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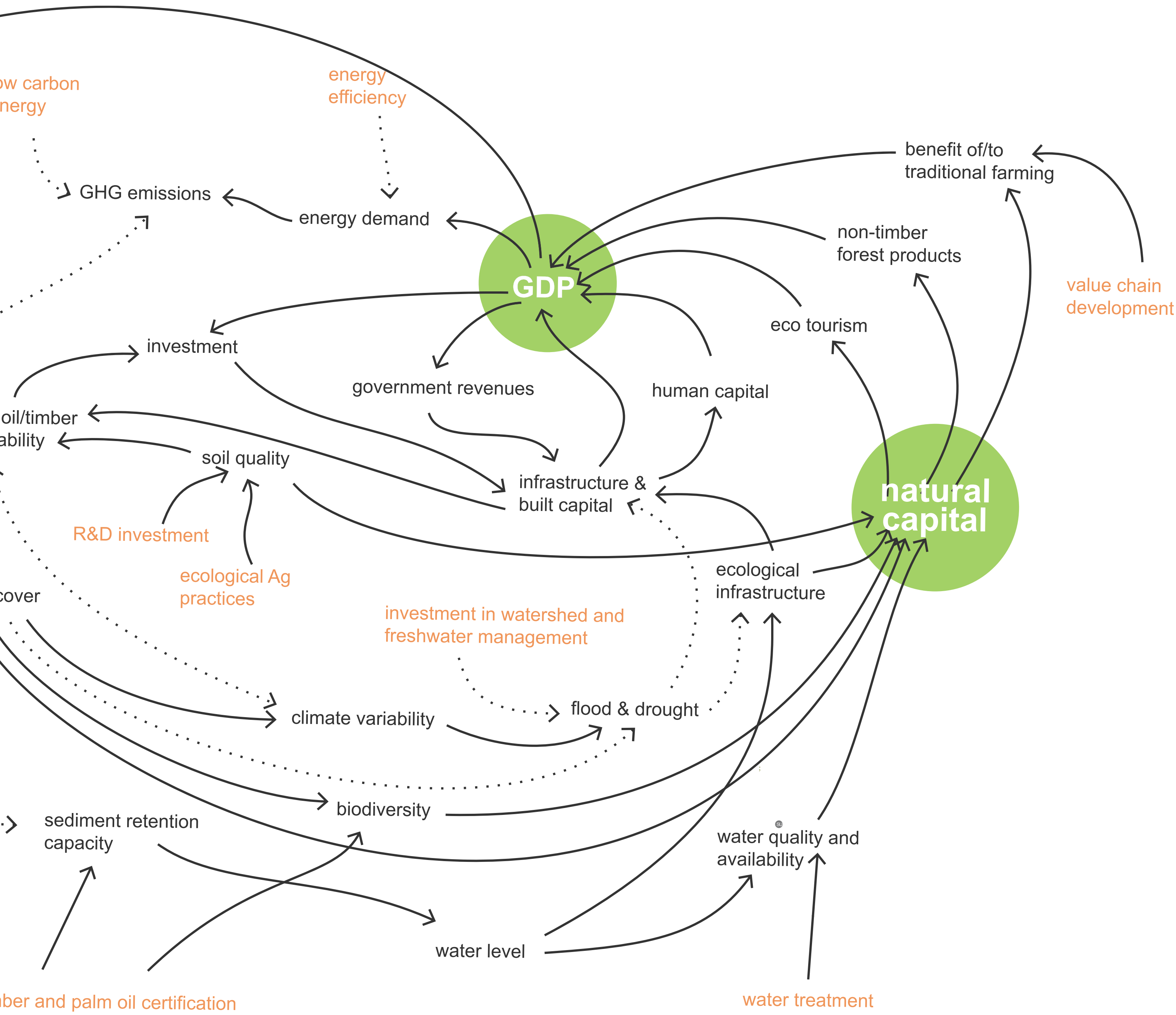
GREEN economy

USING MODELS FOR GREEN ECONOMY POLICYMAKING



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Causal loop diagramme (Van Paddenburg et al., 2012)

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

ADB	Asian Development Bank
ALOS	Advanced Land Observing Satellite
CE	Cambridge Econometrics
CEEESA	Center for Energy, Environmental, and Economic Systems Analysis
CGE	Computable general equilibrium
DEM	Digital elevation model
DICE	Dynamic Integrated Climate-Economy
EGSS	Environmental goods and services sector
EIA	Energy Information Administration
EIO	Environmental input-output
E3MG	Energy-Environment-Economy (E3) model at global level
EMG	Environment Management Group
ENPEP	Energy and Power Evaluation Program
ESA	European Space Agency
FAO	Food and Agriculture Organization
GAINS	Greenhouse Gas and Air Pollution Interactions and Synergies
GCAM	Global Change Assessment Model
GDP	Gross domestic product
GE	General equilibrium
GER	Green Economy Report
GHG	Greenhouse gas
GIS	Geographic information system
GTAP	Global Trade Analysis Project
HoB	Heart of Borneo
I-O	Input-output
IAEA	International Atomic Energy Agency
IEA	International Energy Agency
IEEP	Institute for European Environmental Policy
IFPRI	International Food Policy Research Institute
IGES	Institute for Global Environmental Strategies
IIASA	International Institute for Applied Systems Analysis
IISD	International Institute for Sustainable Development
ILO	International Labour Organization
IMAGE	Integrated Model to Assess the Global Environment
IMF	International Monetary Fund
InVEST	Integrated Valuation of Environmental Services and Tradeoffs
IP	Integrated policymaking
ISO	International Organization for Standardization
JGCRI	Joint Global Change Research Institute
LCA	Life cycle assessment
LCM	Land Change Modeler
LEAP	Long-range Energy Alternative Planning System
M&E	Monitoring and evaluation
MAMS	Maquette for MDG Simulations
MARKAL	Market Allocation Modelling Framework
MDGs	Millennium Development Goals
MEA	Millennium Ecosystem Assessment
MERGE	Model for Evaluating Regional and Global Effects of GHG Reduction Policies
MESSAGE	Model for Energy Supply Strategy Alternatives and their General Environmental Impact
NAMA	Nationally appropriate mitigation actions
NEMS	National Energy Modelling System
OECD	Organisation for Economic Co-operation and Development
PAGE	Partnership for Action on Green Economy
PALSAR	Phased Array type L-band Synthetic Aperture Radar
PNNL	Pacific Northwest National Laboratory
REDD	Reducing Emissions from Deforestation and Forest Degradation
REMIND	Regional Model of Investments and Development
SAM	Social accounting matrix
SCP	Sustainable consumption and production
SD	System dynamics
SERI	Sustainable Europe Research Institute
SNA	System of National Account
T21	Threshold 21
TIMES	The Integrated MARKAL/EFOM System
UN	United Nations
UNCED	United Nations Conference on Environment and Development
UNCSD	United Nations Commission for Sustainable Development
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNEP-WCMC	United Nations Environment Programme – World Conservation Monitoring Centre
UNIDO	United Nations Industrial Development Organization
UNITAR	United Nations Institute for Training and Research
WASP	Wien Automatic System Planning package
WDI	World Development Indicators
WIO	Waste input-output
WITCH	World Induced Technical Change Hybrid model
WPP	World Population Prospects
WRI	World Resources Institute
WWF	World Wildlife Fund

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1 Introduction

1.1 BACKGROUND

The misallocation of capital in the past two decades has contributed to the manifestation of several concurrent crises: climate, biodiversity, energy, food and water, as well as the global financial and economic crisis. In response to these systemic crises, UNEP has stressed the need for a shift to a more sustainable and inclusive economy, reached by effectively incorporating social and environmental policies in development planning.

At the visionary level, UNEP (2011) defines the green economy as "an economy that results in improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities".

The report by the United Nations Environment Management Group (EMG) (2011) points out that at the operational level, the green economy is seen as one whose growth in income and employment (highlighting the need for the green economy to be inclusive) is driven by investments that:

— **Reduce carbon emissions and pollution**
— **Enhance energy and resource efficiency**
— **Prevent the loss of biodiversity and ecosystem services**

These investments need to be catalysed and supported by targeted public expenditure, policy reforms and regulation changes to create the so-called "enabling conditions" for an inclusive green economy. More specifically, the main policy interventions proposed by UNEP include:

— **Addressing environmental externalities and existing market failures**, by introducing measures to reflect the cost of depletion and degradation of natural capital into market prices.
— **Limiting government spending in areas that deplete natural capital,** by removing harmful subsidies and incentives.
— **Promoting investment and spending in areas that stimulate a green economy,** by allocating budget to (a) promote innovation in green technologies and processes; (b) expand infrastructure that support the adoption of green practices; and (c) encourage private sector investments in green infant industries.
— **Establishing a sound regulatory framework,** to accelerate progress towards a green economy and equitably allocate costs and benefits across key economic actors.

The main purpose of green economy policies and investments is therefore dual: (1) to create new and sustainable physical capital, human capital and social capital, and (2) to maintain, enhance and rebuild natural capital as a critical economic asset and source of public benefits. Protecting natural resources, from clean freshwater to forests and air, is especially important for poor people who depend on these resources for their livelihoods and are especially vulnerable to environmental contamination and degradation. In this sense, the 2012 United Nations Conference on Sustainable Development, also known as Rio+20, acknowledged the importance of the green economy as a tool for achieving sustainable development.

In short, the green economy represents an attempt to guide countries towards the adoption of more action-oriented pathways to sustainable development.

In this context, given that no single approach exists for sustainable development, policymakers need support through studies and analyses to help them better identify and understand upcoming challenges and opportunities, as well as to design, choose and implement policy interventions.

A constant, often indicated as a prerequisite for the development of a successful strategy, is inclusiveness, or ensuring broad participation in the policymaking process (UNCED, 1992), thereby avoiding the treatment of the three pillars of sustainable development – society, the economy and the environment – as isolated parts of the system. Also, with sustainable development plans being commonly defined at the national level, green economy strategies need to be conceived, designed and implemented taking into account the local socioeconomic and environmental context.

In light of these needs, the United Nations has already stated that integrated assessments are required to support sustainable development (UNCED, 1992; UNCSD, 2012), and tools are needed that can operationalize this process, as the "means" for sustainable development is "the end".

The Agenda 21 (UNCED, 1992) also reflects the main goal of strategy and planning exercises on the green economy, which is to inform and influence the policymaking cycle to effectively progress towards sustainable development. However, while there is a common and broadly shared goal, involving cross-sectoral amalgamation and integrated assessments, the vast majority of models available to governments are sectoral and cannot be easily coupled with each other's. As a result of this disconnect (single and integrated goal versus multiple disconnected tools), the selection and use of models and their effectiveness in informing decision makers ultimately depends on what needs to be measured and analysed.

1.2 PURPOSE

For the reasons outlined above, starting from the definition of a green economy (what needs to be measured and analysed), this report aims to provide (1) a framework to review and select methodologies and models, and (2) information on what tools are available to governments and are currently being used to support the analysis of green economy strategies at the national and sectoral levels.

While acknowledging that the list provided in this report is not exhaustive, the selection of the models analysed is limited to those that are being applied, customized and used at the country level, particularly in developing countries.

This study offers a critical review of the strengths and weaknesses of various methodologies, and of the adequacy of models to help countries to assess their economies and develop green economy strategies. This report, however, does not identify the best approaches for formulating and evaluating green economy strategies; instead, it provides key information for the ministries tasked with planning and implementing responsibilities to evaluate the adequacy of various models in meeting their specific needs.

There are two main intended audiences for this report: (1) managers of green economy analytical projects, or those responsible for designing quantitative assessment frameworks for green economy interventions, and (2) modellers, or those who would support the analysis and generation of results using quantitative tools.

With these audiences in mind, this report aims at providing a framework and useful information to countries interested in green economy strategic planning exercises. This work focuses on the methodologies and models available to support countries in this endeavour, so that informed decisions can be made on what tools to use and how to implement them, to effectively support policymaking for sustainable development.

The role of UNEP is critical, especially at this stage, in supporting the full incorporation of the environmental dimension in national development planning with adequate tools. This is also done by partnering with other organizations specializing in other aspects of the green economy, such as employment (ILO), energy and resource efficiency (UNIDO), and learning and skills development (UNITAR), and more recently UNDP, all collaborating under the Partnership for Action on a Green Economy (PAGE).

1.3 OVERVIEW OF THE ANALYSIS

The report starts by identifying and defining the criteria for reviewing and evaluating models and methodologies (chapter 2). It then focuses on the actual review and evaluation of methodologies (chapter 3) and models (chapter 4), to explore how they can contribute to policymaking for the green economy.

Methodologies, or the underlying body of knowledge for the creation of different types of simulation models, are analysed primarily in relation to their contribution to the policymaking process, also taking into account their potential in creating an enabling environment for communication and collaboration among various stakeholders.

Models built using one or more specific methodologies are first reviewed in relation to their capacity to deliver useful information relative to the concept of a green economy. They are then analysed in terms of the effort required to create and customize as well as use them.

Further, the evaluation of models includes their applicability to different national contexts (chapter 5). Some countries, depending on their specific context and data availability, may decide to rely on certain models rather than others due to their specific national context, data availability and capability of the tools to address specific issues or relevance. A selection of five typical examples of countries is reviewed and models are suggested depending on the issues at stake.

Chapter 6 stresses the complementarity of the methodologies and models analysed. Through three case studies, it highlights opportunities for merging different approaches or creating new modelling frameworks to effectively inform decision-making on the development of green economy strategies.


UN Photo: Mark Garten

2 Criteria for review and evaluation

Various criteria are considered for reviewing and assessing methodologies and models, with a particular focus on the concerns and needs of developing countries. These criteria primarily focus on tangible dimensions to be reviewed and analysed.[1] Further, this study only assesses the methodologies and models that are most commonly used in developing countries for analysing interventions for a green economy transition. Many[2] studies provide more information on the breadth of models available. The framework presented here is not intended to be exhaustive, but contributes to a better understanding of how useful and adequate methodologies and models can support country-led exercises in formulating and evaluating green economy policy.

The key criteria for assessing the methodologies depend on the extent or nature of their contribution to various stages of the policymaking process. In addition, the complementarity of the methodological approaches is considered, together with the inclusiveness (i.e. stakeholder involvement) of the process to implement them.

Methodologies, or the underlying body of knowledge for the creation of different types of simulation models, can be "static" (data frameworks) or "dynamic" (modelling approaches). Both types are used to create and simulate quantitative models.

These methodologies are described in more detail in chapter 3, and can be used to generate and analyse simulations of social, economic and environmental pathways or scenarios.

It is worth noting that data frameworks often represent the backbone of models, depending on the flexibility and degree of customization offered by the modelling approach utilized (see chapters 4 and 5). Data frameworks are "static", and can be used in two main ways: (1) in isolation, to investigate and understand the history and current state of the system, and (2) embedded in simulation models, to generate simulations of future trends for all the indicators included in the framework selected. Data frameworks include:

— Indicators
— Input-output frameworks (I-O)
— Social accounting matrices (SAM)
— Geographic information systems (GIS)

Modelling approaches refer to the underlying mathematical theories and frameworks that can be used to create and simulate (or solve) quantitative simulation models. These methodologies could therefore be considered "dynamic", as they allow for generating future projections. Modelling methodologies include:

— Econometrics (see sections 4.1.1 and 4.1.3)
— Optimization (see sections 4.1.1, 4.1.2, 4.1.4, 4.2.1, and 4.2.2)
— System dynamics (see sections 4.1.5, 4.2.3 and 4.2.4)

Concerning models, the criteria focus more explicitly on the definition of a green economy (which would vary depending on the national context), and the quantitative outputs required to effectively inform decision-making. As a result, the main criteria that were considered include the capability of models to represent the social, economic and environmental dimensions of the problems and opportunities analysed, as well as their capability to carry out investment and policy analysis.

As an additional layer of the analysis, models are assessed for their ease of customization and use. This is relevant for specific country implementation, where data, time and financial resources may be scarce, and trade-offs need to be addressed.

The following sectoral and macro models are considered (as described in chapter 4):

- Input-output models, also used to generate projections (see sections 4.1.1 and 4.1.3)
- System engineering models, or models of an engineered system, e.g., energy supply (see sections 4.1.2 and 4.2.2)
- Geographic information system (GIS) and natural capital valuation models (see sections 4.1.4 and 4.2.4)
- Computable general equilibrium models, including those coupled with system engineering modules (see sections 4.2.1 and 4.2.2)
- System dynamics models (see sections 4.1.5, 4.2.3 and 4.2.4)

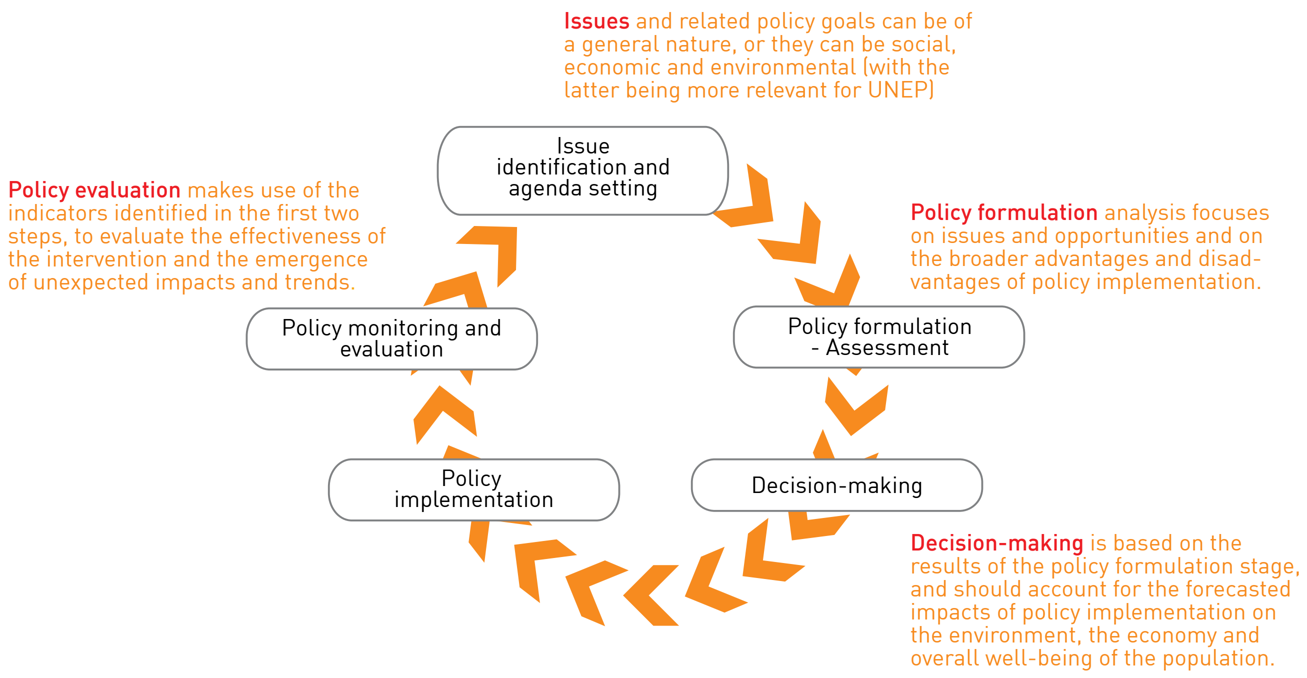
These models use different data frameworks (e.g., CGE models use the SAM) and modelling approaches (e.g., optimization in systems engineering models). More details on methodologies and models are presented in chapters 3 and 4 respectively.

