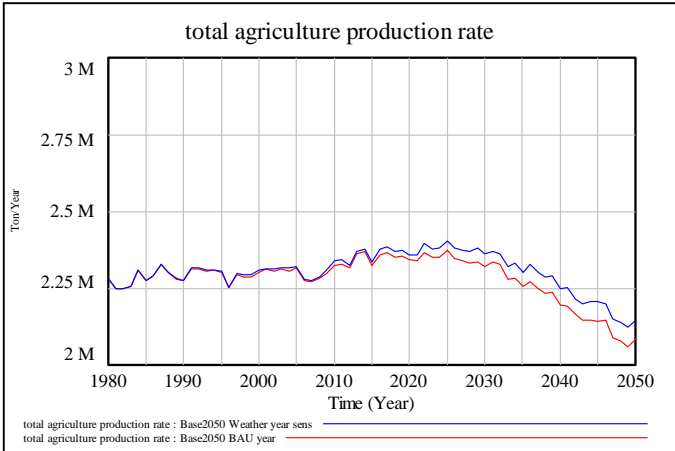


Figure 10 – Total agriculture production rate



## 9.2.2. Water resources

### *Key variables and dynamics*

The available water resources depend on the inflow (precipitation) and the outflow (consumption) of water. Figure 11 provides an overview of the key variables and feedback loops in the water resources sector. The total amount of renewable water resources depend on total precipitation and the evapotranspiration fraction. The evapotranspiration in the model is affected by temperature<sup>19</sup>, assuming that evapotranspiration increases if temperature increases. The total renewable groundwater resources flow based on the percolation fraction either into surface water streams or percolate into groundwater aquifers. The percolation of water into groundwater aquifers depends on soil cover and the health of soil. A healthy vegetation cover above ground is likely to increase the percolation rate, while scarce or no soil cover is likely to cause the percolation rate to decline, and to increase sedimentation.

Both surface water and groundwater are used as sources for extraction of water for human use. It is assumed that water, especially for irrigation, is first extracted from surface water, and that the remaining water demand, water for human consumption (domestic and municipal) and industrial use, is extracted from groundwater aquifers. Water requirements for irrigation that cannot be covered by surface water without depleting the rivers are also assumed to be extracted from groundwater.

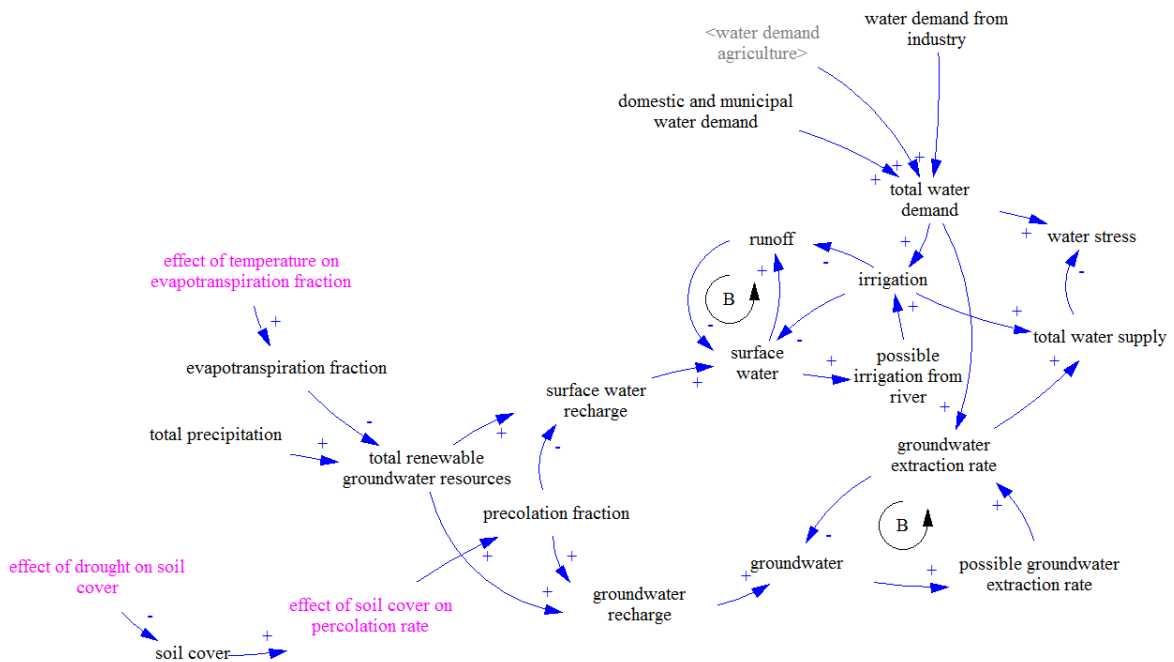


Figure 11 – CLD Water resources

The extraction of water is constrained by threshold extraction rates, which are assumed to account for environmental water requirements.

