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REVIEW OF EXPERIENCE  
WITH EXISTING MODELS  
AND THEIR SUITABILITY FOR  
INTEGRATED  
SUSTAINABILITY ASSESSMENT (ISA)

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## **Preface**

### **About the MATISSE project**

The MATISSE (Methods and Tools for Integrated Sustainability Assessment) project is funded by the European Commission, DG Research, within the 6<sup>th</sup> Framework Programme. The project is interested in the role that Integrated Sustainability Assessment (ISA) could play in the process of developing and implementing policies capable of addressing persistent problems of unsustainable development and supporting transitions to a more sustainable future in Europe. The core activity of MATISSE is to develop, test and demonstrate new and improved methods and tools for conducting ISA.

This work is carried out through developing and applying a conceptual framework for ISA, looking at the linkages to other sustainability assessment processes, linking existing tools to make them more useable for ISA, developing new tools to address transitions to sustainable development and applying the new and improved tools within an ISA process through a series of case studies.

The extent to which the case studies are carrying out a complete ISA for their area of focus varies between attempts to cover all phases of an ISA process to partial implementation of the process. Equally, different case studies are oriented to developing and testing tools and approaches to some, but not all, of the methodological challenges of ISA. The case studies are complementary, however, and the set of cases offers the opportunity to address a wide range of methodological challenges and to explore linkages between cases. An evaluation of practical experiences with ISA implementation in the case studies will provide guidance on the further improvement of methods and tools. Results will also contribute to more informed policy advice.

### **What is ISA?**

Within the MATISSE project, Integrated Sustainability Assessment (ISA) has been defined as a cyclical, participatory process of scoping, envisioning, experimenting, and learning through which a shared interpretation of sustainability for a specific context is developed and applied in an integrated manner, in order to explore solutions to persistent problems of unsustainable development. ISA is conceptualised as a complement to other forms of sustainability assessment, such as Sustainability Impact Assessment, Integrated Assessment and Regulatory Impact Assessment. Whereas these other forms of assessment fulfil the pragmatic need for *ex ante* screening of incremental sectoral policies that are developed within the prevailing policy regime, ISA is conceptualised as a support to longer-term and more strategic policy processes, where the objective is to explore persistent problems of unsustainable development that have a systemic pathology and possible solutions to these. ISA is therefore oriented toward supporting the development of cross-sectoral policies that specifically address sustainable development and at exploring enabling policy regimes and institutional arrangements.

### **MATISSE Working Papers**

Matisse Working Papers are interim reports of project activities that are published in order to illustrate ongoing work and some provisional conclusions, as well as providing the opportunity for discussion of the approaches taken by the project and interim results. This discussion should be both within the project and between project members and the broader scientific and policy communities. Readers are encouraged to contact the authors to discuss the content of MATISSE Working Papers.

Jill Jäger and Paul Weaver

Editors of the MATISSE Working Paper Series

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## **ABSTRACT**

This report is based on results from the EU project SustainabilityA-Test (2004-2006), which was funded under FP6.<sup>1</sup> The report evaluates modelling tools that have been applied to relevant aspects of sustainable development and sustainability assessment. The focus here is on "applied" models, i.e. models that try to simulate real-world processes based on or calibrated to empirical information. Modelling applications considered here have clear relevance to the actual policy-making process with regard to sustainability questions. Hence, pure theoretical models and rather conceptual models, dealing with basic mechanisms without direct link to empirical information, are not included. Based on this broad evaluation, the choice of specific models to be used within MATISSE is explained. Strengths and weaknesses of the chosen models are discussed, and the needs for improvements and linkages within the MATISSE work programme are clarified. Some form of categorisation is necessary to keep the evaluation task of the vast number of available models manageable. The models have therefore been grouped into three categories (biophysical models, socio-economic models, integrated models) with 11 sub-categories. The evaluation of strengths and weaknesses was conducted on the level of the sub-categories. While many other forms of categorisation also would have been plausible, this approach was chosen especially because it allows for the challenges for more integrated modelling in the context of Integrated Sustainability Assessment (ISA) to be illustrated.