2.1 METHODOLOGIES

The growth in income and employment in a green economy is driven by investments. For the investments to be catalysed and leveraged, public expenditure, policy reforms and regulation changes are needed. As a result, methodologies and models must support the policymaking process (see Figure 1), allowing to quantitatively project and evaluate trends (issue identification, stage 1); identify entry points for interventions and set targets (policy formulation, stage 2); assess ex ante the potential impact across sectors and the effectiveness in solving stated problems (or exploiting opportunities) of selected interventions (policy assessment, stage 2); and monitor and evaluate the impact of the interventions chosen against a baseline scenario (policy monitoring and evaluation ex post assessment/analysis, stage 5).

Various methodologies can be used 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). The methodologies presented in this report are most commonly used when the analysis is

Figure 1. The integrated policymaking cycle, highlighting the three main stages supported by the use of quantitative methodologies



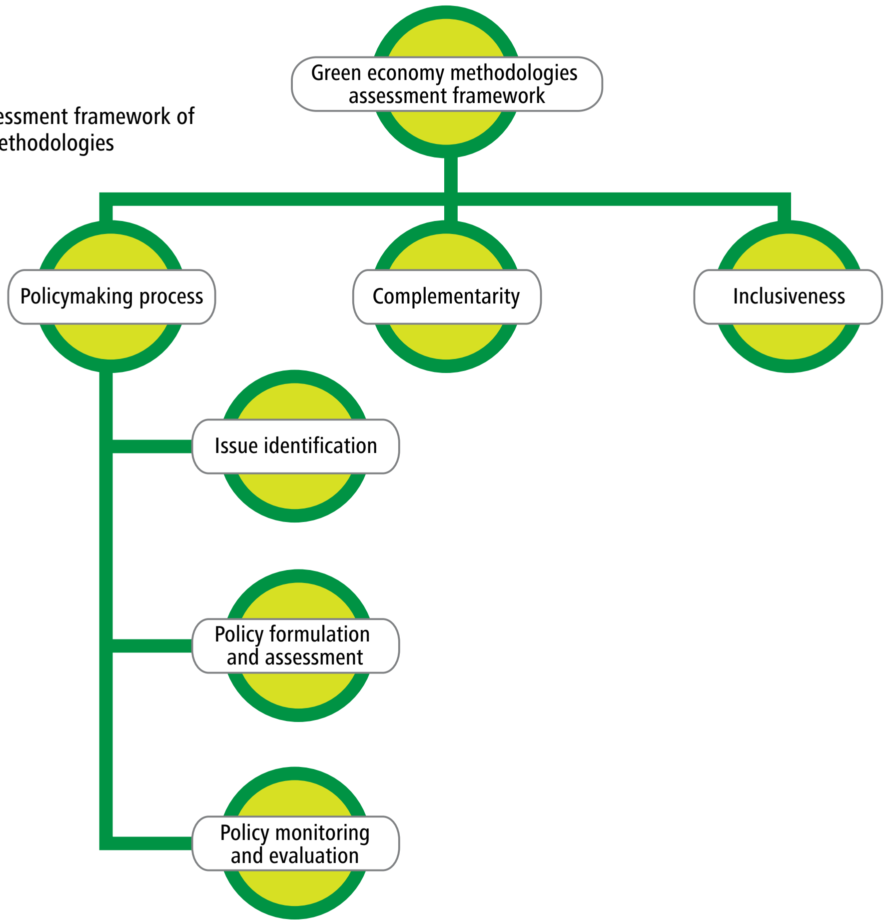
done "ex ante", or before the actual implementation of the interventions (issue identification and agenda setting, and policy formulation and assessment), but they can also be used to carry out "ex post" (policy monitoring and evaluation) analysis:

- Ex ante modelling 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 modelling can support impact evaluation by improving the understanding of the relations 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.

In addition to their capability to support issue identification and agenda setting, policy formulation and assessment, and policy monitoring and evaluation, the methodologies are evaluated on their complementarity with other approaches and their capability to involve a variety of stakeholders in model development and use.

Complementarity is important as it strengthens the analysis and addresses some of the weaknesses of each methodology with inputs from others. Further, the simultaneous use of different methodologies supports the broader involvement of various stakeholders (technical and political) in policy formulation and evaluation. This latter aspect is particularly important in the context of the green economy. The goal being sustainable development, it is crucial that a green economy strategy is developed, and analysed, for its impacts across sectors. The simultaneous evaluation of social, economic and environmental dimensions can only be carried out with the adoption of a multi-stakeholder approach in which projected impacts are evaluated, and if necessary, mitigating and/or complementary actions are designed and evaluated.

Figure 2. The assessment framework of green economy methodologies



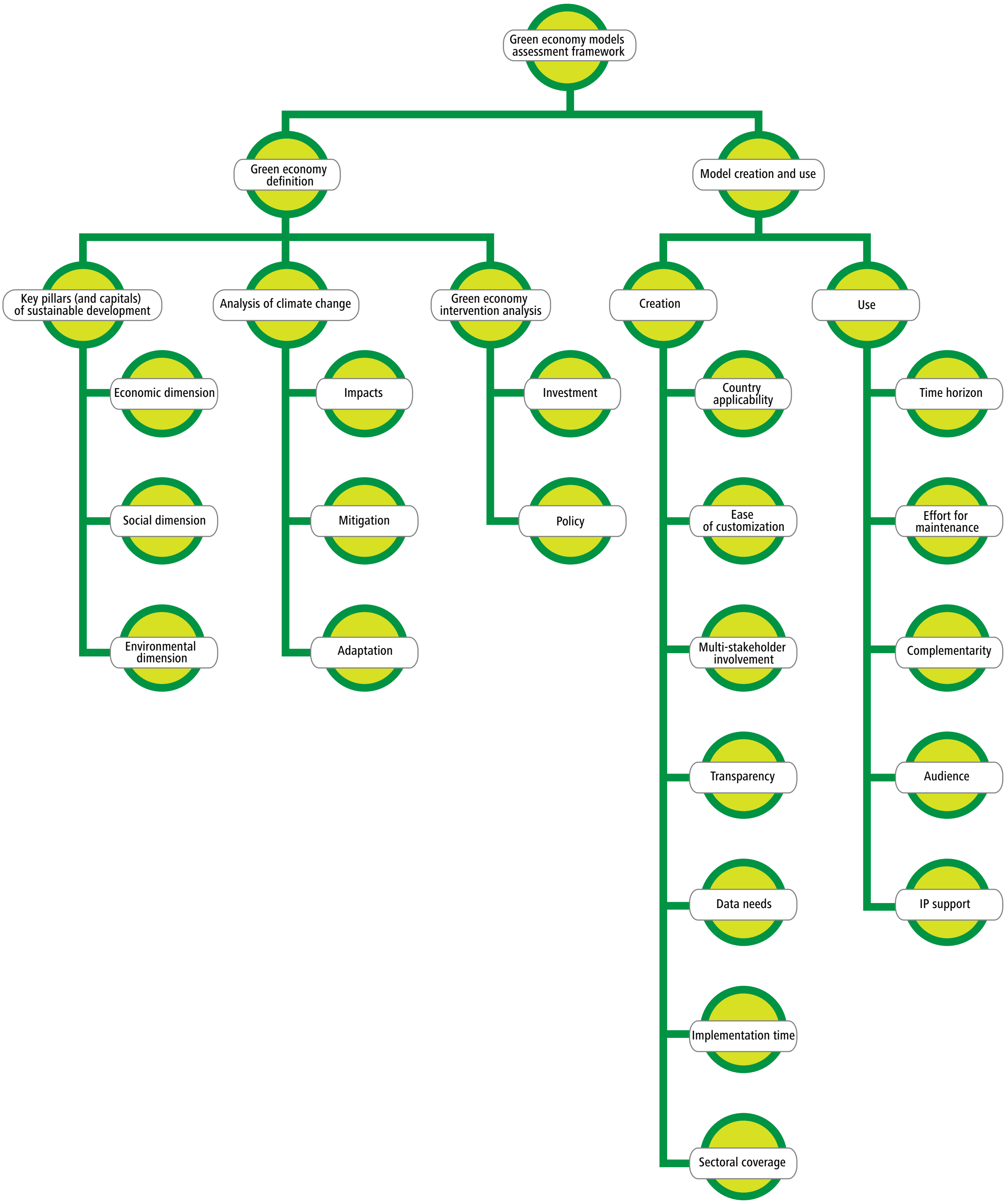
2.2 MODELS

Reviewing and assessing models entail two main criteria: relevance to the concept and definition of a green economy; and ease of creation and use.[3] More specifically, the former is assessed by evaluating the capability of models to:

— Represent the social, economic and environmental dimensions of the problems and opportunities analysed, also incorporating human, economic and natural capital in a single framework of analysis.
— Address climate change, a fundamental upcoming and systemic challenge, by forecasting impacts as well as analysing mitigation and adaptation options.
— Contribute to green economy investment and policy analysis.

The second set of criteria considers model creation and use from a developing country perspective, where data, time and financial resources may be scarce, and trade-offs need to be addressed. In this case, factors such as applicability to a country's context, transparency, implementation and maintenance time, and audience and IP support, take centre stage.

Figure 3. The assessment framework of green economy models



2.2.1 Relevance to the green economy definition

The definition of a green economy is used to identify the key criteria for reviewing and evaluating models. As any modelling work is problem oriented (i.e. it is essential to know what problem needs to be analysed and solved before developing a model), in the case of a green economy it is important to know what are the specific impacts, or dimensions of the transition, that need to be estimated and evaluated to inform policymaking.

Acknowledging that there are various definitions for a green economy, and that these are uniquely tailored to the specific context of each country, the UNEP definition is used in this report. This ensures that the analysis presented is relevant across countries, as the all-encompassing UNEP definition serves the purpose well.

In particular, to curb negative trends and trigger the transition, investments are needed. They would focus on behavioural change, through implementing targeted public expenditure, policy reforms and regulation changes.

The performance of the investments will be evaluated based on their capacity to maintain, enhance and rebuild natural capital as a critical economic asset and source of public benefits. Protecting natural resources, from clean freshwater to forests and air, is especially important for poor people who depend on these resources for their livelihoods and are especially vulnerable to environmental contamination and degradation. Along this line, human well-being and social equity, as variables affected by environmental risks and ecological scarcities, are critical layers to consider as well. Coupling natural and human capital with analysing economic or manufactured capital[4] is crucial to assess the impact of interventions on economic growth and resilience, and closes the loop on capital misallocation (being a cause of historical problems as well as a key driver for the future transition).

As a consequence, a model to be used for the assessment of green economy interventions should focus on one or more (ideally all) of the key indicators mentioned above. If this is the case, the analysis will be multi-layered, dynamically and systemically integrating social, economic and environmental sectors, and therefore accounting for economic, social and natural capital in the estimation of paths towards sustainable development over the next 25 to 50 years (or the life time of the investments tested).

More specifically, with the definition used above, the criteria used to review and evaluate models include:

Representation of the capital that is key to sustainable development[5]

— **Manufactured capital:** Models should include economic accounts (e.g., government and household accounts, balance of payments) consistently with national practices as well as physical infrastructure (e.g., roads, or power generation capacity), as relevant. The analysis should be capable of estimating future investments (private and public; direct, indirect and induced) and capture feedbacks to estimate synergies and side effects (e.g., rebound effect).

The analysis of manufactured capital includes the following themes, among others:

- **Capital misallocation:** Models should be able to generate the historical trend of capital misallocation to better identify and understand the influence of the main drivers of the system.
- **Sustainable consumption and production:** Models should incorporate elements (variables and modules) that allow for evaluating production and consumption patterns, as well as their impact on natural resources (e.g., material flows) and pollution (e.g., emission generation across the value chain), among others.
- **Competitiveness:** Models should be able to incorporate the key drivers of competiveness (at the sectoral and/or national level) to unlock the opportunities emerging from environmental goods and services sectors and evaluate international trade and competitiveness beyond national and regional boundaries.

— **Human capital:** Models should explicitly include skills, employment and job creation, erosion, and substitution, considering the specific characteristics of green and decent jobs. In addition to capturing macro trends, models should be able to estimate job impact across value chains.

Beyond employment, the analysis of the social dimension of sustainable development should include the following themes, among others:

- **Social equity:** Models should account for social equity consideration, especially in relation to investment and policy analysis. This would ensure that a fair and equitable distribution of costs and benefits could be a direct goal of policy formulation and assessment.
- **Human well-being:** Models should include well-being and inclusive wealth to ensure that various dimensions of development (social, economic and environmental) are considered in the analysis, going beyond income and poverty analysis.

— **Natural capital:** Models should include the explicit biophysical and, if and when possible, monetary estimation of natural resource stocks, ecosystem services and ecosystem goods.[6] These three elements should be directly connected to the economic and social sectors, in accordance with the service provided (e.g., energy and water supply and consumption, the use of rivers for transport, or the role of forests in reducing environmental risks).

The analysis of natural capital includes the following themes, among others:

- **Ecological scarcities:** Models should represent and project natural resource stocks and flows, as well as ecosystem goods and the provision of ecosystem services. These are fundamental variables to better understand the relation between the environment and socioeconomic development.
- **Environmental risk:** Models should project the potential emergence of environmental risks, as well as their impacts on society and the economy. These would normally be driven by ecological scarcities or by variability in climate (in relation to the vulnerability of the local context).

Analysis of climate change

— **Climate change impacts:** Models should include the impact of climate change, starting with biophysical impacts (mostly environmental) and then estimating social and economic ones. If not projected endogenously, inputs could be taken from existing climate models, possibly with projections scaled down at the regional and national level.

— **Climate change mitigation:** Models should allow for the analysis of climate mitigation interventions. These pertain to greenhouse gas (GHG) emissions, and span various sectors comprising sources (e.g., energy) and sinks (e.g., forestry). Climate mitigation therefore creates a strong link between the green economy and low carbon strategies (e.g., NAMAs) and REDD+ related strategies.

— **Climate change adaptation:** Models should be built on a cross-sectoral platform to allow for assessing climate adaptation interventions. This analysis involves sectors such as water and agriculture, but also transport and the economy as a whole. Climate adaptation creates a strong link between the green economy and national adaptation programmes of action.

Green economy interventions analysis

— **Investment analysis:** At the core of the green economy definition, models should accommodate the analysis of the impacts and effectiveness of investments. This would particularly be useful in the policy formulation stage, where objectives are set and intervention options are designed. Further, the investment analysis creates a strong link with the finance sector, leveraging domestic and international resources f**or the green economy transition.**

— **Policy analysis: As the main goal of the green economy, m**odels should be able to support policy analysis before and after implementation, in the formulation and assessment as well as monitoring and evaluation phase. Policy analysis is the core instrument for ensuring that green economy considerations are brought to the table of policymakers, especially those involved in economic planning.

2.2.2 Model creation and customization

Since green economy strategies are primarily defined and implemented at the national level, the process of model creation and customization is very important in determining the adequacy of models to support policymaking. Very often, practitioners have to face time, data and budget constraints, so the best technical model may turn out not to be the best choice from a practical point of view.

More specifically, the following criteria have been considered in this study:

- **Applicability to country context:** Does the model reflect the local context and does it coherently represent the problems to be solved? In other words, does the structure of the model naturally fit the system to be analysed?
- **Ease of customization:** If the model can be customized, how easily could it be done? Is the software allowing the use of a modular approach? What is the level of knowledge and proficiency required to make numerical and structural changes to the model?
- **Multi-stakeholder consultation:** Does model creation allow (and is it conducive to) the involvement of a broad range of stakeholders (technical and policy)? Could they take an active role in the design of the model and analysis? Can their knowledge and practical expertise (or understanding of the core functioning of the system analysed) be fully incorporated in the modelling exercise?
- **Transparency:** Is the model transparent or a "black box", meaning that its source code (i.e. equations) can be easily accessed and understood? Would it support learning of the green economy at the country level? Is there broad knowledge of the methodology, software and model in the country? How long would it take to develop the knowledge and skills to create the model and/or understand its results?
- **Data needs/intensity:** Is the model heavily reliant on data? Would the confidence in the results greatly decrease in case data are not available? Could the model incorporate qualitative variables, and could equations (relations among variables) be developed even in the absence or lack of data?
- **Time required for implementation:** How long does it take to calibrate, customize and run the model? Is this an activity that could be carried out locally or does it require expert support?
- **Sectoral coverage:** Is the model covering only one or more sectors? What is the level of detail of the analysis? Is there any vertical (within the sector, e.g., value chain, income distribution) and/or horizontal integration (across sectors, e.g., energy-water and environment-economy nexus)?

2.2.3 Model use and support for the policymaking process

The use of models and their support in the policymaking process are to be evaluated in the context of a green economy transition. In particular, model relevance should be assessed along the policy cycle, from policy formulation and assessment to policy implementation, monitoring and evaluation.

While acknowledging that models play only a limited to marginal role in determining the successful implementation of policies, certain criteria can be identified that would align expectations with their potential medium- to long-term contribution to policymakers.

More specifically, the following criteria have been considered in this study:

- **Time horizon of the analysis:** Does the model capture short-, medium- and/or long-term impacts of policy interventions? Short-term projections are generally more valuable for informing the budgeting process (carried out on an annual basis), while medium- and longer-term projections contribute more effectively to the development of medium-term plans and long-range national development plans.
- **Effort for maintenance and use:** How frequently should the model be updated? How long would it take to update the model? For how long would simulations remain valid (assuming no structural changes)? Is funding available for regular maintenance and updates, as well as for capacity-building on model creation and use?
- **Complementarity with other methodologies and models:** Could the results of the analysis, and the model itself, be coupled with other policy-related analysis and modelling exercises? Is there a possibility to cross-check the results of the model with other analysis regularly carried out in house?
- **Target audience (multi-stakeholder involvement):** Would the model be developed to address a sectoral question, and would it project results across a variety of thematic indicators? Does the analysis of results require the involvement of various stakeholders for validation? Are the results of a technical or policy nature? Will policymakers be directly involved in the analysis of results?
- **Support in the policymaking process:** Is the model able to support various stages of the policymaking process? If so, could it be employed throughout the cycle to ensure continued use? Can the model be easily institutionalized and owned locally?