<sup>19</sup> From the discussion it was added that wind also plays a crucial role for evapotranspiration. The effect of wind on evapotranspiration will be accounted for in future iterations of the model.

### Climate impacts on water resources

The total water demand in the Weather scenario increases above the BAU level as a consequence of the decreasing trend in baseline precipitation. Less rainfall and constant crop water requirements lead to an increasing demand for water for irrigation which increases the amount of water extracted from rivers and groundwater aquifers. Figure 12 compares the total water demand in the Weather scenario to the total water demand in the BAU scenario. The peaks in water demand represent the dry season.

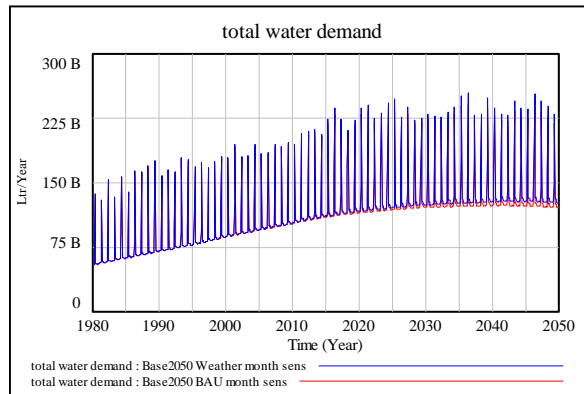


Figure 12 - Total water demand

The increasing water demand combined with a decreasing annual precipitation rate causes the inflow of renewable water resources to decrease over time. Once the total demand for water exceeds the total renewable water resources, the groundwater level starts to decrease and water resources are depleted at an increasing rate (if no extraction threshold is enforced). Figure 13 illustrates the development of the groundwater stock of the Weather and the BAU scenario if no sustainable extraction policy is enforced. The groundwater level in the Weather scenario (blue line) decreases faster than it does in the BAU scenario, although the groundwater stock level decreases in both scenarios at an increasing rate.