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<sup>1</sup> The results of SustainabilityA-Test are well documented in a web-book at [www.sustainabilitya-test.net](http://www.sustainabilitya-test.net).

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# REVIEW OF EXPERIENCE WITH EXISTING MODELS AND THEIR SUITABILITY FOR INTEGRATED SUSTAINABILITY ASSESSMENT (ISA)

## 1 Overview of existing modelling tools

Many scientific disciplines rely to an increasing extent on the use of computer modelling tools to represent, describe, analyse and simulate major processes related to research questions in their realm. The continuous increase in computer power makes it possible to simulate even very complex problems and to conduct "virtual experiments" of large-scale environmental or socio-economic processes. Modelling tools help to structure scientific thinking, to focus on the most relevant processes, analyse important trade-offs between conflicting goals, quantify scenarios, and, to a certain extent, make predictions of likely future developments.

Specialised computer models have been developed within traditional scientific disciplines. During the process of specialisation a wide variety of modelling approaches has emerged, differing in theoretical background and paradigms, mathematical structure, time scales, spatial scales, thematic coverage, modelling objectives, and outcomes.

As defined in the MATISSE project, Integrated Sustainability Assessment<sup>2</sup> requires, together with the development of more integrative scientific thinking, a broader scope for modelling activities. Model integration and model coupling across disciplines are key challenges for providing appropriate tools for the combined assessment of environmental, economic and social processes.

This report identifies modelling tools that have been applied to relevant aspects of sustainability and sustainable development. The focus here is on "applied" models, i.e. models which try to simulate real-world processes based on or calibrated to empirical information. Modelling applications to be discussed should have some relevance to the actual policy-making process with regard to sustainability questions. Hence, pure theoretical models and rather conceptual models, dealing with basic mechanisms without direct link to empirical information, are not included in this report.

Some form of categorisation is necessary to keep the evaluation task of the vast number of available modelling tools manageable. The tools have been grouped into three categories: biophysical models, primarily covering natural-scientific phenomena, socio-economic models, focussing on human dimensions of sustainability, and integrated models, covering attempts to bridge the gap between natural and social sciences and combine aspects from both domains into one modelling framework. While many other forms of categorisation would also have been plausible, the current approach was chosen, because

- (1) it reflects the development and application of models in their traditional disciplinary setting and hence will be most familiar to model developers and potential users, like policy-makers and the wider public;
- (2) it shows the relative position of available models, along the lines of increasing thematic integration; and
- (3) it illustrates the challenges for more integrated modelling, which reflects the more general challenge of truly integrated research on sustainability impacts.

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<sup>2</sup> Weaver P. M. and Rotmans J. (2006) Integrated Sustainability Assessment: what is it, why do it, and how? , International Journal of Innovation and Sustainable Development. Vol. 1, No.4

Each of the three categories covers a number of generic modelling approaches, which are illustrated with specific model examples. The evaluation of strengths and weaknesses was conducted only on the level of generic modelling approaches (see Appendix), as the number of specific models is simply too large.

## 1.1 *Biophysical models*

Model-based analyses of environmental sustainability have been mostly concerned with aspects of climate change, hydrological cycles, air pollution and terrestrial biogeochemical processes. In fact, research on global climate change has to a certain extent driven the development towards more general research activities on sustainability in a wider sense. Although the tools in this category are focussing on biophysical phenomena, some of them are also "integrated" in a narrow sense.

Biophysical models usually take human impacts as exogenous conditions, but treat several parts of the natural system as endogenous. Climate models are mostly concerned with atmospheric processes, but also analyse carbon flows between the atmosphere, oceans and the terrestrial biosphere and, hence, have to provide explicit links between these natural sub-systems. Hydrological models have to take into account human water withdrawals, but also vegetation, climate and soil conditions. Biogeochemical cycles are influenced by climate, hydrology and soil conditions, but also by human activities.