3 Review of methodologies

3.1 INTRODUCTION

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.

3.2 DATA FRAMEWORKS

3.2.1 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. They are particularly useful to highlight trends that can shed light on causal relations among the elements composing the system and in analysing 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, 2012a). Using inventory data and/or surveys, indicators can be grouped in four main categories:

- **Indicators for issue identification and agenda setting** help decision makers identify and prioritize problems, present and/or upcoming, and set the agenda for policy interventions.[7]
- **Indicators for policy formulation** support the identification of intervention options and the analysis of their strengths and weaknesses. Focus is given to the use of indicators that allow for evaluating the adequacy of the interventions analysed in relation to stated goals and targets.[8]
- **Indicators for policy assessment** contribute to the estimation and evaluation of policy impacts in addressing the problem, across sectors and actors, with a more marked focus on socioeconomic impacts and well-being.[9]
- **Indicators for policy monitoring and evaluation,** building on the indicator categories listed above, support the verification of whether the policy is generating expected results, and eventually lead to formulating and implementing corrective measures.

3.2.2 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. More specifically, I-O frameworks are often employed to estimate changes in material flows, employment creation and emission reductions within and across industrial sectors. Further, I-O tables are used to estimate the impact of interventions on trade, for monetary and materials flows as well as emissions (e.g., carbon leakage).

While I-O tables are relatively easy to use, they are generally very data intensive, and the preparation of an I-O framework is a time-consuming exercise. Nevertheless, these tables can be developed for different levels of detail, depth and sectoral coverage, depending on the problem to be analysed.

3.2.3 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.

SAMs are normally based on the System of National Account (SNA), which is commonly available at the national level, and which the International Monetary Fund (IMF) also compiles. As a consequence, the SAM can be seen as a tool for organizing information in a single matrix of the interaction between production, income, consumption and capital accumulation in an economy.

SAMs are generally embedded in CGE models to examine the effects of real shocks on the economy and on the distribution of income across socioeconomic groups of households.

3.2.4 Geographic information system

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

GIS applications are tools that allow users to create interactive queries (user-created searches), analyse spatial information, edit data in maps, and present the results of all these operations. 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. However, 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). Nevertheless, in the context of the green economy, the most important contribution of GIS is the explicit representation of natural resource stocks, as well as ecosystem services.

3.3 MODELLING APPROACHES

3.3.1 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). Traditional econometric and macro-econometric models used at country level use primarily economic theory to define the structure of the model (e.g., a Cobb-Douglas production function can be used to forecast GDP). The quality and validity of projections is therefore highly connected to the soundness of the theory used to define the structure of the model (see Sims 1980 for a critique of this traditional approach to macro-econometric modelling).

The most important limitations of the traditional econometrics modelling 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 back track historical data) and with the reliability of forecasts that are only based on historical developments and on exogenous assumptions. In fact, the analysis of unprecedented events or policies that have never been implemented in history leaves room for uncertainty given that this type of econometrics do not provide extensive insights on the mechanisms that generate changes in the system. On the other hand, the field is not limited to these applications, with models that can incorporate more general behavioral assumptions and make use of endogenous variables, such as in the case of vector autoregression applications (Lütkepohl, 2005). Time series modelling such as vector autoregression has been useful in solving many of the mentioned limitations, particularly in its applications to empirical macroeconomics. More recent applications have also stressed the use of Bayesian statistics, arguing for its power in formulating and evaluating economic policies (Sims, 2011).

3.3.2 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). On the other hand, they do not generate extensive insights on what might happen in such situation or what the impact of actions may be. Policy makers often use optimization models to define what the perfect state of the system should be in order to reach the desired goals -information that allows them to formulate policies intended to reach such perfect state of the system and, ultimately, their goals.

In order to optimize a given situation, these models use three main inputs: (1) the goals to be met (i.e., objective function, such minimizing the cost of energy supply), (2) the areas of interventions and (3) the constraints to be satisfied. Therefore, the output of an optimization model identifies the best interventions that would allow reaching the goals (or to get as close as possible to it), while satisfying the constraints of the system (IIASA, 2001, 2002).

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 external inputs. In addition, some specifications of this type of model assume specific functional forms and use behavioral equations whose parameters are econometrically estimated. In many cases, this replicates many of the problems of traditional econometrics models (McKitrick, 1998).[10]

3.3.3 System dynamics

System Dynamics are descriptive models which are 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 behaviour of the system are. This implies identifying properties of real systems, such as feedback loops, nonlinearity and delays, via the selection and representation of causal relations existing within the system analysed. The results of the simulation would then show the existence of correlations in a dynamic manner, which are the outputs of an econometric analysis.[11] Instead of adopting general economic theories for the causal relations forming the structure of the model, simulation models proposed a theory of their own, highly customized and tailored around the issues to be analysed and the peculiarities of the system. 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 analysed (e.g., relating to the use of causality rather than correlation).

3.4 COMPARATIVE ASSESSMENT

A comparative assessment of the methodologies analysed in this study is provided in Table 1. 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 that will be presented in more detail in the following chapters of this study.

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 modelling 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 M&E, 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 modelling process and planning. This is primarily due to the ease of incorporating cross-sectoral factors in the model (e.g., energy-economy-environment nexus).

Beyond table 1, Chapter 6 presents the complementarity of various methodologies through the coupling of models. In fact, among others, System Dynamics models can be optimized and may use econometric inputs, and/or include I-O tables and spatially disaggregated data. CGE models run an optimization routine, use the SAM as their underlying economic accounting framework and can include I-O employment and material flow tables. Spatial models, using GIS data as foundation, can be used to run simulations (optimizing future trend and/or simulating "what if" scenarios).

Table 1. Review of methodologies for green economy assessments; contribution to the policy process, complementarity and stakeholder participation

Methodology	Main strengths in assessing the green economy	Main trade-offs relative to the green economy	Problem identification	Policy formulation	Policy assessment	Policy M&E	Complementarity	Accessibility – participation
Static								
Indicators	Support the entire policy cycle, quantify trends	Require harmonization; primarily limited to (quantitatively) measurable variables	✓	✓	✓	✓	✓	✓
Input-output	Represent value chain impacts, and ripple effects across sectors	Data intensive; material flows not generally available	✓	✓	✓	✓		
Social accounting matrix	Estimates economic flows across the main economic actors	Covers exclusively monetary flows; lacks feedbacks		✓	✓		✓	
Geographic information system	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	✓	✓	✓	✓	✓	✓
Dynamic (projections)								
Econometrics	Entirely based on historical trends; quick implementation	Traditional modelling lacks the explicit representation of feedbacks and does not capture possible emerging dynamics. Time series modelling has the potential to solve these issues.	✓		✓	✓	✓	✓
Optimization	Supports the estimation of target; understanding key limits of the system	Provides and "end" with little insights on the "means"; not viable for highly dynamic and cross-sectoral systems		✓	✓			✓
System dynamics	Focuses on structure to drive behaviour; horizontal sectoral representation; knowledge integrator (ad hoc)	Highly reliant on knowledge available in other fields; relatively long implementation time for national models	✓	✓	✓		✓	✓

4 Review of models

4.1 SECTORAL OR THEMATIC FOCUS

4.1.1 Employment with I-O, SAM and CGE

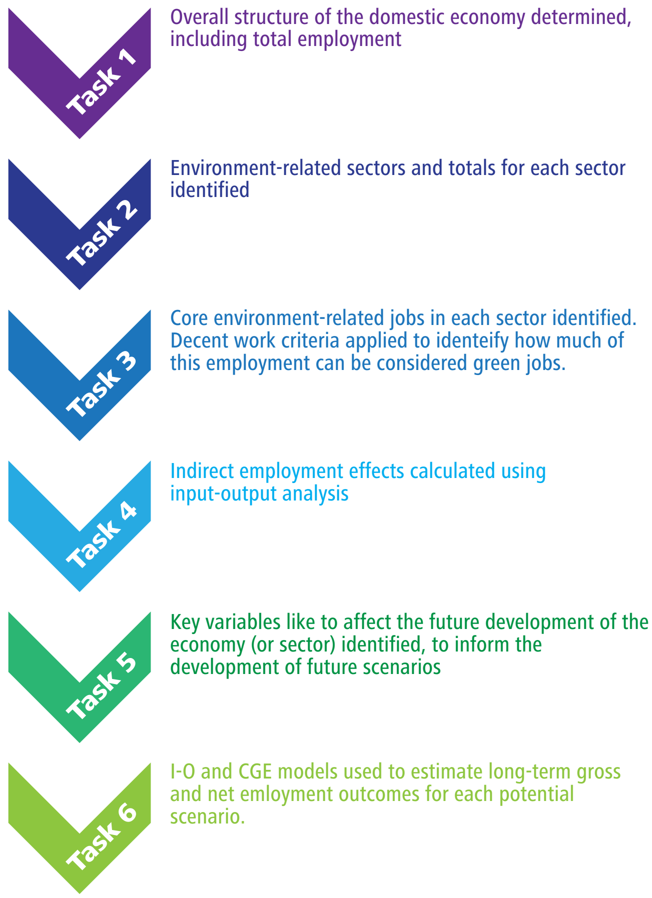
Policy definitions for green jobs emphasize their capacity for reducing negative environmental impacts, their potential for building more environmentally, economically and socially sustainable enterprises, and for providing fair employment (ILO, 2012). The use of models to assess green jobs (e.g., the potential impact of policies on green job creation) has to be carefully analysed, as it must consider whether available data are sufficiently detailed that jobs may be assessed for their green credentials on an individual basis, or whether there are only enough details for certain industries or companies, in their entirety, to be treated as green.

Several methodologies can be used to estimate green jobs. These include (1) employment factors, (2) input-output analysis, (3) social accounting matrices and (4) CGE models.

Employment factors measure the number of jobs created per unit of product produced or service provided. They are often used for employment estimation in the energy sector, where jobs in the manufacturing, construction and installation, as well as operation and management, of power plants can be estimated (ILO, 2012a). The data for calculating employment factors generally come from industry surveys, specific enterprises or projects and/or from feasibility studies and technical literature.

Of more interest, I-O analyses and SAMs are empirical tools that rely on the construction of a matrix or table listing all subsectors in an economy and detailing how outputs from one sector are used as inputs in others. With information on the labour intensity of the economic activity of a given sector, and all the sub-activities in the value chain, an I-O analysis can estimate the potential employment creation of a change in demand (or production) and/or in investment. In other words, I-O analysis can answer the question, "How many jobs could be created by investing US$1 million in a given sector, and what would be the direct and indirect number of jobs created?"

Figure 4. Research process for the estimation on green jobs in ILO work, an example (ILO, 2012)



I-O models and SAMs can effectively support the comparison of employment creation across various economic sectors, but are usually static and therefore are used to provide short-term projections of policy impacts. CGE models can expand the analysis of I-O and SAM to the medium and longer term, by simulating full economy responses to exogenous changes and by estimating induced job creation as well, as done by the ILO (ILO, 2013).

Table 2. Assessment of model creation and use: Employment with I-O, SAM and CGE

Model creation	Country applicability	Fully tailored to national statistics and market structure
	Ease of customization	Standard framework; easily adjustable based on data availability and knowledge of sectors/value chain
	Multi-stakeholder consultation	Limited, although various stakeholders may be involved if employment is estimated across sectors
	Transparency	Highly transparent
	Data needs	Generally heavy, depending on the scope of the study
	Time of implementation	In the order of weeks or months, depending on data availability
	Sectoral coverage	Generally narrowly focused, but could be cross-sectoral/dimensional
Model use and IP support	Time horizon	Short term
	Effort for maintenance	Minimal once the table is created – updates are not time-consuming; skills may be available at the country level, but for green economy assessments, training is required
	Complementarity	Limited, but its outputs could be used as inputs for other types of analysis
	Audience (multi-stakeholder involvement)	Medium; various stakeholders involved if employment is estimated across sectors and/or a national priority
	IP support	Primarily focused on policy formulation and assessment, but may be used for issue identification as well

4.1.2 Energy demand and supply with MARKAL/TIMES, WASP and LEAP

Various types of methodologies and models can be used to analyse energy demand and supply.[12] Generally, apart from a few exceptions in which simulation is used, optimization is the preferred methodology, with energy system models or computable general equilibrium models that are either global or national. While global models can capture international trade and regional dynamics, the national models can capture country specificities. Further, while energy system models include technological details of energy production and consumption technologies, CGE models account for macroeconomic feedbacks and changes in energy demand and trade (Johansson et al., 2012).

Energy supply models include MARKAL/TIMES (Loulou et al., 2005), which turns into an energy system model when coupled with MACRO (a macroeconomic CGE module), and is similar to the International Energy Agency's World Energy Model (OECD and IEA, 2012). These models optimize energy supply to minimize production costs, or, more specifically, MARKAL is a "partial equilibrium bottom-up energy system technology optimization model employing perfect foresight and solved using linear programming" (Loulou et al., 2004). The structure of MARKAL and its many derivative models is very detailed and takes into account primary energy sources as well as secondary ones, representing every step of the conversion process of various energy forms. The structure of the model can be modified according to the availability of energy sources and processes used in the selected area of study, and a modular approach is usually adopted (Loulou et al., 2004). The main exogenous assumptions used in energy system models include economic growth (e.g., based on the work of the OECD, IMF and World Bank), demographics (e.g., from the United Nations Population Division), international fossil fuel prices and technological developments. Macroeconometric models can also be used to project energy demand, such as in the case of the Energy-Environment-Economy (E3) model at global level (E3MG) (Barker and Scrieciu, 2010).

Other examples of energy system models more commonly used at the national level include WASP (IAEA, 2001) and LEAP (Heaps, 2012). The former is intended for long-term electricity generation planning including environment analysis. The latter is a tool for integrated energy planning (including demand and supply) and greenhouse gas mitigation assessment, applicable at local, national and regional levels.

Figure 5. World Energy Model overview (OECD/IEA, 2012)

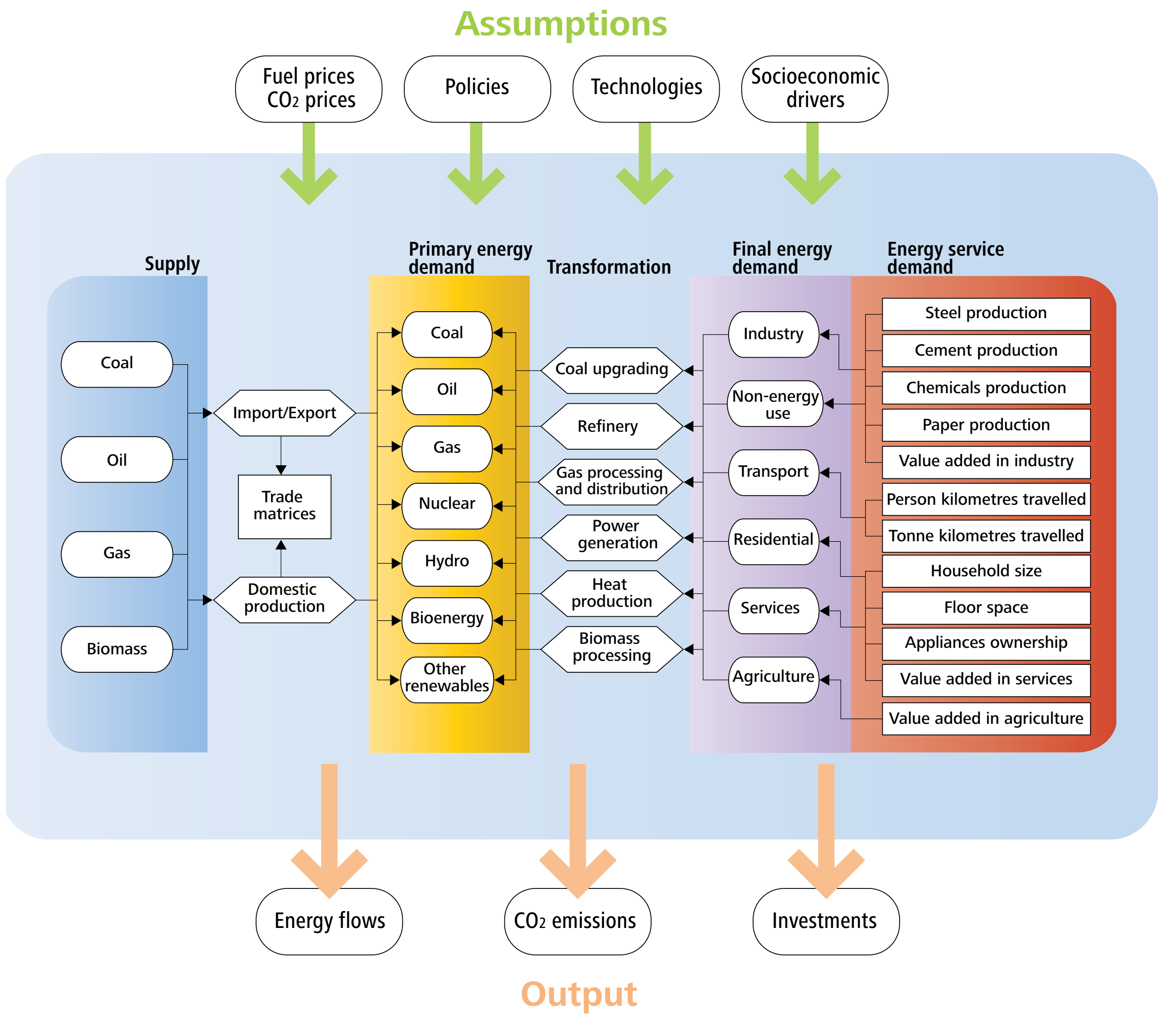


Table 3. Assessment of model creation and use: Energy analysis with MARKAL/TIMES, WASP and LEAP

Model creation	Country applicability	Easily applicable, as all energy sectors have roughly the same structure
	Ease of customization	Standard framework; easily adjustable based on data availability and structure of the energy sector
	Multi-stakeholder consultation	Generally limited to the energy sector
	Transparency	Transparent, but requires knowledge of the energy sector
	Data needs	Generally heavy, but information is normally available
	Time of implementation	In the order of weeks for sectoral analysis, or months when coupled with macroeconomic modules
	Sectoral coverage	Generally narrowly focused on energy and emissions
Model use and IP support	Time horizon	Medium to longer term
	Effort for maintenance	Minimal once the model is created – updates are not time consuming unless model expansions are needed; requires proficiency with modelling techniques
	Complementarity	Medium; energy analysis is often coupled with other planning exercises
	Audience (multi-stakeholder involvement)	Medium; energy is relevant to several sectors, but the policy analysis is carried out at the sectoral level
	IP support	Primarily focused on policy formulation and assessment; may help with issue identification (for emerging trends)