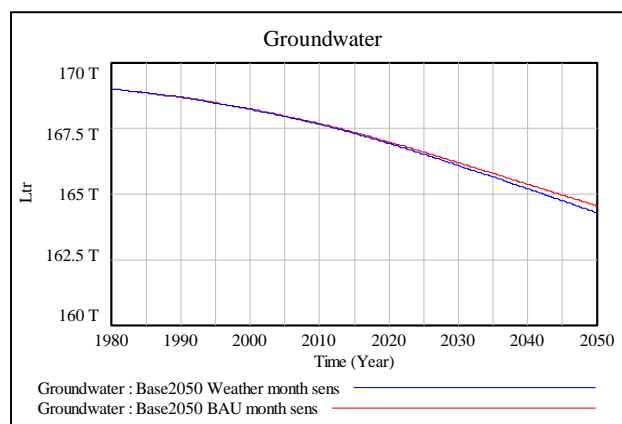


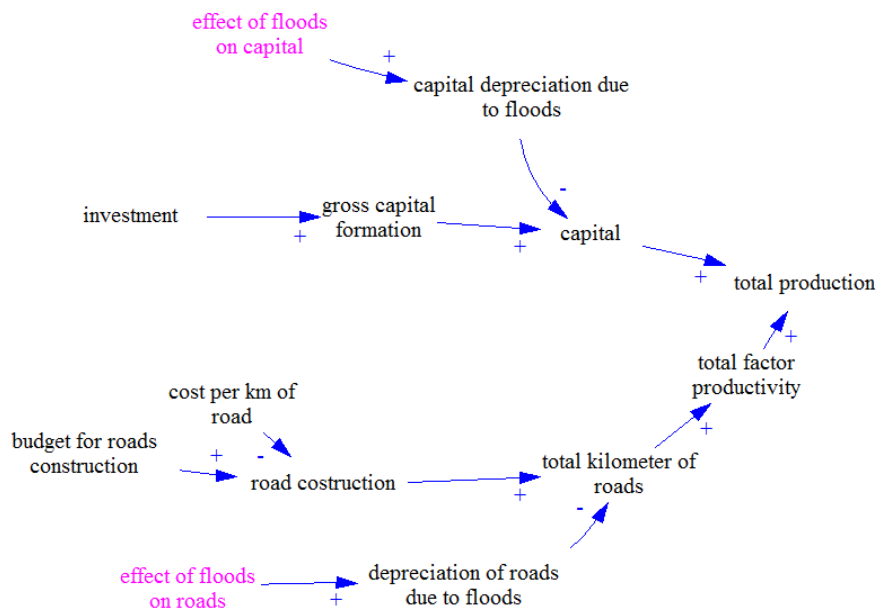
Figure 13 - Groundwater level

### 9.2.3. Infrastructure

#### *Key variables and dynamics*

The two main infrastructure components that are affected by adverse weather events are roads and other built capital. The total kilometers of roads depend on the kilometers of road that are built and the kilometers of road that are decommissioned or destroyed by floods. Road construction is driven by the budget for road construction and the cost per kilometer of road. The depreciation of roads due to floods depends on the number of floods and the intensity of floods. A functioning road network increases the accessibility to markets and accelerates the exchange of goods and services. Together with other variables (e.g. literacy rate and access to health care), a functional road network has a beneficial effect on total factor productivity and contributes to GDP.

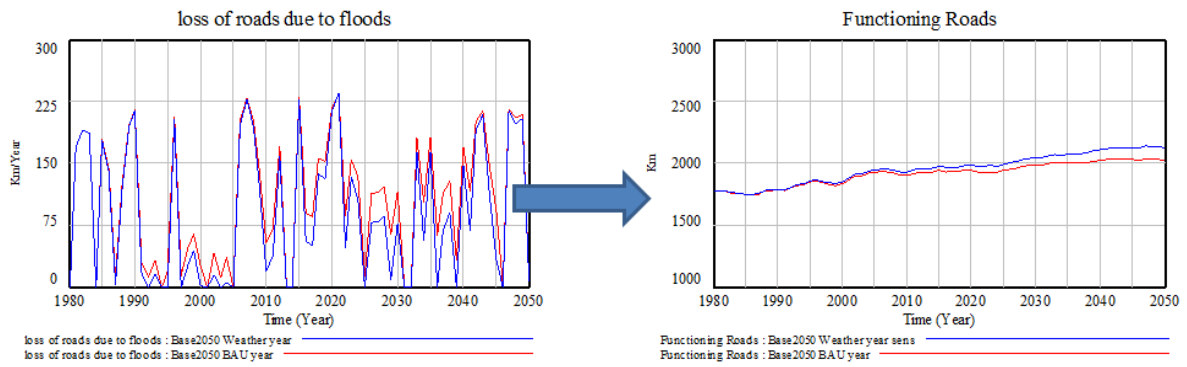
The amount of capital depends on gross capital formation (i.e. investment) and the depreciation of capital due to floods. Gross capital formation is driven by public and private investments and depends on GDP and public and private savings and borrowings. Losses of capital due to floods are represented as depreciation of capital.



**Figure 14 - Key variables in the Infrastructure sector**

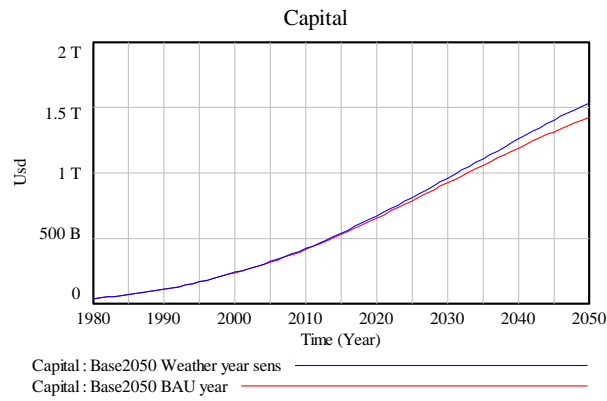
#### *Climate impacts on infrastructure*

Including the effect of floods on roads and capital allows for estimating the potential damage that is caused by future adverse weather events (e.g. on kilometers of roads lost, or the corresponding economic value). The strength of the effect depends on the strength and duration of the event, and the amount of capital/roads that is affected by a certain event. The left graph in Figure 15 provides an indication of the kilometers of roads that are destroyed due to floods in the Weather and the BAU scenario. The graph on the right shows the respective kilometers of functioning roads in both scenarios. The total kilometers of functioning roads is higher in the Weather scenario, because the decreasing number of floods leads to a less intense flood events.



**Figure 15 - Loss of roads and kilometer of functioning roads**

Figure 16 shows the development of the capital stock in the Weather and the BAU scenario. In the BAU scenario, more capital is lost due to floods than in the Weather scenario. The loss of capital affects total production, as illustrated in Figure 14, which subsequently reduces GDP and the capacity to further invest in capital to foster economic production.