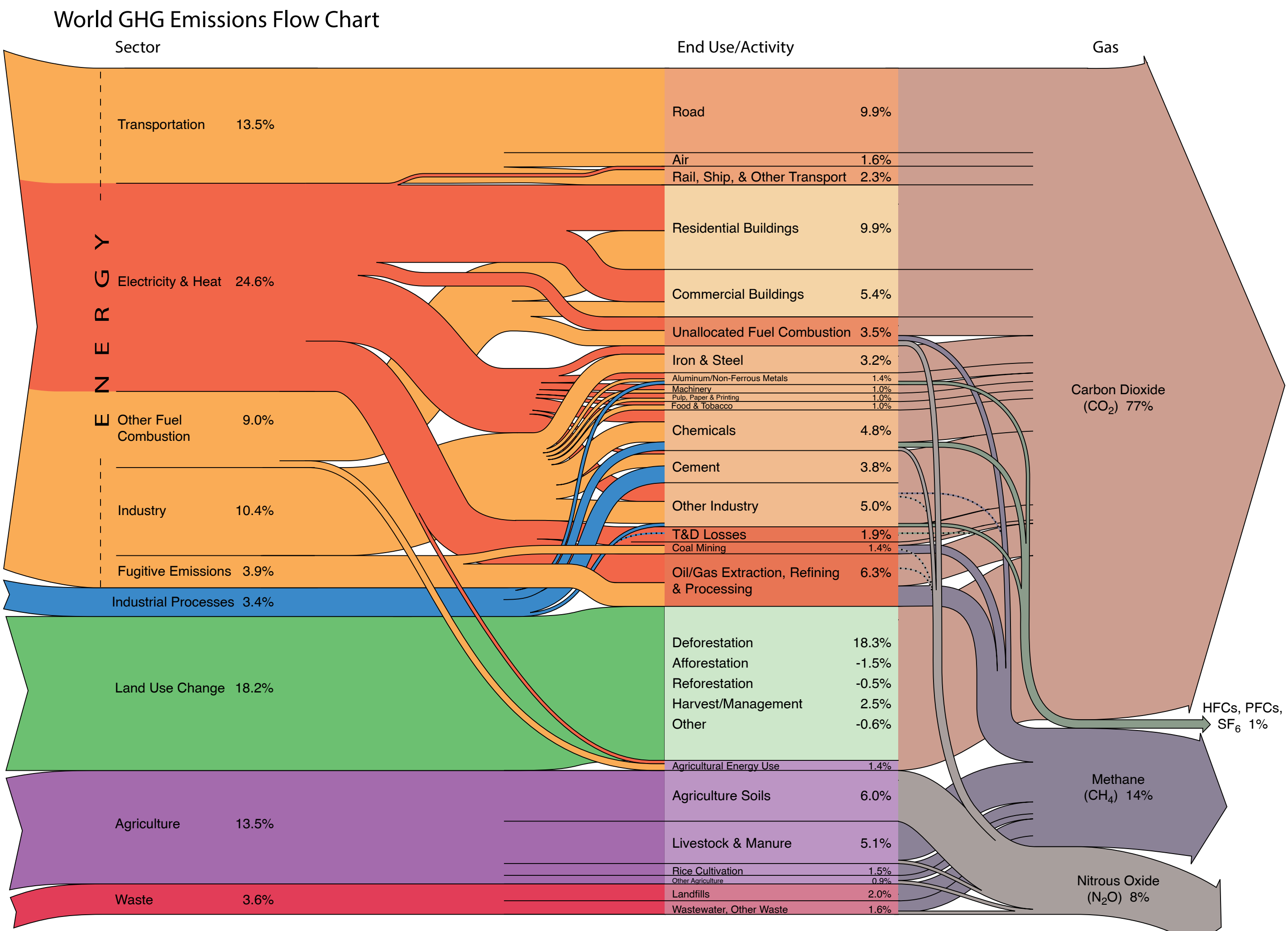
CGE models are instead top-down models based on the economic structure and technologies of a reference year. Deviating from this equilibrium is possible through substituting energy inputs with capital inputs (technique effect) or by shifting demand to less carbon-intensive sectors (composition effect) (Johansson et al., 2012). Both effects are driven by changes in relative prices rather than by changes in the energy supply mix.

Energy system models can also combine several methodologies to estimate demand and supply. For instance, while optimization is often used for estimating supply, econometrics (e.g., ENPEP, see CEEESA, 2008), general equilibrium (optimization, e.g., MARKAL MACRO, see Johansson et al., 2012, and Fishbone and Abilock, 1981) and simulation (e.g., NEMS and certain versions of T21, see EIA, 2009) are all used to estimate demand.

4.1.3 Emissions and material flows with I-O

Since the early 1990s, I-O analysis has been widely used for environmental accounting, such as in carbon footprint assessment and the calculations of embodied emissions and virtual water at the sectoral level for a nation, a region or multiple regions, depending on the purpose of the research (IGES, 2010). More specifically, environmental applications of I-O models include accounting of ecological footprints, embodied emissions and embodied primary resources, material flows, life cycle impacts of products, and waste flows. The principles for life cycle assessments and carbon footprints are also featured in ISO International Standards, in this specific case ISO 14044 and 14067 respectively.

Figure 6. World GHG emissions flow chart, 2000 (World Resources Institute, 2005)



Sources & Notes: All data is for 2000. All calculations are based on CO_2 equivalents, using 100-year global warming potentials from the IPCC (1996), based on a total global estimate of 41,755 $MtCO_2$ equivalent. Land use change includes both emissions and absorptions; see Chapter 16. See Appendix 2 for detailed description of sector and end use/activity definitions, as well as data sources. Dotted lines represent flows of less than 0.1% percent of total GHG emissions.

Table 4. Assessment of model creation and use: Emissions and material flows with I-O

Model creation	Country applicability	Fully tailored to national statistics and market structure
	Ease of customization	Standard framework; easily adjustable based on data availability and knowledge of sectors/value chain
	Multi-stakeholder consultation	Limited, although various stakeholders may be involved if the table includes economic and biophysical indicators
	Transparency	Limited, due to the data manipulation, in particular the aggregation of products, processes and firms into sectors
	Data needs	Generally heavy, depending on the scope of the study
	Time of implementation	In the order of weeks or months, depending on data availability and the analysis to be carried out
	Sectoral coverage	Generally narrowly focused on economic or selected material flows, but could be cross-sectoral and multi-dimensional
Model use and IP support	Time horizon	Short term
	Effort for maintenance	High; once the table is created, new analysis can be carried out relatively quickly, but any update or extension is time consuming
	Complementarity	Difficult to fully incorporate in other modelling exercises due to the level of disaggregation of data, but its outputs can be used for several other types of analysis
	Audience (multi-stakeholder involvement)	Limited, although various stakeholders may be involved if the table includes biophysical indicators
	IP support	Primarily focused on policy assessment, but may be used for issue identification as well

One of the advantages of using I-O is that, "despite its conceptual and operational simplicity, it encompasses price and quantity relationships, production factors and technology, income distribution, labour and capital investments, international trade, dynamics and structural change" (Suh, 2009), within and across value chains. Further, in the case of environmentally extended I-O analysis, the carbon footprint is increasingly being recognized as a valuable indicator in the field of greenhouse gas emissions management, which aims to measure all the direct and indirect carbon emissions caused by consumption. The above indicates that I-O tables allow for estimating direct, indirect and induced impacts, with a high level of sectoral disaggregation.[13]

I-O models are commonly used to estimate the impact of policy implementation at the sectoral level, within and across value chains, and also to estimate potential leakages across countries.[14]

I-O tables for this type of analysis are often organized by industry. In the context of the green economy, definitions have to be clearly set and agreed upon, as the type of sectors analysed – such as environmental goods and services sectors – and the availability of data to represent their value chain, can represent a challenge for the quality and validity of the results obtained (Gibbons et al., 1982; Wiedmann, 2009). I-O tables that track material flows are also providing valuable support to studies relating to sustainable consumption and production (SCP), as well as to the more specific field of integrated waste management. Their ability to track activity at the sectoral level, using a matrix representing upstream and downstream flows, provides useful information for estimating the impact of policies in shifting production as well as consumption patterns (Pettit et al., 2010; Fiksel, 2010; Cimren et al. 2010; Fiksel and Bakshi, 2010).

4.1.4 Natural capital and ecosystem services with InVEST

Ecosystems, if properly managed, yield a flow of services that are vital to humanity, including the production of goods (e.g., food), life support processes (e.g., water purification) and life-fulfilling conditions (e.g., beauty, recreation opportunities), and the conservation of options (e.g., genetic diversity for future use, see MEA, 2005).

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

Overview of the InVEST model framework, input data, models and model output

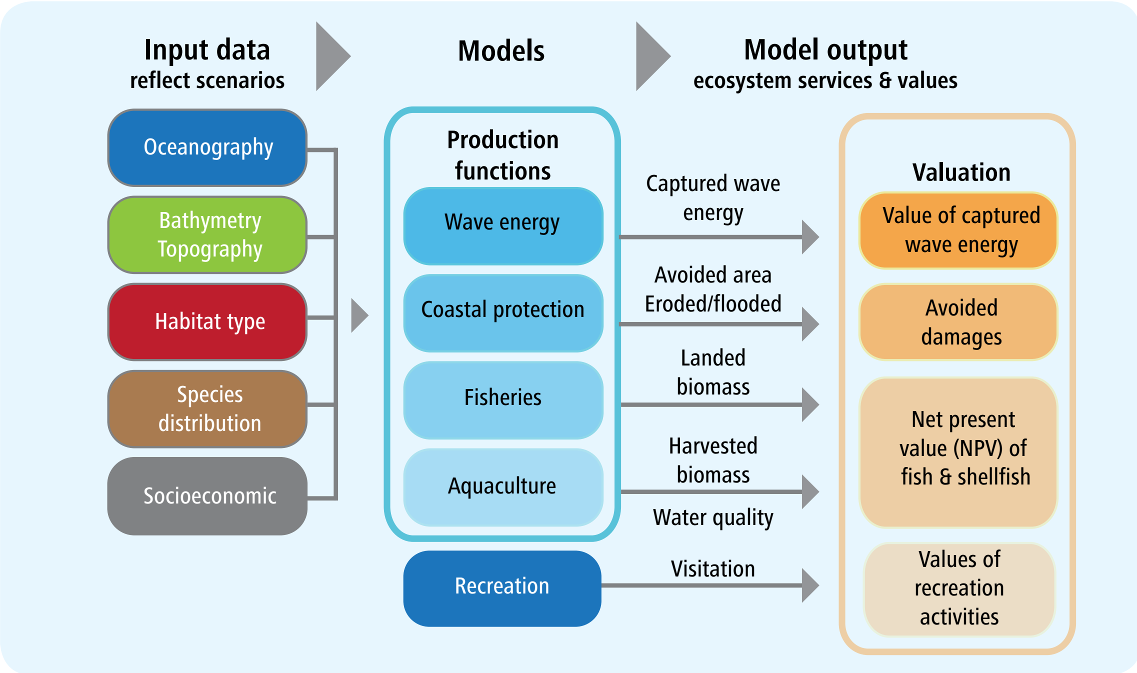


Figure 7. Overview of the InVEST approach (top) and example of output: Maps of nitrogen exports, where red is high and yellow is low, for three watersheds, 2009 and 2020 (Van Paddenburg et al., 2012)

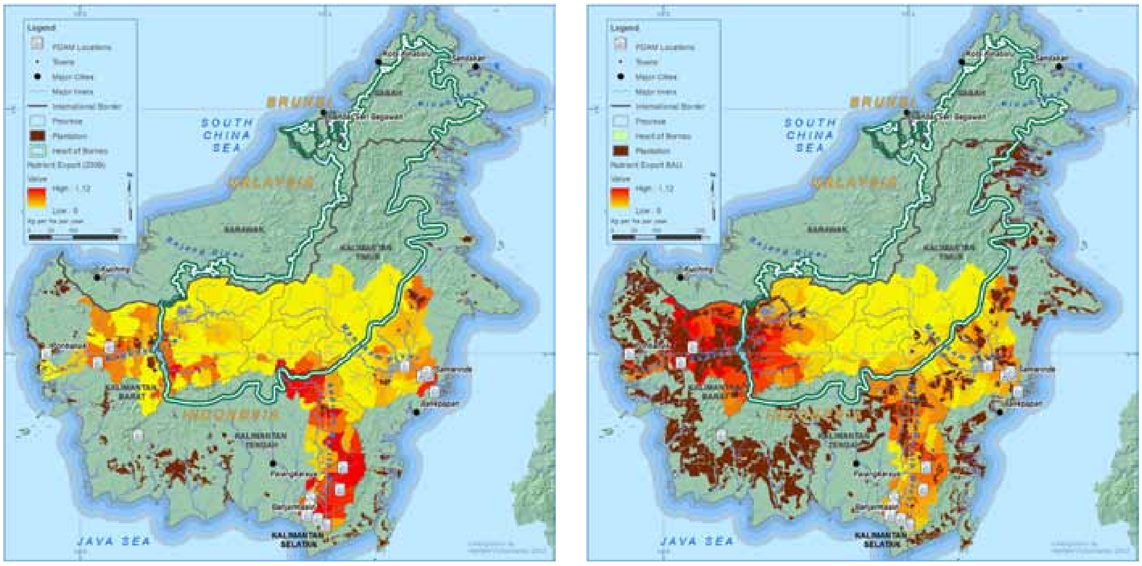


Table 5. Assessment of model creation and use: Natural capital and ecosystem services with InVEST

Model creation	Country applicability	Fully tailored to national context
	Ease of customization	If data are available and scales are consistent, the customization to a local context can be done effectively
	Multi-stakeholder consultation	Potentially high, in understanding spatially disaggregated data, across sectors
	Transparency	Highly transparent, with extensive user guide for model documentation
	Data needs	Cannot be customized without spatial data; potentially heavy data needs, depending on the scope of the study
	Time of implementation	In the order of weeks to months, depending on data availability and scope of the analysis
	Sectoral coverage	Despite the reliance on spatial data (natural capital), potentially high cross-sectoral coverage (e.g., economic)
Model use and IP support	Time horizon	No limitation; short, medium and longer term
	Effort for maintenance	Low for running the model (input data does not change with software update) and medium for expanding the model; training is required, as skills are often not available at the country level
	Complementarity	High; its outputs could be used as inputs for many other types of analysis
	Audience (multi-stakeholder involvement)	Potentially high, in understanding consequences of policy implementation on spatial development
	IP support	Focused on problem identification, policy formulation and monitoring and evaluation

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.

Coupled with stakeholder consultations and scenario development, InVEST can estimate the amount and value of environmental services that are currently provided or in future scenarios. In this respect, government agencies could use InVEST to help determine how to manage lands, coasts and marine areas to provide an optimal mix of benefits to people, or to help design payments for ecosystem services or permitting and mitigation programmes that sustain nature's benefits to society.[15]

InVEST models are spatially explicit, using a combination of maps and tables as information sources and producing maps as outputs. InVEST returns can result in 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 data sets exist,[16] allowing users to address questions on a local, regional or global scale.

The InVEST toolset includes models for quantifying, mapping and valuing the benefits provided by terrestrial, freshwater and marine systems. Specifically, it includes models for coastal vulnerability, coastal protection, marine habitat risk assessment, terrestrial biodiversity, carbon storage and sequestration, and water provisioning and purification through nutrient and sediment retention, as well as timber production and crop pollination.

Despite the depth of the analysis generated, InVEST is not very data-intensive compared to other scientific models. The tool is freely available on the website of the Natural Capital Project and new modules are frequently added. One version of the tool can run on Arc-GIS and another newer version runs on its own platform, and can be used in combination with any free GIS viewer.

The project is a joint venture of The Nature Conservancy, WWF, University of Minnesota and Stanford University.

4.1.5 Integrated sectoral assessment with system dynamics

System dynamics is a flexible methodology that allows for fully incorporating biophysical variables in monetary models, and vice versa. Making use of this strength of the methodology, sectoral models can be developed that represent key sectoral causal relations (i.e. the main drivers of change) and their cross-sectoral linkages, by explicitly accounting for feedbacks, delays and non-linearity through the representation of stocks and flows. These models allow for limiting the boundaries of the analysis to the sector, without excluding the impacts that a policy might generate across sectors.

Several models have been created to date using this methodology, including energy, agriculture and waste and water management, and all are fully tailored to the problem to be analysed and the local context (see, for instance, UNEP, 2013a; Bassi et al., 2009a). By explicitly representing causal relations, effectively being descriptive models (as opposed to prescriptive) and incorporating social, economic and environmental indicators, they support multi-stakeholder participation and consensus-building (see, for instance, Bassi et al., 2009). For these reasons, and for their ease of customization and use, sectoral system dynamics models have been used to support green economy assessments in several countries in Central and Latin America, Africa, Eastern Europe and South-East Asia.

Thanks to the flexibility of the approach, the level of detail of these models can vary greatly, and they can incorporate elements of optimization and econometrics, as well as integrate I-O tables and couple with spatial models (Van Paddenburg et al., 2012).