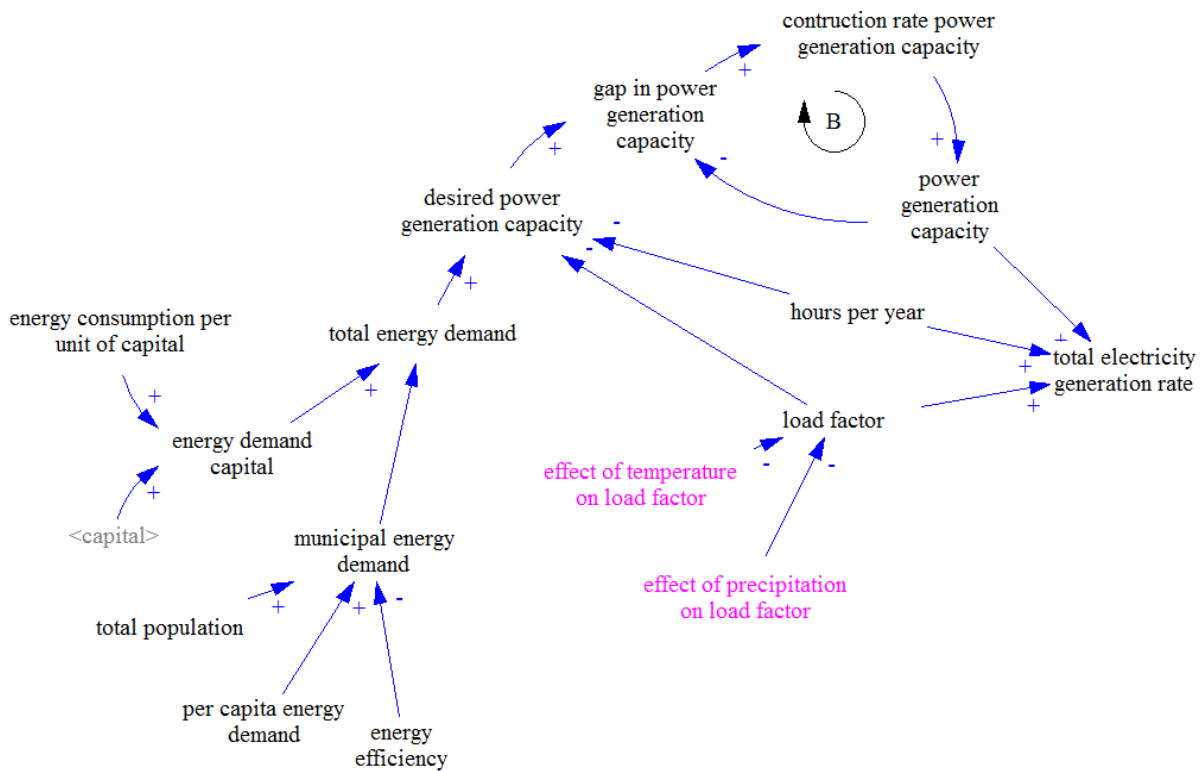
**Figure 16 - Capital: BAU vs Weather scenario**

### 9.2.4. Electricity generation

#### *Key variables and dynamics*

The construction of power generation capacity is driven by a balancing loop that reduces the gap between the current level of power generation capacity and the desired power generation capacity. The desired power generation capacity is determined by the total energy demand and the (technology specific) load factor, which represents the efficiency of power generation technologies. The model discriminates between conventional power generation capacity, renewable power generation capacity and hydropower. The load factor for conventional power generation capacity is affected by precipitation, to account for the availability of water for cooling purposes, and temperature, as capacity has to be shut down if temperature exceeds a certain critical threshold. The load factor for hydropower is affected by precipitation and sedimentation.

Total energy demand is estimated as the sum of municipal energy demand and the energy demand from capital. Municipal energy demand is calculated based on total population, the energy demand per capita and an energy efficiency coefficient. The energy demand from capital is based on total capital and the energy consumption per unit of capital.

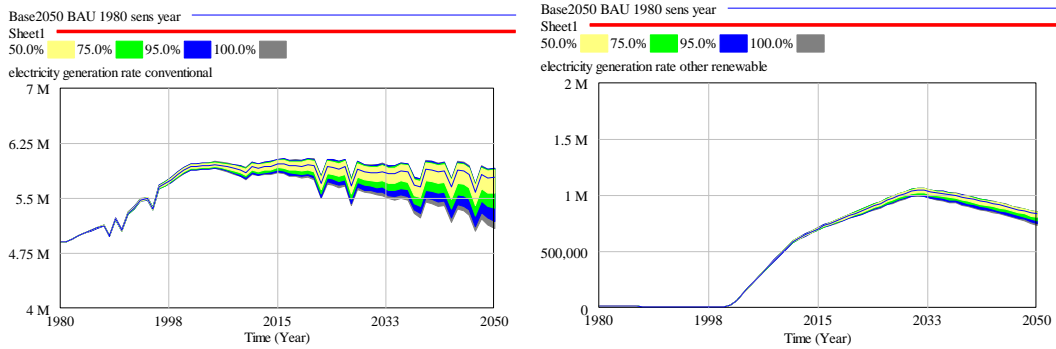


**Figure 17 - CLD Energy generation**

Total power generation, on the right of Figure 17 represents the total annual electricity generation. The total electricity generation depends on the installed power generation capacity, the number of hours per year and the load factor, which is affected by temperature and precipitation.

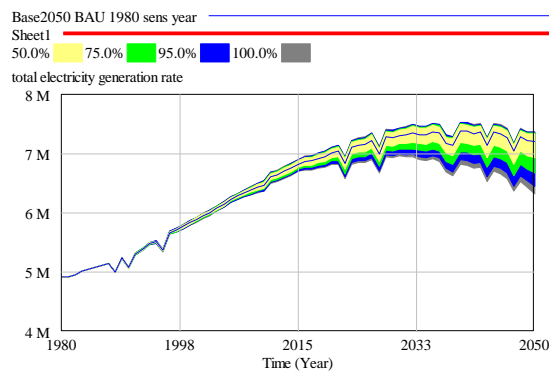
*Climate impacts on energy generation*

Figure 18 displays a sensitivity graph for the electricity generation from conventional power generation capacity (left) and the electricity generation rate from other renewable power generation capacity (right) in the BAU scenario. The change in precipitation variability was used as an input for the sensitivity simulations from which the graphs in this section are derived.



**Figure 18 – Sensitivity graph: Conventional and other renewable electricity generation rate**

The amplitude of the confidence intervals in Figure 18 illustrates that electricity generation from conventional power generation capacity is more vulnerable to adverse weather events than the electricity generation from renewables. The reason is that conventional technologies are sensitive to high temperatures and dependent on water for cooling purposes, where renewable technologies as solar panels or wind turbines are depending on solar radiation and wind<sup>20</sup>. Figure 19 shows a sensitivity graph for the total electricity generation rate from all sources.



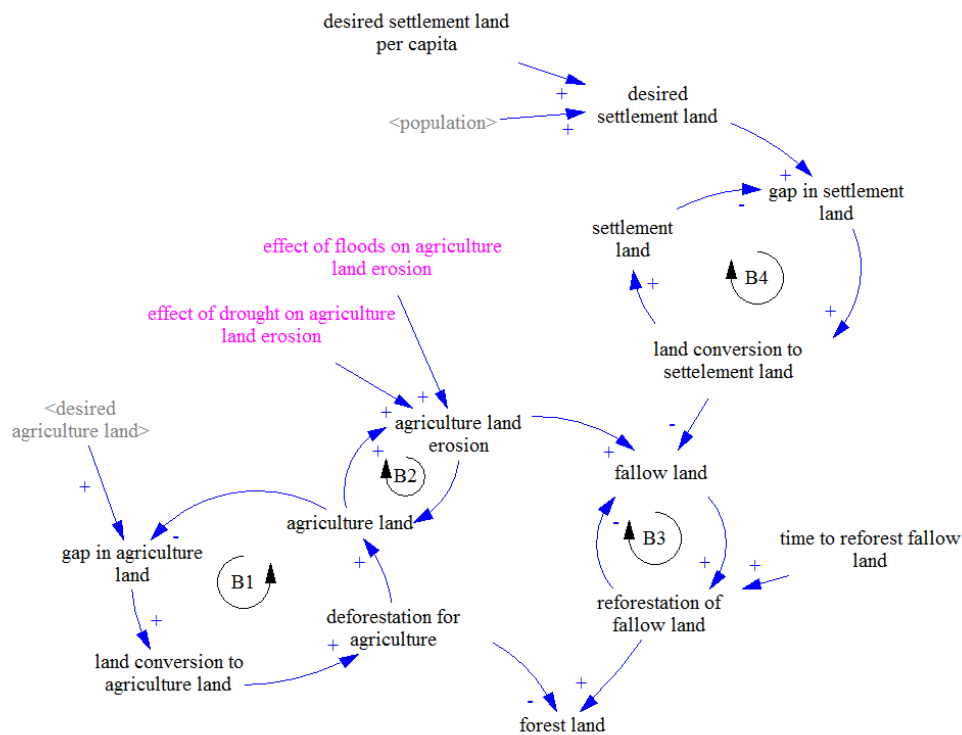
**Figure 19 – Sensitivity graph: Total electricity generation rate**

<sup>20</sup> Solar radiation and wind speed are not included in this version of the model. Including solar radiation and wind speed is likely to increase the confidence intervals of the electricity generation rate from other renewable technologies.