With respect to the green economy, the main outputs of these models 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., agricultural yield and production), direct employment creation and relative income generated, and eventual natural capital improvements (on stocks, flows and ecosystem goods and services).
- Avoided costs include savings from avoided energy consumption (e.g., through energy efficiency

Figure 8. Key outputs of the analysis for a sectoral study on energy, including both demand and supply

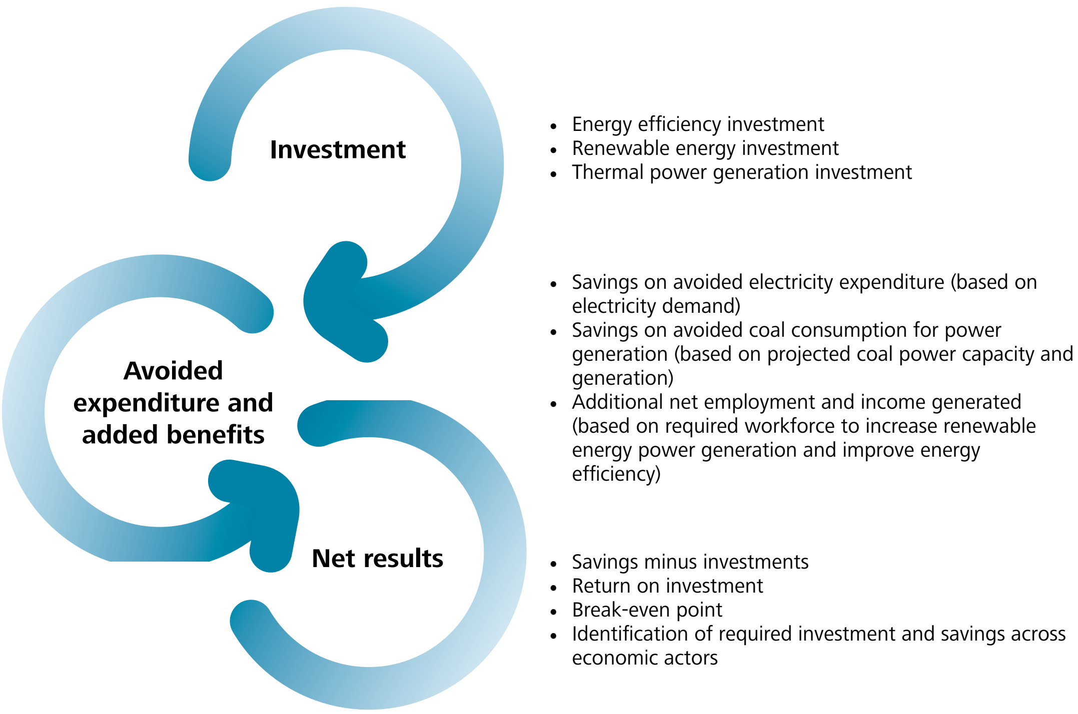


Table 6. Assessment of model creation and use: Integrated sectoral assessment with system dynamics

Model creation	Country applicability	Fully tailored to issues to be analysed
	Ease of customization	With key indicators and a good understanding of the functioning of the system, easy customization
	Multi-stakeholder consultation	Broad, to capture cross-sectoral drivers and effects
	Transparency	Highly transparent
	Data needs	Medium; a causal descriptive model does not require full time series and a large set of data
	Time of implementation	In the order of weeks
	Sectoral coverage	Focused primarily on one sector, but with relevant cross-sectoral links
Model use and IP support	Time horizon	Generally medium to longer term
	Effort for maintenance	Medium, depending on whether the structural drivers of the system change over time; little knowledge of modelling required to run the model and analyse result
	Complementarity	High; other methodologies can be incorporated in this model, and other models can be coupled with it
	Audience (multi-stakeholder involvement)	Broad, as it captures cross-sectoral drivers and effects
	IP support	Potentially capable to support all stages of the policy making process, depending on model design

interventions, or due to the switch to renewable sources from fossil fuel), and potential avoided ecosystem restoration and replacement costs.

— These added benefits and avoided costs are compared with investments and costs, as potential damages may be created by the policy implemented.

These results allow for estimating the economy-wide social, economic and environmental impacts of green economy policy interventions. Indicators include biophysical variables, which drive economic performance, such as the annual and cumulative cash flow of the project/policy, from the perspective of the government, households and the private sector. The return on investment and the break-even point are also estimated, as well as returns on employment and emissions, for example.

These indicators actively contribute to policy formulation, as they can indicate what the economic impacts across economic agents are (see, for instance, Mihajlov et al., 2012.). As a result, it is easier to identify funding sources, or financing mechanisms, to ensure the effective design implementation of green economy interventions.

4.2 NATIONAL, CROSS-SECTORAL FOCUS

4.2.1 National economic trends and regional dynamics with CGEs

A computable general equilibrium model is a representation of the main economic flows within and across the key actors of the national economy. The model couples equations to an economic database, using the SNA, the SAM and I-O tables as pillars. In this respect, CGEs take I-O tables and SAMs a step forward, allowing for generating future projections while ensuring internal consistency.

There are many CGE models available today, and most governments use them to generate short- to medium-term economic projections. The most notable CGE model is global, the GTAP (Global Trade Analysis Project), which lends its database to several country applications. Also, the World Bank's MAMS is available for over 50 developing countries (Lofgren and Diaz-Bonilla, 2010).

CGE models analyse the impact of shocks to the systems (a shock being a policy or an external intervention), using elasticities to relate the change in one variable to other variables. Impacts can be estimated nationally

Figure 9. Flow of marketed commodities in IFPRI CGE model (Lofgren et al., 2002)

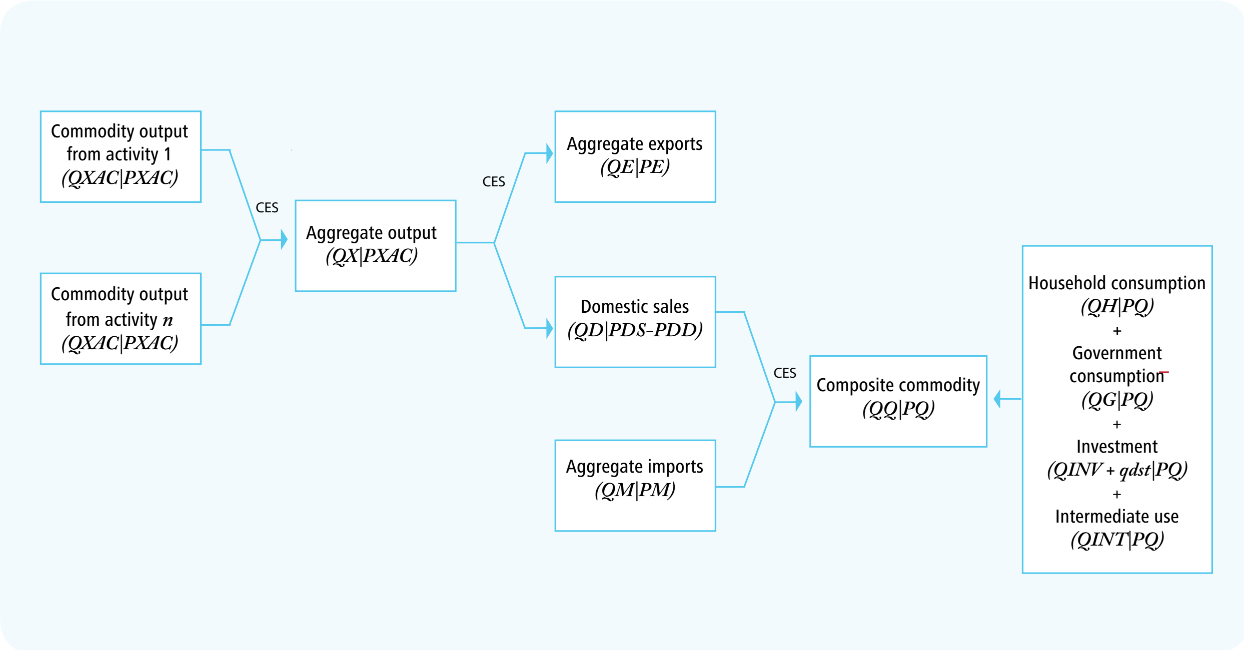


Table 7. Assessment of model creation and use: National economic trends and regional dynamics with CGEs

Model creation	Country applicability	Generally a standard framework, based on national accounting practices
	Ease of customization	Model designed based on national statistics; can be customized
	Multi-stakeholder consultation	Broad, covering the economy in its entirety, but primarily on economic policy/interventions
	Transparency	Largely a “black box”
	Data needs	Heavy; high reliance on data
	Time of implementation	In the order of months
	Sectoral coverage	Narrowly focused on the economy, but detailed representation of economic sectors and actors
Model use and IP support	Time horizon	Medium to longer term; at times used for short-term analysis as well
	Effort for maintenance	Medium, based on the availability and consistency of country statistics (calibration may be very time consuming in this respect); modelling skills often available at the country level
	Complementarity	Medium; its results can be used by other studies
	Audience (multi-stakeholder involvement)	Broad, covering the economy in its entirety
	IP support	Primarily focused on policy formulation and assessment

or across countries, and CGE models can represent in detail sectors, commodities and types of household, for example.

These models are widely used to analyse the aggregate welfare and distributional impacts of policies whose effects may be transmitted through multiple markets, or contain provisions for different tax, subsidy, quota or transfer instruments (Sue Wing, 2004). The three conditions of market clearance, zero profit and income balance are employed by CGE models to solve simultaneously for the set of prices and the allocation of goods and factors that support general equilibrium, but these theoretical assumptions must not hold in the political reality.

CGEs can be static (e.g., see Löfgren et al., 2002, for the IFPRI model) or dynamic (e.g., MAMS). The difference lies in the inclusion of (recursive) dynamics (i.e. a time dimension) for the generation of projections that accumulate (or consider previous) change over time.

Among the main characteristics of these models are the predominant focus on economic variables (e.g., targeting the economic value of the production and trade of natural resources, rather than the material flow), the reliance on equilibrium and therefore an implicit assumption that the capacity to get external or internal resources is unlimited at the country level (unless explicitly specified), and the generation of scenarios that heavily relate to history, with limitations in analysing cases of emergent behaviour. For these characteristics, and also adding a high level of detail provided for economic analysis, CGE models have been consistently used in ministries of finance to support budgetary processes at the country level.

4.2.2 Integrated regional planning and scenarios with ENV-Linkages

The OECD ENV-Linkages is an economic general equilibrium (GE) model that describes how economic activities are linked to each other across sectors and regions (OECD, 2012). This model, and especially how it is linked with several other ones, is proposed as an example of the group of integrated assessment models.[17]

In fact, while ENV-Linkages uses economic activity to project environmental pressures, specifically on

Figure 10. The modelling framework for the OECD Environmental Outlook to 2050 (OECD, 2012)

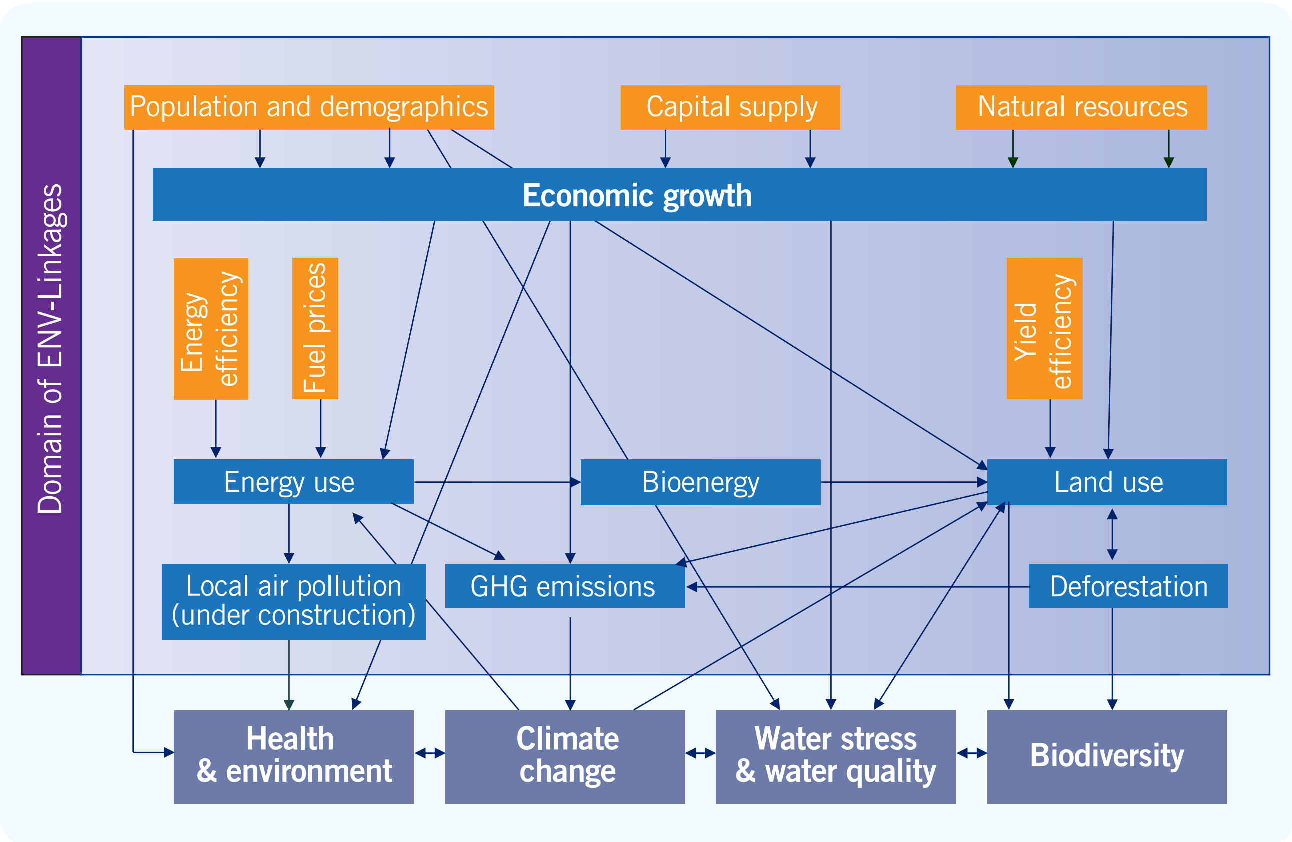


Table 8. Assessment of model creation and use: Integrated regional planning and scenarios with ENV-Linkages

Model creation	Country applicability	Standard framework; includes the main drivers that apply to most countries
	Ease of customization	Model designed for regional analysis and national benchmarking; not easily customized
	Multi-stakeholder consultation	Broad, covering the economy in its entirety
	Transparency	Largely a "black box"
	Data needs	Heavy; high reliance on data
	Time of implementation	In the order of months for development, but model already available for simulation and analysis of results
	Sectoral coverage	Broad, cross-sectoral coverage
Model use and IP support	Time horizon	Medium to longer term
	Effort for maintenance	Medium, but carried out in-house at OECD and other research organizations; knowledge barriers are difficult to overcome for institutionalization at the country level
	Complementarity	Medium; its results can be used by other studies, but technical integration requires high proficiency in modelling
	Audience (multi-stakeholder involvement)	Broad, covering the economy in its entirety
	IP support	Primarily focused on policy formulation and assessment; scenarios can also be used for problem identification

GHG emissions, a fully integrated assessment can be achieved by linking ENV-Linkages to models that describe the biophysical consequences of these environmental pressures, such as the IMAGE suite of models for land use (Kram et al., 2012), and partial models that contain detailed information on, for example, agriculture (LEITAP, with the OECD Trade and Agriculture Directorate) or the energy system (with the International Energy Agency for the World Energy Outlook). Overall, in its basic version, the underlying complexities of these additional models are approximated in ENV-Linkages in a stylized and aggregated manner where sector-specific transformation elasticities are used to represent land use changes.

ENV-Linkages is a global economic model built primarily on a database of national economies. The core of the static equilibrium is formed by the set of SAMs that describes how economic sectors are linked; these are based on the GTAP database. Many key parameters are set on the basis of information drawn from various empirical studies and data sources.

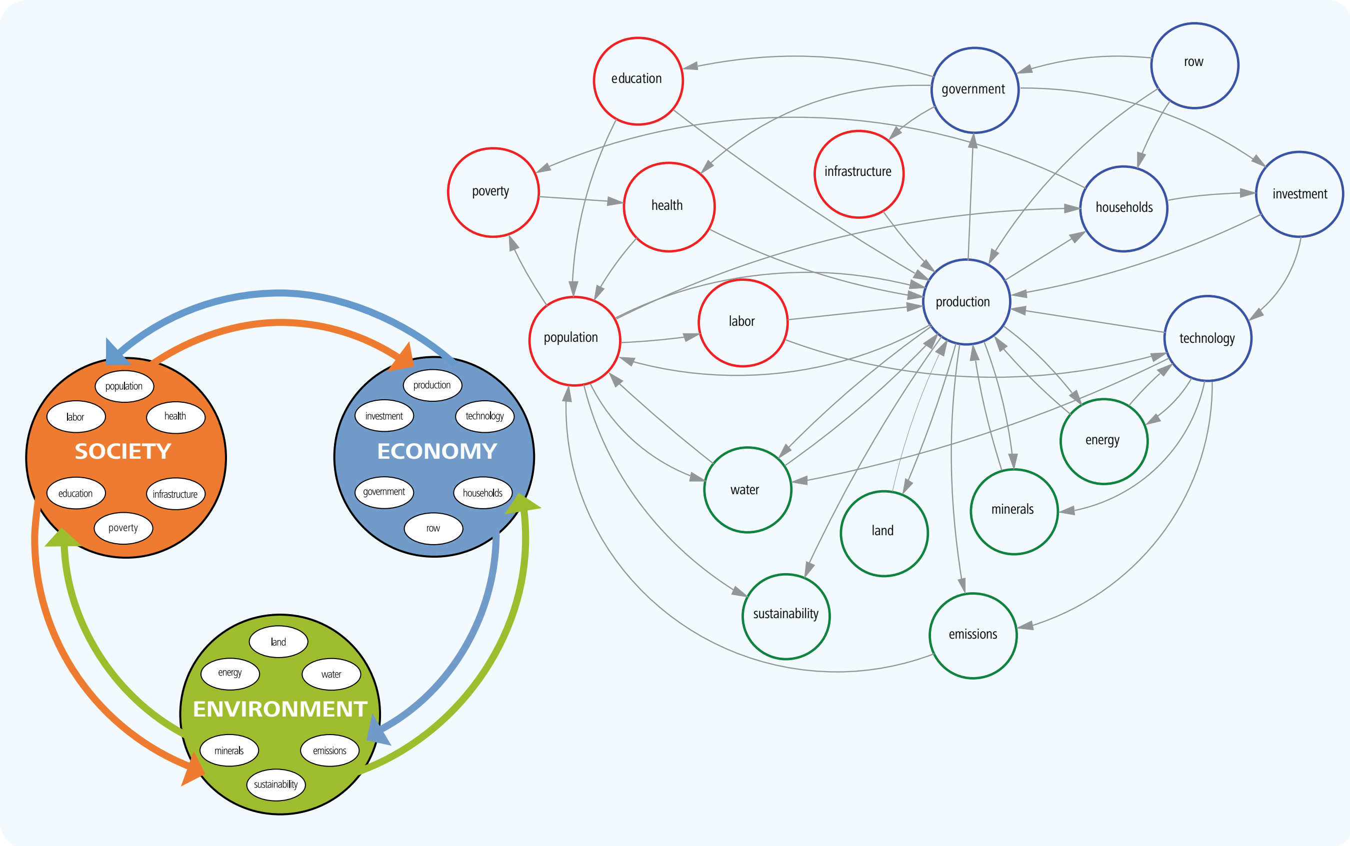
The model includes full government and households accounts, and production is assumed to operate under cost minimization with an assumption of perfect markets and constant returns to scale technology. Beyond the economy, the land-based sectors, including three agricultural sectors and forestry, provide direct links to indicators for climate change (e.g., emissions from deforestation), biodiversity (e.g., land under forest cover) and water. The energy sectors contribute to the estimation of CO_2 emissions. Other GHG emissions are linked to output.

The advantages of multi-sectoral, multi-regional dynamic GE models like ENV-Linkages are several, and include their global dimension, their overall consistency and the fact that they build on rigorous microeconomic foundations. These models are best suited for analysing the medium-term implications of large policy shifts requiring significant reallocation across sectors and countries/regions, as well as the associated spillover effects.

4.2.3 Long-term national planning with Threshold 21

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

Figure 11. Subsystem diagramme of the Threshold 21 model



T21 is, in the vast majority of cases, a country model explicitly representing stocks and flows (running differential equations), and integrating economic as well as biophysical variables in a single framework of analysis (Bassi, 2010).

The development of each national T21 model starts with the implementation of a Starting Framework, which is subsequently customized to capture the peculiar issues of the country being analysed. The T21 Starting Framework is a relatively large size model, comprising more than a thousand equations, about 60 stock variables, and several thousand feedback loops. The model is built on three spheres – society, economy and environment – which are further broken down into sectors and modules.

The economy sphere contains major production sectors (agriculture, industry and services), which are characterized by Cobb-Douglas production functions. A simplified SAM is used to elaborate the economic flows and to balance supply and demand in each of the sectors. The social sphere contains a demographic model, and calculates for example employment, education (both demand and supply) and health. The environment sphere tracks CO_2 and GHG emissions from fossil fuels, as well as consumption of natural resources (both renewable and non-renewable), such as land use, energy and water.

The structure of the individual modules is based on well accepted work in the field, "translated" in stock and flow language by modellers, and integrated with ad hoc research. As a result, the T21 model is an effective knowledge integrator that prioritizes horizontal integration and dynamic complexity, over vertical disaggregation and detailed complexity. Further, every T21 application is customized at the country level (see, for instance, Bassi et al., 2011; UNEP, 2013).

T21, and all other system dynamics models, are "causal-descriptive" (theory-like, "white-box"). In this respect, it represents a statement as to how real systems actually operate in some aspects. The lack of extensive reliance on historical data requires two layers of validation for T21: structural (i.e. equations) and behavioural (i.e. projections) (Barlas, 1996). In fact, generating an "accurate" output behaviour is

Table 9. Assessment of model creation and use: Long-term national planning with Threshold 21

Model creation	Country applicability	Uses a starting framework created for developing countries, then tailored to the issues to be analysed
	Ease of customization	With key indicators and a good understanding of the functioning of the system, elaborate customization
	Multi-stakeholder consultation	Broad, to capture cross-sectoral drivers and effects
	Transparency	"White box", but requires knowledge of the methodology/software to be perceived as transparent
	Data needs	High; a causal descriptive model with high cross-sectoral representation
	Time of implementation	In the order of months (four to eight)
	Sectoral coverage	Broad, incorporating social, economic and environmental sectors
Model use and IP support	Time horizon	Medium to longer term
	Effort for maintenance	High; while modelling may not be extensive, the lack of knowledge of the methodology and model at the country level is an important constraint
	Complementarity	High; other methodologies can be incorporated in this model – it is harder to incorporate T21 in other studies
	Audience (multi-stakeholder involvement)	Broad, as it captures cross-sectoral drivers and effects
	IP support	Potentially capable to support all stages of the policymaking process

not sufficient for model validity; what is crucial is the validity of the internal structure of the model. In short, it is often said that a system dynamics model must generate the "right output behaviour for the right reasons".

The most important application of T21 is contributing to the national planning process. T21 is also a valuable tool for conducting stakeholder consultations with an inclusive and participatory approach.

4.2.4 System-wide assessment of land-use scenarios with WWF HoB

Three models were used to develop and analyse various impacts of selected spatial development scenarios in the Heart of Borneo (HoB), and more specifically in Kalimantan, Indonesia. The models forming the HoB modelling framework are:

- IDRISI Land Change Modeler (LCM)
- Integrated Valuation of Ecosystem Services and Trade Offs (InVEST)
- System dynamics macroeconomic model

Land cover and land use data represent fundamental sources of information for the analysis of interventions influencing land use and biodiversity, and are critical for the effective use of the three tools listed above. Satellite earth observation provides the most cost-effective, timely and accurate source. The ESA GlobCover provided time series land cover data, as did the Indonesian Ministry of Forestry. A biomass map from SARVISION derived using ALOS PALSAR data and a biomass map produced by Biotrop were also analysed in relation to the global climate regulation benefits provided by the HoB (Clark Labs, 2009; van Paddenburg et al., 2012).

LCM is a tool used to develop spatially explicit and contrasting scenarios of future development. LCM allows for projecting future land cover based on historical, observed land cover change and other potential drivers of change. LCM provides tools to model land cover transition potentials that express the likelihood that land will transition in the future using, for the HoB analysis, logistic regression.

InVEST, which was presented in section 4.1.4, is a GIS toolbox that contains models to map the distribution of carbon stocks and sequestration, water yield, sediment export and retention, and nutrient (pollution) export and retention, and to assess how these could change under the spatially explicit and contrasting scenarios developed through LCM. Using GIS, it is possible to overlay the distribution of different services produced

Figure 12. Simplified causal loop diagramme highlighting the main systemic relations between natural capital and key socioeconomic and environmental variables on Borneo (van Paddenburg et al., 2012)

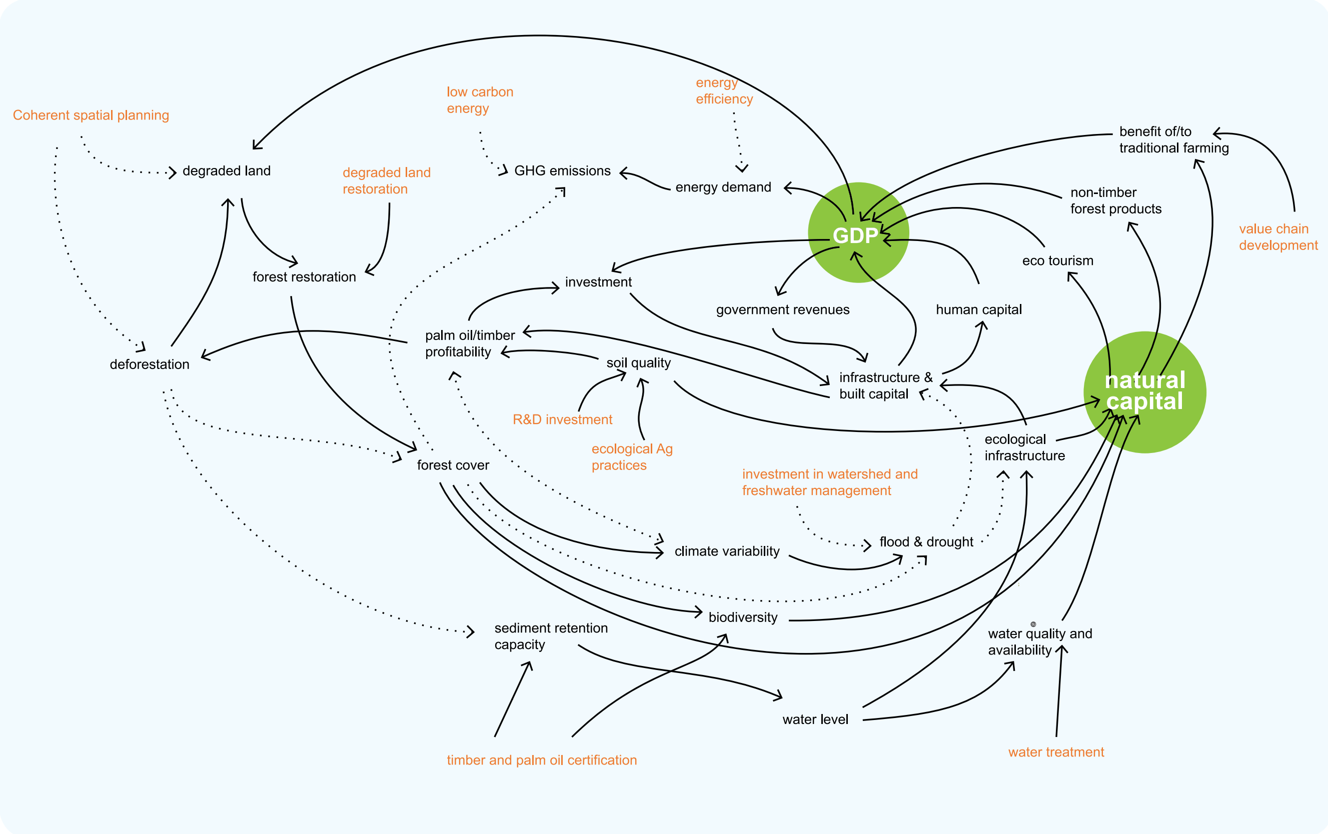


Table 10. Assessment of model creation and use: System-wide assessment of land use with WWF HoB

Model creation	Country applicability	Fully tailored to national context
	Ease of customization	Easy customization of InVEST; medium effort in coupling it with a system dynamics model
	Multi-stakeholder consultation	Broad, in understanding spatially disaggregated data, and capturing cross-sectoral drivers and effects
	Transparency	Highly transparent, but requires basic training for full understanding of the methodology
	Data needs	Generally heavy (due to the need for data for several sectors), depending on the scope of the study
	Time of implementation	In the order of months, depending on data availability and scope of the analysis
	Sectoral coverage	High cross-sectoral coverage
Model use and IP support	Time horizon	No limitation; short, medium and longer term
	Effort for maintenance	Low for running the model (input data does not change with software update) and medium for running new scenarios that require an expansion of the spatial model
	Complementarity	High; its outputs could be used by many other types of analysis, and other methodologies can be incorporated
	Audience (multi-stakeholder involvement)	High, in understanding consequences of policy implementation on spatial development, across-sectors
	IP support	Potentially capable to support all stages of the policy making process, depending on model design

by InVEST to assess trade-offs and synergies across these services under the two scenarios and identify areas where multiple services are provided. Such analyses help to target specific areas for implementing programmes to maintain, restore and enhance the provision of ecosystem services. In combination, LCM and InVEST are useful GIS tools to develop scenarios and assess the impact of changes in ecosystem services under two contrasting futures.

The most important contribution of the system dynamics model is its systemic structure that includes endogenous links within and across the social, economic and environmental sectors through a variety of feedback loops. Through the use of endogenous formulations, and by using the results of LCM and InVEST (aggregated and used as inputs for the simulation of scenarios) the model provided information on the socioeconomic repercussions of various scenarios, highlighting key systemic drivers (both reinforcing and balancing) that would influence future scenarios.

Used in combination, the above methods enabled the generation of broad, cross-sectoral spatial scenarios addressing social, economic and environmental issues in a single coherent framework for analysis. The same approach can also be applied to analyse the impact of specific infrastructure projects, and their short-term versus long-term direct, indirect and induced socioeconomic and environmental impacts.

4.3 COMPARATIVE ASSESSMENT

A comparative assessment of the models is provided in Table 11, which shows how models include the different dimensions relevant to the green economy. No model can capture all the facets of the green economy. However, CGEs coupled with sectoral biophysical models (e.g., energy, water and land use) and system dynamics could potentially satisfy most criteria if some information from the other models is available (e.g., InVEST, concerning natural capital).

More specifically, I-O models can provide a high level of sectoral disaggregation and generate results analysed 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, 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 green economy 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 analysing impacts, mitigation (especially sinks, through land use) and adaptation options. Spatial models are generally better suited to analyse 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 estimating income distribution). Human capital can also be estimated, despite methodological constraints, regarding employment and 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 for a fuller estimation of competitiveness, 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 analyse 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 analysed from a macro perspective, tracking consumption of the most relevant inputs to production (especially natural resources). Further, competiveness 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 a model, criteria which relate primarily to the problem to be analysed, the stage of the policymaking process to influence and the constraints related to timing, budget and human resources (e.g., local knowledge of modelling techniques and time availability). The relevance of the context in which these models would be used is presented in the next chapter.

Table 11. **Review of models for green economy analysis; relevance to the green economy definition and assessment**

		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	Sustainable Consumption and production	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	✓	✓	*	✓	✓	*	✓	*	✓	*	*	✓	✓	✓	✓

The * indicates the possibility to include basic variables and to address the criteria more extensively with information generated by other models.

5 Relevance by country context

Every country faces challenges that are made unique by the distinctive characteristics of its society (including cultural values and institutional arrangements), economy and environment. Depending on the problems to be solved, and the policymaking process in which the country is embedded (or embarking), certain methodologies and models may be more useful and timely than others in informing decision-making.

It is acknowledged that nearly all countries would make use of an I-O framework for the analysis of green jobs, system engineering models for planning in the energy and water sectors, InVEST for natural capital assessments, CGE models for budgetary purposes, and perhaps T21 for long-term planning exercises. Nevertheless, five mock countries are further analysed, and a few of their unique characteristics are used, to assess the potential contribution and relevance of methodologies and models to their green economy transition. There are several more models than the ones presented in this study that could be used to carry out a similar (if not the same) analysis required to address the issue mentioned below.

LAND-LOCKED, DRY AND SUB-HUMID COUNTRY WITH A DOMINANT AGRICULTURE SECTOR AND IN EARLY PHASES OF DEMOGRAPHIC TRANSITION AND URBANIZATION

With the predominant role of the agriculture sector, and given the water profile of the country, an assessment of land productivity in relation to the impacts of climate change, water availability and ecosystem services with InVEST and sectoral models could effectively support development planning. With a likely rapidly changing socioeconomic path, budgetary planning would be relevant, requiring CGE models to effectively allocate resources across sectors and provide public services to the population. System dynamics would complement the planning exercise, to ensure that short-term budgetary decisions are aligned with a longer-term vision. In this respect, the environment needs to be fully incorporated in national planning by bridging science and policy, and by analysing policy impacts in both economic and biophysical terms.

Problem: Decreasing agricultural production
Causes: Water shortages in the country are caused by changing rainfall patterns (shifting rainy seasons and higher rainfall variability) and obsolete irrigation systems, as well as insufficient (or absent) rainwater harvesting systems. The result of changing precipitation trends and obsolete infrastructure lead to the inefficient use of water with high loss and evaporation, causing land erosion and ecosystem degradation that directly impacts agriculture production. Additional impacts can be observed on the economy (with lower income for farmers, as well as forced migration from rural to urban areas where unemployment is higher), society (with lower food security and negative impacts on nutrition, but also on access to clean water and sanitation) and the environment (with soil erosion and desertification).

TROPICAL OR SUB-TROPICAL SMALL ISLAND DEVELOPING STATE WITH DOMINANT TOURISM AND FISHERIES

With the heavy reliance on tourism and fisheries, natural capital is extremely important for small island states. These countries are also highly vulnerable to climate change and the macroeconomic trends of their main trading partners. The identification of key indicators for policy formulation and assessment, coupled with the use of InVEST and system dynamics, would support the country to identify and monitor natural capital as an asset for competitiveness and subsistence. Medium- and longer-term planning would be of primary importance, as well as trade (with the help of CGE models), for the economic prosperity of the country. Fully incorporating the environment (especially ecosystem services) in national planning

Problem: Declining trend of fish landings
Causes: The reduced fish catch is due to ecosystem degradation, in turn caused by unsustainable tourism practices, overfishing and climate change. Impacts are visible on the economy (reduced fish production), society (food insecurity) and the environment (reduced ecosystem services from coral reefs, mangroves, poor fish regeneration, etc.).

would support social and inclusive development, while increasing resilience.

LOW-LYING COASTAL, MIDDLE-INCOME COUNTRY WITH RAPID INDUSTRIALIZATION AND URBANIZATION, AND RELATIVELY ADVANCED DEMOGRAPHIC TRANSITION

Industrialization is at the core of the economic development of the country, and emphasis should be put on competitiveness and employment creation. With economic growth being a key objective, CGE models and I-O frameworks should be used to support the budgeting process and monitor industrial development (regarding employment as well as pollution and material flows). In addition, due to the growing pressure of the industrial sector on natural resources and on the provision of basic services, more integrated approaches should be used, such as system dynamics models, to evaluate the impact of sectoral policies on the overall socioeconomic and environmental performance of the country. In a rapidly changing economic environment, short-term and long-term national planning are of equal importance, both affecting the use of natural resources and the provision of social services (a critical asset for competitiveness).

Problem: Increasing pollution and growing cost of living
Causes: Rapid, horizontal urbanization and fast industrialization are leading to an increase in the number of low-income families in urban areas. Energy and water have become expensive due to the pressure from the industrial sector (growing demand), and pollution is requiring increased public expenditure for water purification. Impacts are felt on health and on the quality of the environment.

MOUNTAINOUS COASTAL COUNTRY WITH MINING, AGRICULTURE AND FISHERIES

Ecosystems are key to the correct functioning of an economy highly reliant on natural resources to support itself and its well-being. With deforestation causing the disruption of the hydrological cycle, leading to soil erosion and more frequent and acute floods and droughts, the use of InVEST and integrated models would provide valuable information to policymakers in identifying the source of problems and designing interventions that would generate double and triple dividends. In this specific example, floods and droughts could cause soil degradation and lower agriculture production, while also reducing the potential for fish catch. To fully incorporate the environment in development planning, CGE models should be coupled with biophysical sectoral models. Further, system dynamics could be used to simulate the impact of new regulations on land use, and evaluate eventual system responses and potential side effects emerging in the medium and longer term. The impact of these interventions on specific sectors within the value chain of timber production (on employment and/or profitability) could be analysed with I-O models. This approach would create a bridge between a microeconomic analysis at the industrial level and a macroeconomic analysis at the national level, while merging economic and biophysical indicators in policy impact assessment.

Problem: Increasing frequency of floods
Causes: Floods are due to high deforestation in mountain ecosystems, caused by unsustainable mining activities. The impacts are felt on the environment (e.g., biodiversity, sedimentation and high vulnerability to atmospheric events), the economy (e.g., reduced use of rivers for transport, and more damage during extreme weather events) and society (e.g., decreasing cultural and economic values of mountain ecosystems, and possible displacement due to floods).