### 9.2.5. Land use

#### *Key variables and dynamics*

Figure 20 provides an overview of the key variables and feedback loops that are governing the land use module. The land use dynamics in the model are entirely driven by population and i) desired settlement land per capita, and ii) desired agriculture land (see section 0). Land conversion takes place for the expansion of agriculture (loop B1) and settlement land (loop B4). The conversion of land to settlement takes place based on the gap between current and desired settlement land, whereby desired settlement land depends on total population and the desired settlement land per capita. The model assumes that fallow land is used for the conversion of land to settlement areas, while forest land is used for the expansion of agriculture land. This leads to a decline in the stock of fallow land if settlement areas are expanded, and a decline the stock of forest land in case on an expansion of agriculture activities.



**Figure 20 - CLD Land use**

The erosion of agriculture land (loop B2) is affected by adverse weather events and reduces the amount of agriculture land. Eroded agriculture land is assumed to become fallow land. The reduction in agriculture land widens the gap between current and desired agriculture land, which continuously drives deforestation until the desired level of agriculture land is reached. Forest land is decreased by the deforestation for agriculture, and can be increased through the reforestation of fallow land, which would reduce the amount of fallow land (loop B3).

### Climate impacts on land use

The impacts of adverse weather events on land use that are currently included in the model are second order impacts. Figure 21 shows sensitivity graphs of agriculture land and forest land in the BAU scenario. More agriculture land comes at the expense of forest land, meaning that a growing population causes higher deforestation rates to maintain and extend agriculture land for subsistence and economic purposes.

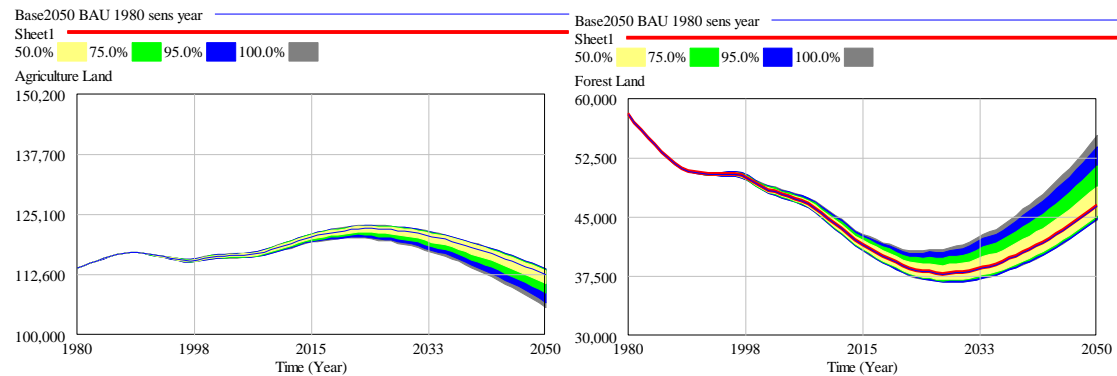


Figure 21 - Sensitivity graphs: Agriculture land and Forest land

The graphs in Figure 21 further illustrates that land use dynamics and the resilience of human systems towards adverse weather events are narrowly connected. An example from the agriculture sector could be the cultivation of monocultures, as for example oil palm or coffee. Monocultures, as opposed to integrated farming practices, facilitate soil erosion due to the lack of vegetation cover between the crops that are cultivated. Erosion reduces the amount of fertile soil and thereby increases the need for and application of fertilizers to make up for the loss in fertility. In addition, monocultures are more vulnerable to extreme rainfall because the lack of vegetation cover reduces the percolation rate and thereby fosters a rapid runoff towards the next river and likely contributes to the emergence of flood events.



## 9.2.6. Macro-economy

### *Key variables and dynamics*

GDP is used as an indicator of macroeconomic performance. Figure 22 provides an overview of the key variables and feedback loops that are used to determine the macroeconomic performance.

In addition to the reinforcing loop that is depicted in Figure 22, multiple major feedback loops that run through other sectors (e.g. roads, education, and health care) affect GDP and investment through the variable total factor productivity. These loops are not displayed in this CLD.