DEVELOPED COUNTRY WITH FEW NATURAL RESOURCES BUT HIGH POTENTIAL (AND FINANCIAL RESOURCES) FOR EFFICIENCY IMPROVEMENT

Developed countries can count on the availability of capital, technology and knowledge to stimulate innovation and remain competitive at the global level. However, efficiency is key, and several policies are being considered to stimulate investment in the substitution of outdated capital with a more energy-efficient one. This can be seen in the US and Europe, with targets for the energy efficiency of vehicles and their emissions level. Other examples in Europe and Japan include energy efficiency standards for appliances and energy consumption in residential and commercial sectors. In this case, the use of sectoral system engineering models for the energy sector would provide useful information on energy demand and supply, and the resulting market prices and consumer costs, when coupled with a CGE model.

Problem: Rising energy costs, with negative impact on investments and competitiveness
Causes: The intensive and inefficient use of fossil fuels, primarily for manufacturing, transport and power generation, is impacting the economy (e.g., increased production costs), society (e.g., rising transportation costs and growing cost of living) and the environment (e.g., growing GHG emissions and CO_2 concentration). Further, the incidence of disease related to air pollution is increasing, leading to higher health costs and lower labour productivity.

Further, CGE and system dynamics models could be used to carry out a specific policy analysis, such as the introduction of incentives from an economy-wide perspective. The impact of interventions aimed at stimulating a specific technology (e.g., solar water heating) could be analysed with I-O models, to assess changes in material flow, employment and profitability across the value chain. In the case of longer-term policy objectives, system dynamics models could support the analysis of the impacts (synergies and/or bottlenecks) that the energy sector may create across society, the economy and the environment, including health impacts and – making use of supplementary research – consequences on labour productivity.

6 Exploiting the complementarity of existing methodologies and models for a green economy assessment

The work of UNEP on the green economy has focused so far on filling gaps in the policy process to fully incorporate the environmental dimension in national planning. UNEP has highlighted the main policy interventions needed to appreciate emerging opportunities and to create new and more sustainable development paths. This has been accomplished through research, the identification and use of indicators, and the development and use of simulation models.

With respect to simulation models, gaps have been identified in the inclusion of the social and environmental dimensions of development in modelling exercises related to national planning, and in the use of long-term projections to inform policymaking. UNEP focused so far on the development of system dynamics models for:

- Their capability of integrating the economy, society and the environment in a single framework of analysis
- Their capability to involve a variety of stakeholders in the modelling process, making use of system thinking and through incorporating economic and biophysical indicators
- The existence of a model, T21, which already targets long-term development planning and avoids the need for creating new tools

Nevertheless, as the field of the green economy evolves and new challenges arise, it is becoming more and more evident – and not surprisingly so – that no perfect model exists, and that certain contexts might require a suite of highly customized models to effectively inform policymaking. Before model(s) can be selected, the goals and issues should be clearly identified and the state of the policymaking process analysed. It may well be that more than a model is needed to solve a given problem or support a single policy process, especially if cross-sectoral linkages are important and both short- and longer-term analysis is needed. In addition, certain governments may have already embarked on modelling work and might want to make use of their existing models and knowledge to support ongoing planning efforts. They may at the same time need to develop other models ad hoc. For these reasons, complementarity will play a key role in determining the usefulness of quantitative assessments for policy formulation and evaluation at the country level.[18]

Table 12 highlights the key commonalities and interdependencies of various models, indicating how apparently different streams of work can complement each other. This table should be analysed in conjunction with Table 11 (especially in relation to the asterisks presented in the table). While the specific technical characteristics and capabilities of each model are analysed in Table 11, the following one refers uniquely to the analysis that could originate from aligning the use of different models.

The complementarity of models in creating a coherent green economy analysis is evident when considering their sectoral coverage and time horizon, and also when taking into account their support to the policymaking process (see Table 1). Some models are better suited to help decision makers in the issue identification phase (e.g., the analysis of historical trends with InVEST), while others are designed to shape policy formulation (e.g., with the identification of goals and targets, as in the case of optimization). As mentioned above, an additional layer of complementarity is the time horizon of the analysis created with simulation models. Due to methodological characteristics (both strengths and

Table 12. Review of the complementarity of models in creating a green economy analysis

		Information provided				
Information received	**Model**	**Input-output (I-O)**	**Energy and other system engineering models**	**Geographical information system (GIS) and InVEST**	**Computable general equilibrium (CGE models)**	**System dynamics (SD) (e.g., T21)**
	Input-output (I-O)		Projections, planned capacity expansion*	Spatial distribution of employment, material flow	Projections, economic growth across sectors*	Projections, with feedbacks across sectors*
	Energy and other system engineering models	Energy flow, for value chain analysis		Water availability for cooling, proximity of transport means for fuels (e.g., coal)	GDP, for energy demand estimation	Socioeconomic impacts of energy choices, repercussions on energy demand
	Geographical information system (GIS) and InVEST	Employment in sectors affecting or impacted by the environment	Emissions and fuel/ water requirements from/for power generation		Economic growth	Socioeconomic impacts of environmental trends/ policies: direct, indirect and induced
	Computable general equilibrium (CGE models)	Employment and material flow (for extended CGEs)	Energy price (production cost) and investment information	Spatial information, natural resource stocks (for extended CGEs)		Long-term feedback responses (e.g., rebound effect)
	System dynamics (SD) (e.g., T21)	Employment, material and energy flow	Energy system structure, construction, and operation and maintenance costs	Spatial information, natural resource stocks, ecosystem services	SAM structure	

*Input-output tables generally only provide information to other models. These data, used as input, are then simulated using econometrics, optimization and system dynamics.

weaknesses), some models are better suited for short-term analysis (e.g., I-O), while others are designed to address medium- and longer-term trends (e.g., T21).

Three case studies are provided to highlight the potential of combining various models for a comprehensive green economy assessment. The first one refers to a specific problem or policy objective, namely fossil fuel subsidy removal. The second case study presents the national modelling framework developed for the Green Economy Assessment of Mexico, using several methodologies to integrate sectoral and macroeconomic, biophysical and monetary analysis. The third case study is more general in scope, and evaluates the interconnections between the economy, society and the environment at the global level, in the context of longer-term trends. Several additional examples are available to highlight the complementarity of modelling approaches, both at the national and sectoral level.

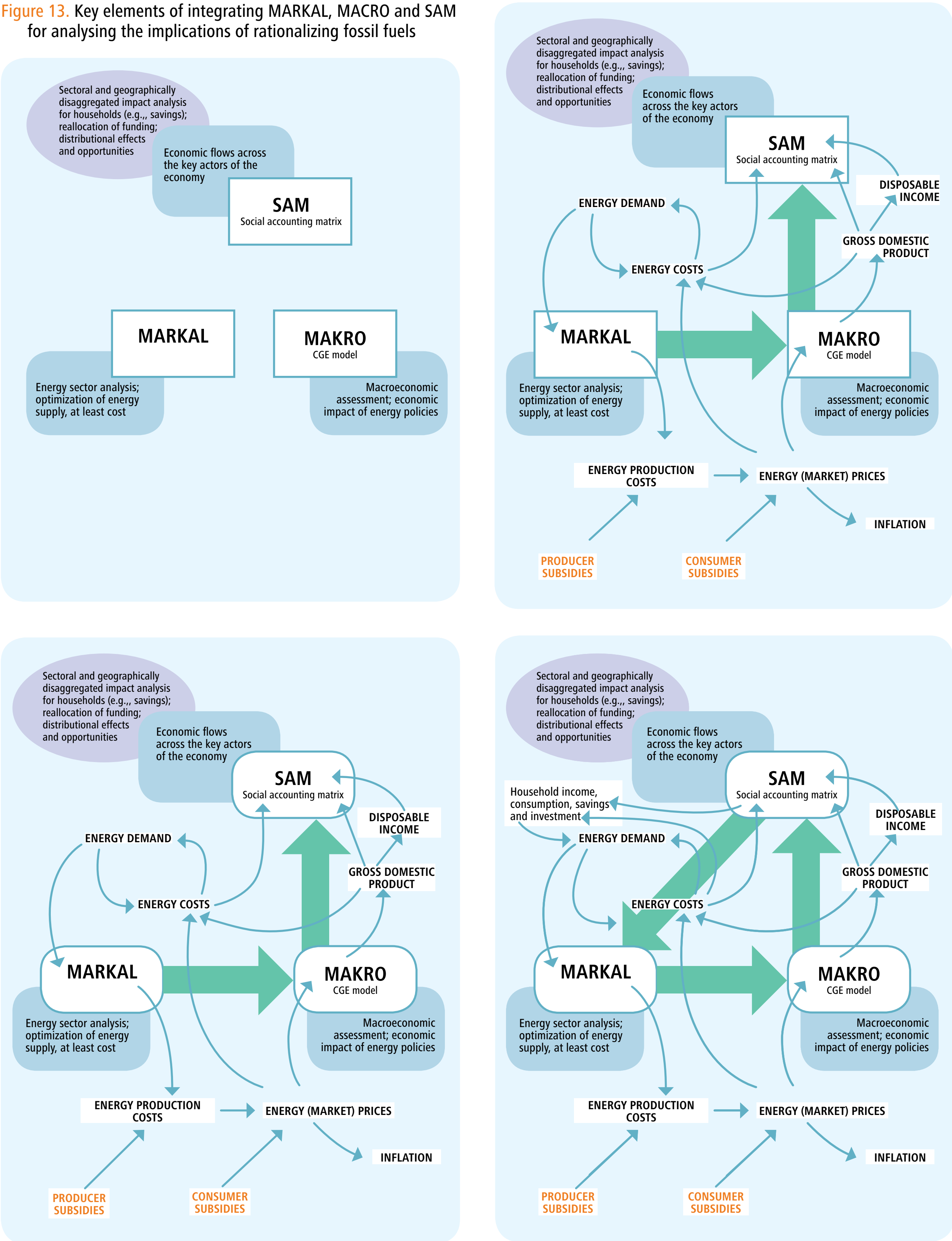
The three case studies proposed in this report are illustrative of the coupling that can be achieved, either by running different models or by incorporating existing knowledge in a single framework of analysis. Both approaches have pros and cons, as highlighted in chapters 4 and 5.

6.1 CASE STUDY: FOSSIL-FUEL SUBSIDY REMOVAL

Assessing the implications of rationalizing fossil-fuel subsidies requires a cross-sectoral analysis, touching upon social and economic indicators and also affecting energy (fossil fuel) consumption and production, and as a consequence impacting the environment (Bassi, 2012). As a result, several methods and tools are needed to carry out a comprehensive and solid analysis of the impacts of fossil-fuel subsidies removal.

Most of the efforts in designing the analytical framework and methodology for a study carried out by IISD for the Asian Development Bank[19] consisted of identifying the synergies that can be created by using

Figure 13. Key elements of integrating MARKAL, MACRO and SAM for analysing the implications of rationalizing fossil fuels



MARKAL is used to generate information on energy production costs, taking into account producer subsidies. With energy costs and consumer subsidies, energy market prices can be estimated. Energy prices are then used to estimate energy demand (and possibly GDP and other macroeconomic flows) in MACRO, and inflation. MACRO is used in conjunction with the SAM to estimate GDP and household income, as well as consumption, savings and investment. With data from the household survey, it is possible to disaggregate impacts by income classes and location, and also estimate household energy costs. This is done by combining estimates on energy demand (potentially using driving needs – e.g., distance from the workplace – and household or housing size) and energy prices, obtained from the MARKAL and MACRO. Finally, income, originating from the SAM and the household survey, will also be used to estimate household energy demand at the micro level, in addition to using prices and specific needs.

existing methods and tools. With the goal to adopt a framework that is easy to implement and replicate, but still solid and rigorous, the team has selected three main tools, all based on (and supported by) quantitative data. These are (1) the MARKAL energy model; (2) a macroeconomic CGE model (referred to in this case study as MACRO); and (3) the SAM. Strong synergies can be created when using the three tools simultaneously, as they can (and should) feed results to each other to allow for a comprehensive and solid assessment.

With respect to the analysis of the impacts of fossil-fuel subsidies, it can be argued that:

- The SAM and MACRO are particularly useful in analysing consumer subsidies from a macroeconomic perspective, with data (such as household surveys) being necessary to carry out a detailed assessment of the impact on households (e.g., considering income classes, regional differences among the population and other social factors).
- MARKAL and MACRO are needed to analyse producer subsidies, with the former emphasizing the biophysical dimensions of the energy sector, and the latter estimating the economic impacts of decisions on energy supply.

As mentioned above, the MARKAL, MACRO and the SAM can be very complementary, strengthening the analysis that otherwise would be carried out with each used independently. In fact, the basic accounting structure and much of the underlying data of CGE models are derived from a SAM, making them useful and easy to implement for the analysis of consumer subsidies, and MARKAL has been improved and expanded by linking it with CGE models, making them excellent tools to use in conjunction when analysing producer subsidies.

Figure 13 shows how the three tools can be used in a synergetic manner to make use of the strengths of each and carry out a solid and easily replicable analysis of the implications of rationalizing fossil fuels.

The combined use of these three tools is necessary to generate coherent projections and to analyse them in the context of rationalizing fossil-fuel subsidies. In this respect, several policy-related questions can be analysed, starting from the various options for subsidy removal (e.g., what reduction, by when, and in which shape/form), and ending with the potential reallocation of avoided public expenditure (to which household groups, and with which policy intervention option). Additional analyses become relevant depending on the scenarios simulated, including the differences between short- and long-term impacts as well as policy and system responses.

6.2 CASE STUDY: GREEN ECONOMY ASSESSMENT FOR MEXICO

Finding that most currently available national planning models are either too detailed or narrowly focused, this study proposes an approach that: 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 between the economy, society and the environment. The inclusion of cross-sectoral relations supports a wider analysis of the implications of alternative policies, and the long-term perspective proposed allows for the identification of potential side effects and sustainability of different strategies.

The approach proposed uses several methodologies, including optimization, econometrics and system dynamics. A computable general equilibrium model is developed for macroeconomic analysis, especially focused on subsidy removal, and sectoral models are employed to analyse in more detail the agriculture, fishery, forestry, water and transport sectors. System dynamics is used to represent stocks and flows in sectoral models, and to fully integrate social, economic and environmental dimensions in the framework of analysis.

All sectoral models are customized to represent the specific context of Mexico. The resulting integrated national development model is well suited to: (1) generate projections of future developments, emphasizing short-, medium- and longer-term impacts; (2) provide an integrated analysis and evaluation of green economy interventions; and (3) increase the understanding of the relations underlying the system analysed. Figures 14 and 15 provide an overview of the modelling framework, and Table 4 proposes a small sample of the main indicators included in

Figure 14. Graphical overview of the modelling framework employed for this study; sectoral models are used to estimate green economy investments, resulting in avoided costs and added benefits. This analysis, spanning across social, economic and environmental dimensions and accounting for short-, medium- and longer-term impacts, is integrated and systemic.

Agriculture, water, fishery, forestry, transport and economy are analysed in isolation, while results are generated across spheres

Social, economic and environmental impacts of green economy interventions and analysed systematically

Figure 15. Graphical overview of the modelling framework employed for this study; the sectoral analysis generates results across social, economic and environmental dimensions. The economic results are used as inputs for the macroeconomic analysis, which generates results across all key economic sectors.

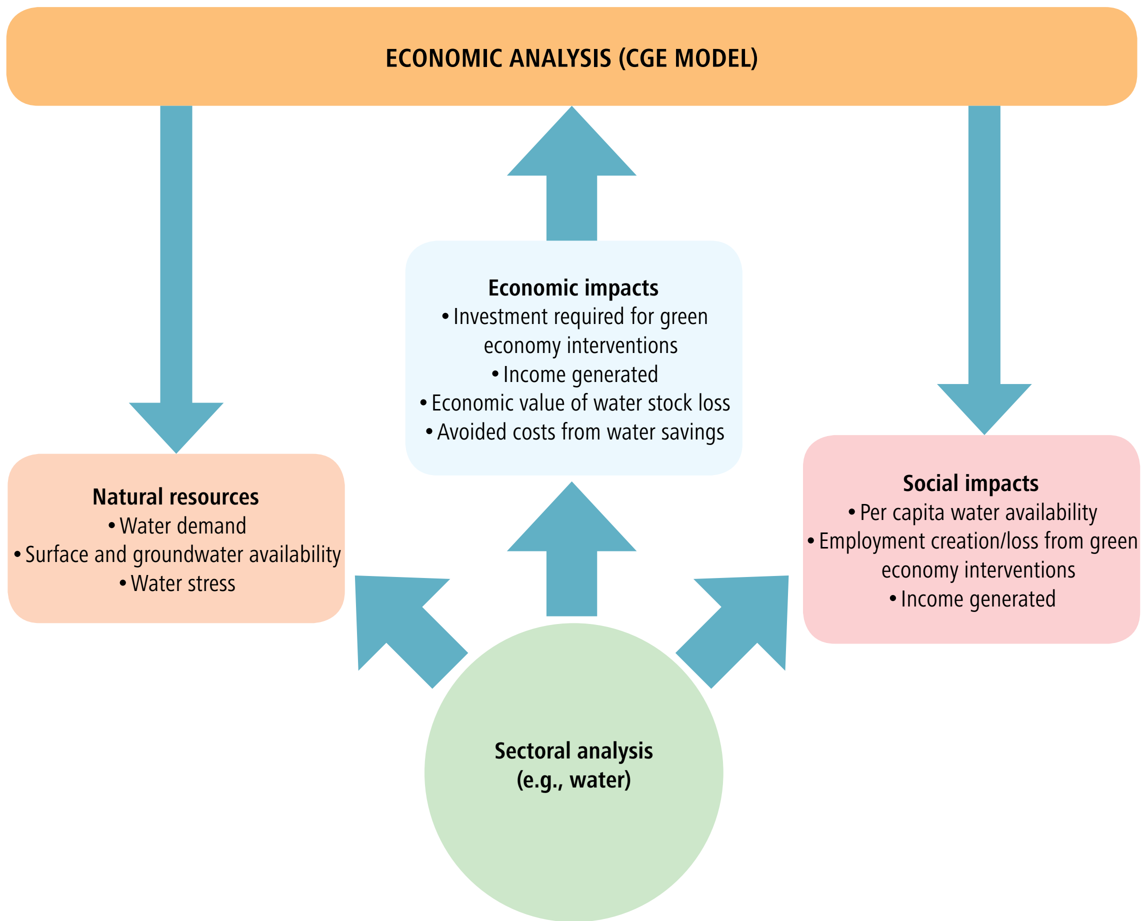


Table 13. Sample of main sectoral indicators and green economy scenarios for selected sectors

Selected sectors	Sample indicators	GE scenarios
Water	**Water demand:** Residential, commercial and industrial, agriculture **Water supply:** Surface and groundwater stocks and flows **Regional disaggregation:** North, centre and south	Reduction of groundwater loss (equilibrium in centre and south) Maintenance of minimum environmental surface water flow
Forestry	**Forest area:** Primary and secondary forest, divided into specific land cover categories, and others **Forestry:** Production and employment **CO_2 capture and storage:** In biomass and soil	Reduction of deforestation (with reforestation for all forest land cleared)
Fishery	**Capacity:** Small and large vessels/boats **Fishery:** Production and employment	Stabilization of the fish stock, to avoid the collapse of the sectors
Transport	**Vehicle stock:** Seven types of vehicles, various engine types **Road network:** Roads, congestion and employment **Energy and emissions:** By energy source (gasoline and diesel) and vehicle type	Several interventions aimed at reducing energy consumption and emissions, and limiting congestion

*Input-output tables generally only provide information to other models. These data, used as input, are then simulated using econometrics, optimization and system dynamics.

selected sectoral models developed for this study, and the green economy scenarios analysed.

The main outputs of the sectoral models and of the green economy analysis include the investment required to implement the intervention desired, added benefits and avoided costs (see Figure 8). Among the benefits, indicators include sectoral value added (as driven by natural resources stocks and flows, e.g., agricultural yield and production), direct employment creation and relative income generated, and eventual natural capital improvements (on stocks, flows and ecosystem goods and services). 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 (and, for instance, the return on employment and emissions).

6.3 CASE STUDY: GLOBAL GREEN ECONOMY TRANSITION

The interconnection between poverty, hunger, energy issues and climate change has become more visible over the past decade, urging policymakers to find ways to solve several critical and interrelated problems. The modelling work included in the UNEP Green Economy Report (GER) (see UNEP, 2012a) was conceived to analyse the impact of investments aimed at lowering carbon intensity, improving resource efficiency and supporting economic resilience while curbing trends of ecosystem degradation. With this goal, emphasis was put on economic impacts (e.g., GDP), but also on social (e.g., employment and poverty) and environmental (e.g., energy and water consumption, and emissions) indicators.

The development of a model for this study, using T21 as a starting point and profoundly changing it to address the main questions posed by the green economy, required the use of data for a variety of sectors, and as a consequence from numerous sources. These sectors include population, agriculture production, energy, transport, water and more, with data collected from, for example, the United Nations' *World Population Prospects* (WPP), the World Bank's *World Development Indicators* (WDI), the OECD *Environmental Outlook to 2030*, the FAO *FAOSTAT* and *State of World's Forests*, McKinsey's *Charting Our Water Future* report, the IEA *World Energy Outlook*, and Global Footprint Network reports.

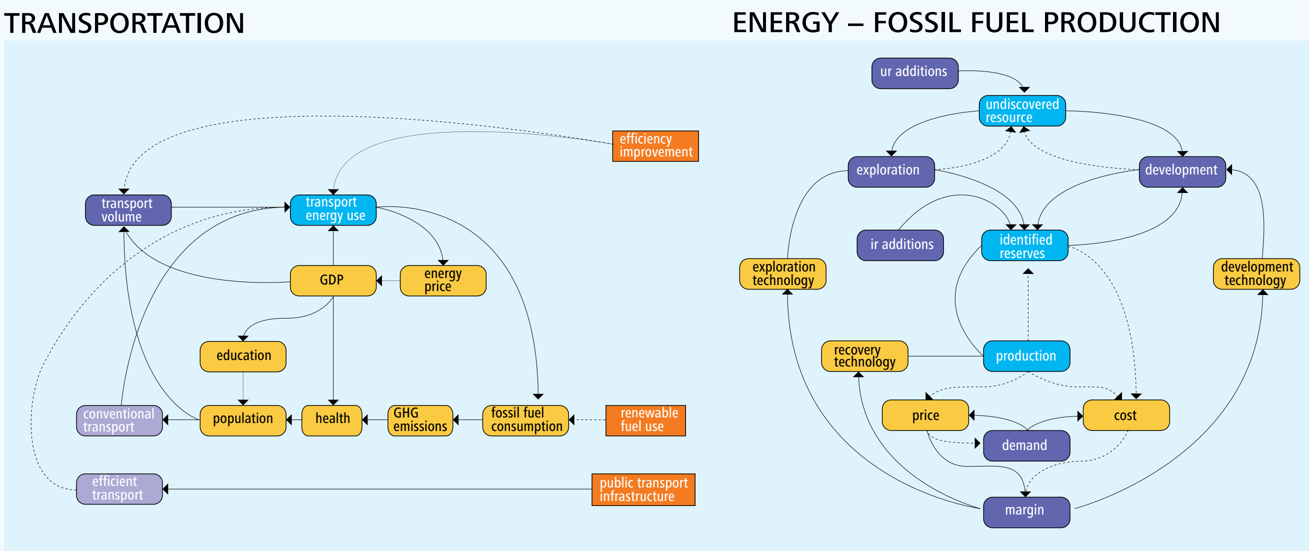
Together with data, the models used to generate projections at the global level, in the respective field, were also analysed. The model was then built using the T21 Starting Framework as well as key relations found in, among others, the UN demographic model (used to produce the *World Population Prospects*), the IEA World Energy Model and Mobility Model (used to generate projections included in the *World Energy Outlook*), and the Global Footprint Network methodology for calculating the ecological footprint. As a result, the model developed is de facto a knowledge integrator, coherently incorporating several sectoral models in a single framework of analysis. Also, several methodologies were incorporated in the model, including optimization (energy sector, with a life cycle approach applied to fossil fuels), material flow (I-O in the waste sector) and econometrics (in the economic sphere).

Given the specific focus of the study and its global aggregation, only macro trends and key aggregate variables were analysed, avoiding excessive and unnecessary detail. In fact, better models exist to carry out a more solid and detailed analysis at the sectoral level, and the modelling effort for the GER only focused on filling existing gaps, namely cross-sectoral integration and the lack of coherent long-term projections.

The full incorporation of several sectors in a single model framework, achieved through the explicit representation of feedback loops, delays and non-linearity, allows for identifying synergies and side effects emerging within and across sectors. Two examples are that (1) coupling the expansion of renewable energy with energy efficiency measures would lower capital costs while maintaining high employment in the power sector; and (2) enacting renewable energy mandates would likely reduce the price of fossil fuels used for power generation, lowering imports or increasing exports, further stimulating the economy and potentially increasing energy consumption in other sectors. Other synergies can be found between ecological agriculture and forestry, or between forest management and water availability (and, more broadly, climate resilience). Overall, the simulation of integrated models is more likely to highlight unexpected gains, or synergies and "hidden" costs and bottlenecks, making them valuable tools to be used side by side with more detailed sectoral models.

Apart from global trends, the application of a similar approach at the country level would require unique customizations. Examples of relevant green economy interventions with impacts across sectors include, among case studies tested to validate the integrated approach proposed in the GER, the introduction of payments for ecosystem services in Ecuador; a shift to a low-carbon energy sector in the US; increased food self-sufficiency in Mauritius; the relevance of consumption patterns in China; social development in Mali; and the relationship between national government and regions – municipalities – in Denmark.

Figure 16. **Simplified causal loop diagrams, or subsystem diagrams, of the transport and fossil fuel production modules of T21-World**



Plain arrows indicate a positive (direct) causal relation, while dotted arrows indicate a negative (inverse) causal relation.

7 Conclusions

With the growing interest of countries to embark on green economy planning exercises, the use of several methodologies and models is being considered to support the policymaking process. The common purpose of using these tools is to help plan green economy strategies, support policy development and assess green economy opportunities with quantitative analysis.

A variety of methodologies and models are available nowadays, with new approaches emerging as a result of the evolving needs of decision makers. To highlight the potential contribution offered by selected methodologies and models, starting from the definition of the green economy (what needs to be measured and analysed), this report offers a critical review of their strengths and weaknesses, and of the adequacy of models in helping countries in their definition of green economy strategies.

Various criteria are considered for the review. Starting with methodologies, a green economy strategy requires an action-oriented approach to sustainable development. As a result, it is clear that the goal of any quantitative analysis is to support the policymaking process. The extent to which methodologies (data frameworks and modelling approaches) can contribute to the main stages of the policymaking process represents the main set of criteria used to assess them. In addition, the complementarity of the methodological approaches is also considered, together with the inclusiveness (i.e. stakeholder involvement) of the process to implement them. Concerning models, the criteria focus more explicitly on the definition of the green economy and the quantitative outputs required to effectively inform decision-making. As a result, the main criteria considered include the capability of models to represent the social, economic and environmental dimensions of the problems and opportunities analysed, as well as their capability to carry out investment and policy analysis. Further, models are assessed for their ease of customization and use. This is relevant for specific country implementation, where data, time and financial resources may be scarce, and trade-offs need to be addressed.

While not aiming at identifying the best methodologies and models for the definition and analysis of green economy strategies, this study provides key information for the ministries tasked with planning responsibilities to evaluate the adequacy of various models in meeting their specific needs. As demonstrated by the case studies, integrating and/or linking different modelling approaches and models is often required for the types of complex questions posed by a green economy assessment. In this respect, there are two critical factors to consider:

1. The peculiarities of the local context
2. The analysis carried out with models

The former was already addressed in this report and includes data availability, knowledge and skills available within critical ministries and national research organizations. The latter refers to the fact that the potential to effectively inform the policymaking process is highly dependent on the type and breadth of the analysis carried out, as models may be misused or utilized below their potential. For this reason, the evaluation of models emphasizes the need to ensure broad stakeholder involvement and the necessity to estimate impacts across sectors for the short, medium and longer term, while considering direct, indirect and induced impacts of action and inaction. These aspects of a green economy assessment, applied to selected green economy policy intervention options, will be addressed in more detail in upcoming work.

Notes

[1] While it is acknowledged that the political dimension is crucial, there are limitations on the extent to which this can be captured by the use of models. As a result, although the process of model building and calibration is often affected by political dynamics, this criterion is not explicitly considered in the analysis presented in this report.

[2] These include, among others: CE and SERI (2010) for a review of macroeconomic models and their approach to sustainability; IEEP et al. (2009) for a review of models used to project scenarios of biodiversity and ecosystem services; and GEO-5 (UNEP, 2012) for a review of scenarios across sectors.

[3] A variety of additional and more technical criteria could be proposed to assess models, such as the use of discrete or continuous simulation, and how they handle uncertainty. However, this report is seen as an introductory document, and a more detailed assessment of the strengths and weaknesses of simulation models in relation to specific policy analysis will be included in the upcoming volume II of this study.

[4] As one of the five types of capital enabling sustainable development, economic or manufactured capital includes man-made physical infrastructure, industries and more (EMG, 2011).

[5] While acknowledging the existence of five types of capital in relevant literature (e.g., EMG, 2011) – natural, human, social, manufactured and financial capital – the analysis here focuses on the three dimensions that are more easily quantifiable for inclusion in mathematical models that can be used to inform decision-making on green economy strategies and action plans. These are (i) economic (or manufactured) capital, (ii) human capital and (iii) natural capital.

[6] Given the existence of externalities, however, these valuations could be distorted. This requires a dedicated effort to continuously improve measurement in this front.

[7] Examples include the review of storm-related damages to assess the impact of climate change, or water intensity and productivity, to then evaluate options to offset the depletion of groundwater resources.

[8] Examples include the use of indicators on existing fossil fuel, water and fishery subsidies for green fiscal reform, or the economic valuation of natural capital for pricing externalities.

[9] Examples include the analysis of policy-induced employment creation, as well as improvements in the access to modern forms of energy and sanitation as result of policy implementation.

[10] This paper argues that the choice of functional forms affects not only industry-specific results, but aggregate results as well, even for small policy shocks.

[11] Note that this implies that these models could suffer from some of the critiques made to the econometric models if estimations are done in a more traditional way.

[12] A more detailed review and comparison of energy models can be found in the following studies, among others: Jebaraj and Iniyan, 2006; Connolly et al., 2010; Bassi, 2009, 2010; Suganthi and Samuel, 2012.

[13] Examples include, among others, ecological footprint assessment (Bicknell et al., 1998; Ferng, 2001; Hubacek and Giljum, 2003; Lenzen and Murray, 2001; and Zhou and Imura, 2011), material flow analysis using a physical input-output table (PIOT) (Giljum and Hubacek, 2009), product life cycle analysis using the hybrid LCA approach (Moriguchi et al., 1993) and the environmental input-output life cycle assessment (EIO-LCA) developed by the Carnegie Mellon University (Hendrickson et al., 1998; Matthews and Small, 2001), analysis of the interdependence between the flows of goods and waste by the waste input-output (WIO) model (Nakamura and Kondo, 2008), and the calculations of embodied emissions and embodied primary resources (for a review, please see Wiedmann, 2009) and virtual water (Guan and Hubacek, 2007).

[14] Examples of work done at the national level include Wyckoff and Roop, 1994; Munksgaard and Pedersen, 2001; Peters and Hertwich, 2008; Hertwich and Peters, 2009; and Zhou et al., 2010.

[15] http://www.naturalcapitalproject.org/InVEST.html.

[16] While there is flexibility in the approach used, care should be taken when working with data available on different scales. For instance, water models cannot be run with a DEM coarser than about 200 m in order for the hydrological routing to function properly. This is generally not a problem, because 30 m DEMs are globally available, but 30 m land cover is not, so there is likely going to be a mismatch of scales for some data sources, and results should be interpreted at the coarsest scale of input data used.

[17] Other examples include DICE (Dynamic Integrated Climate-Economy) by Nordhaus and Boyer (2000), MERGE (Manne and Richels, 2004), WITCH (Bosetti et al., 2006), REMIND (Leimbach et al., 2010), GAINS/MESSAGE (Messner and Schrattenholzer, 2000; Höglund-Isaksson L. and Mechler R., 2004), GCAM from the Joint Global Change Research Institute (PNNL) (Brenkert et al., 2003).

[18] A considerable amount of work is being done to improve the integration of economic, social and environmental factors in integrated assessment models. While this type of work is beyond the scope of the report, more information can be found at the Integrated Assessment Modelling Consortium website (http://www.globalchange.umd.edu/iamc).

[19] The project is "TA-7834 REG: Assessment and Implications of Rationalizing Fossil-Fuel Subsidies", done in the context of the IISD Global Subsidies Initiative.

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Glossary and definitions

Complex systems: Systems dominated by dynamics that are often beyond control. These dynamics are the result of multiple interactions between variables that do not follow a regular pattern.

Complicated systems: Systems composed of many different interacting parts whose behaviour follows a precise logic and repeats itself in a patterned way.

Computable general equilibrium (CGE) models: A class of economic models that represent the main economic flows within and across the key actors of a national economy. The model couples equations with an economic database, using the System of National Accounts (SNA), the social accounting matrix (SAM) and input-output (I-O) tables as pillars.

Delays: In system dynamics models, delays are "a phenomenon where the effect of one variable on another does not occur immediately" (Forrester et al., 2002).

Detailed (organized) complexity: Found in systems characterized by a large number of linear relations (complicated systems).

Dynamic (disorganized) complexity: Found in systems characterized by cross-sectoral connections, with non-linearity and delays (complex systems). The aggregated behaviour of the system shows properties not resulting from the mere sum of its components.

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

Endogenous (dependent) variable: A variable whose value is determined by the states of other variables in the system.

Exogenous (independent) variable: An external input, or a variable independent from changes in the other variables of the model.

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

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

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

Green investment: An investment that promotes the green economy by reducing carbon emissions and pollution, enhancing energy and resource efficiency, preventing the loss of biodiversity and ecosystem services, and creating green jobs.

Green jobs: According to the International Labour Organization, green jobs are decent jobs that reduce consumption of energy and raw materials, limit greenhouse gas emissions, minimize waste and pollution, and protect and restore ecosystems.

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

Input-output: A framework that depicts 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).

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

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

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

Non-linear system: A non-linear system is one whose output is not directly proportional to its input.

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

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

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

Social accounting matrix (SAM): An accounting framework that captures the transactions and transfers between the main actors in the economy. A SAM normally includes firms, households, government and "rest of economy".

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

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

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

System engineering model: Model of an engineered system. Systems engineering is an interdisciplinary field of engineering that focuses on how to design and manage engineering projects.

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

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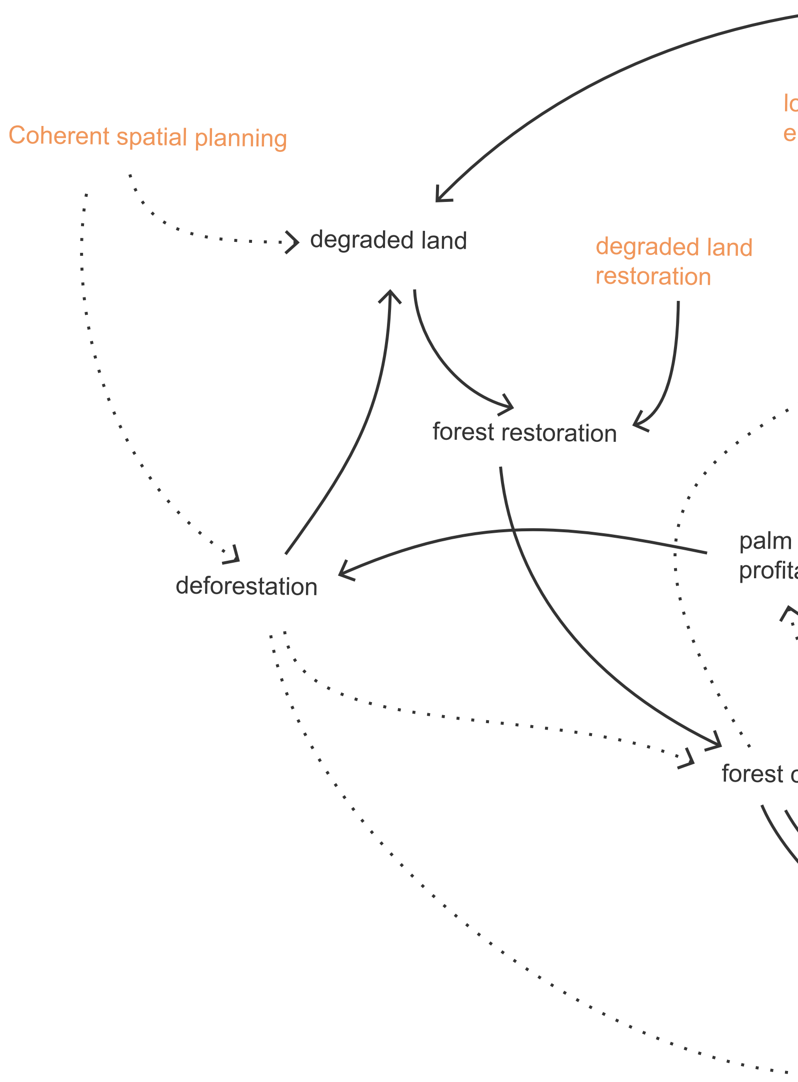

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