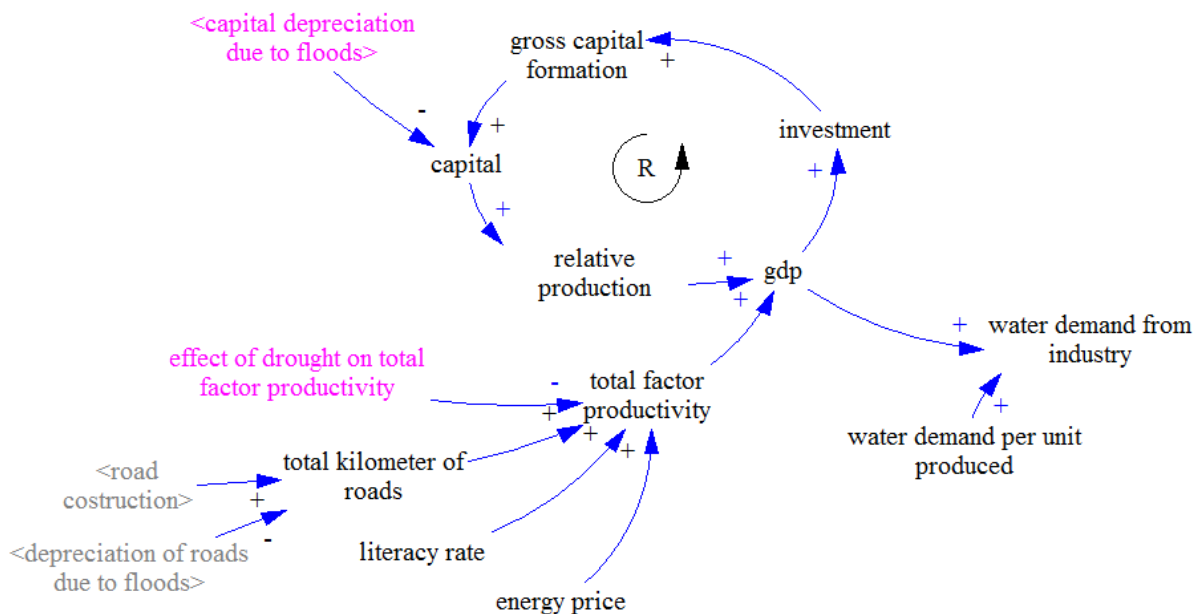


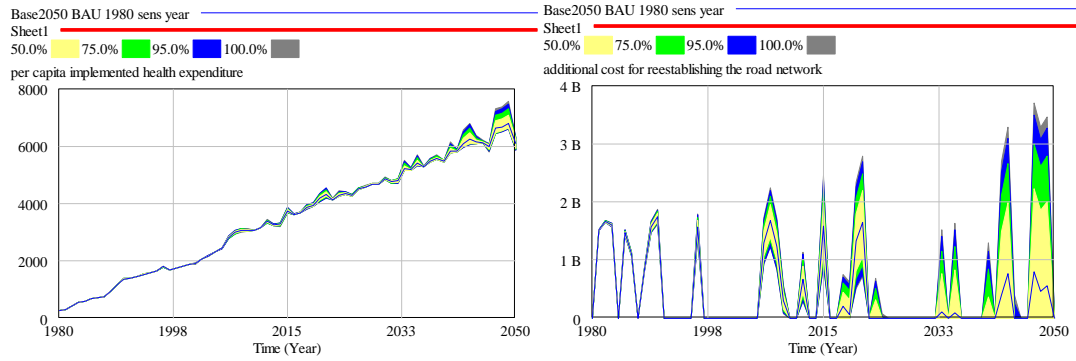
Figure 22 - CLD Macro-economy

Macro-economic performance is affected by adverse weather i) through the depreciation of capital, and ii) the effect of drought on total factor productivity. The depreciation of capital due to floods captures the loss of roads and capital through flood events, and the intensity of the loss depends on the intensity of the event, as described in section 9.2.3 in more detail.

### *Climate impacts on macro-economic performance*

Macro-economic performance is affected indirectly through adverse weather events. GDP in this model is estimated using labor, capital and productivity and therefore it is indirectly affected by a variety of sectors. Therefore, the impacts that adverse weather events have on GDP can be considered second order impacts, aside from the case of agriculture.

Per capita health care expenditure and the additional costs for maintaining the road network are modeled as weather-related impacts on GDP, in addition to the direct effect of drought on total factor productivity. Including the additional costs for health care and the re-establishment and maintenance of the road network provides an indication of the potential damage that is likely to be caused by adverse weather events. Figure 23 displays sensitivity graphs for per capita health care expenditure and the additional costs for re-establishing the road network for the BAU scenario. While the confidence interval for the per capita health care expenditure is fairly small (ranges around 500 USD per person per year by 2050), the confidence interval for the re-establishment of the road network ranges up to 3.5 billion USD per year.



**Figure 23 – Additional costs through adverse weather**

Including the potential costs of future adverse weather events into the analysis i) affects the macro-economic performance by accounting for climate-related impacts on capital and productivity, ii) provides an indication on the total costs that are likely to incur if no measures are taken that increase the preparedness for and the resilience to adverse weather events, and iii) provides an estimation of the potential minimum investment that would be justified in actions that would improve resilience.

## 10. References

- Afari-Sefa, V., & Gockowski, J. (2010). *Economic Cost-Benefit Analysis of Rainforest Alliance Certified Cocoa in Ghana*. Accra: International Institute of Tropical Agriculture.
- Agol, D., Latawiec, A., & Strassburg, B. (2014). Evaluating impacts of development and conservation projects using sustainability indicators: Opportunities and challenges. *Environmental Impact Assessment Review*, 48, 1-9.
- Blackman A. & Rivera J. (2010). *The Evidence Base for Environmental and Socioeconomic Impacts of "Sustainable" Certification*, Washington: Resources for the Future.
- Boschken, H. (2013). *Scale, the Silo Effect and Intergovernmental Cooperation: Institutional Analysis of Global Cities and Ecological Sustainability*. American Political Science Association 2013 Annual Meeting. San Jose State University.
- Costantini, V., & Monni, S. (2008). Environment, human development and economic growth. *Ecological Economics*, 64(4), 867-880.
- Emerton, L. (2006). *Counting Coastal Ecosystems As An Economic Part Of Development Infrastructure*. Ecosystems and Livelihoods Group Asia, IUCN, Colombo.
- European Commission, FAO, IMF, OECD, UN, World Bank (2012). *System of Environmental-Economic Accounting (SEEA). Central Framework*.
- IPCC (2007), "Climate Change 2007: Impacts, Adaptation and Vulnerability", Working Group II Contribution to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, "Chapter 17: Assessment of Adaptation Practices, Options, Constraints and Capacity", Cambridge University Press, Cambridge, pp. 717-743.
- Macfadyen, G. & Huntington T. (2007). *Potential Costs and Benefits of Fisheries Certification for countries in the Asia-Pacific Region*, Bangkok: FAO.
- Marine Stewardship Council. (2013). *Use the MSC Ecolabel. Costs.*, Available at: <http://www.msc.org/get-certified/use-the-msc-ecolabel/costs>
- Mccool, S. F., & Stankey, G. H. (2004). Indicators of Sustainability: Challenges and Opportunities at the Interface of Science and Policy. *Environmental Management*, 294-305.
- Millennium Ecosystem Assessment (MA) (2005). *Ecosystems and Human Well-Being. Synthesis*. Island Press, Washington DC.
- Némes, N. (2009). *Comparative Analysis of Organic and Non-Organic Farming Systems - A critical assessment of farm profitability*.
- Owens M.C. (2008). *Sustainable Seafood Labeling: An Analysis of the Marine Stewardship Council*, University of California San Diego.
- Pažek, K., & Rozman, C. (2012). *Option Models Application of Investments in Organic Agriculture*. In P. Konvalina, *Organic Farming and Food Production*. InTech.
- Pretty, N., Noble, A., Bossio, D., Dixon, J., Hine, R., Penning de Vries, F., et al. (2005). Resource-conserving agriculture increases yields in developing countries. *Environmental Science and Technology*, 40, 1114-1119.

Schreiber, J. (2006). A Cost Benefit Analysis of Forest Certification at The Forestland Group. Durham: Duke University.

The Economics of Ecosystems and Biodiversity (UNEP TEEB) (2010). Ecological and Economic Foundations, Edited by Pushpam Kumar

UNDP (2005). Adaptation Policy Framework for Climate Change: Developing Strategies, Policies and Measures. Lim, B., E. Spanger-Siegfried, I. Burton, E. Malone and S. Huq (Eds). Cambridge University Press, 258p.

UNEP (2011). Towards a Green Economy: Pathways to Sustainable Development and Poverty Eradication. Nairobi.

UNEP (2012a). Measuring progress towards an inclusive green economy. Geneva: UNEP.

UNEP (2013a). An inclusive and equitable green economy in the context of sustainable development and poverty eradication

UNEP. (2014). Using Indicators for Green Economy Policymaking. UNEP.

WWF (2013). The Economic Value Of Ecosystem Services In The Mekong Basin- What We Know, And What We Need To Know. WWF – World Wide Fund For Nature, Gland, Switzerland.