Climate models include (1) General Circulation Models (GCM), like the HadCM model or the ECHAM model, and (2) Earth system Models of Intermediate Complexity (EMIC), which are spatially explicit and include all relevant major natural components of the Earth system, i.e. atmosphere, hydrosphere, cryosphere and biosphere. Prominent examples of EMICs are CLIMBER and MAGICC/SCENGEN.

Hydrological models include, for example, WaterGAP at the global level, and SWIM at the regional level focussing on a specific river basin. Several modelling approaches, including agent-based models, are being used within the GLOWA projects, focussing on the Elbe, Danube, and Volta river basins. In the GLOWA projects the hydrological parts are combined with models on the regional economy and land use.

Biogeochemistry models have been used, for example, to assess the impact of climate change on biomass productivity, carbon and water cycles, and crop growth. They are also labelled as "ecosystem models" or "vegetation models". A prominent example of this tool type is the Lund-Potsdam-Jena (LPJ) dynamic vegetation model, which has been applied on global and continental scales. VECODE is a somewhat simpler biogeochemistry model which has been used in integrated assessment studies. WOFOST and ACCESS are examples of crop growth models which have been applied on the regional scale. The 4C model covers forest vegetation on a regional scale.

## 1.2 *Socio-economic models*

Model-based assessments of social and economic sustainability have been mostly concerned with the general economy (especially macro-economic stability and financial aspects), partial economic sectors (like energy, transport or agriculture), demographic change, or public health concerns. While computer modelling is more commonly used in economics than in other social sciences, certain social aspects, like income distribution, employment, or education, are taken into account in some economic models. Environmental conditions are usually treated as exogenous.

General Economy models include (1) Computable general equilibrium (GE) models, like the Global Trade Analysis Project (GTAP) model (and its derivatives), WorldScan, GEM-CCGT, GEM-E3, and SNI-AGE, and (2) Macro-econometric models, like E3ME, QUEST-II, NEMESIS, and GINFORS. Some general economy models are highly aggregated, i.e. treating the whole economy as one sector, while others distinguish a large number of economic activities. While GE models follow an

equilibrium concept and are calibrated to conditions in a base year, macro-econometric models are based on time series analysis for the derivation of model parameters.

Partial economic sector models take the general economic conditions as exogenous, but treat the characteristics of specific economic sectors with much more detail than general economy models. They have been applied to the analysis of different policy scenarios and to a range of environmental economic questions. Energy sector models include POLES, PRIMES, and MARKAL. Agricultural sector models include WATSIM, IMPACT, CAPRI, and RAUMIS. An example for a transport sector model is TREMOVE.

Demographic models are used to develop long-term projections of population growth, depending on external scenarios on economic development, fertility and public health. Examples to be evaluated are the PHOENIX model and the IIASA Population Project.

Public health models are used to analyse the impact of environmental and socio-economic scenarios on human health, with special focus on important diseases. The impact of climate change on malaria has been analysed with the model MIASMA. Other relevant health models are PHSF and TARGET.

### **1.3 Integrated models**

While many biophysical models and socio-economic models are to some extent "integrated" within their respective disciplinary realm, the category "integrated models" in this report includes modelling approaches that include both biophysical and socio-economic aspects as endogenous parts of their modelling system. Even more than in the first two tool categories, there are considerable overlaps between the integrated model tools as defined here. For pragmatic reasons, the tools have been distinguished according to their focus on (1) land use, (2) integrated assessment, (3) qualitative systems analysis, and (4) scenario building and planning. The first two tool types are closely related to and mostly based on coupled biophysical and socio-economic models, as described above. The other two tool types depart from the standard quantitative approaches in various ways.

Land use models usually integrate economic components (above all agriculture, forestry, infrastructure) with representations of environmental conditions most relevant to these human activities (i.e. soil conditions, water, climate, vegetation growth). Land use models include large-scale applications based on general economy or sector models, regional approaches with an agent-based modelling framework, or GIS-based applications. Global models include FARM, AgLU, and MAgPIE. Regional models include CLUE and SFARMOD. CORMAS represents the agent-based modelling approach.

Integrated assessment models have been used for scenario modelling, projections and specific policy analyses, e.g. on the energy system, climate change, carbon and water cycles, land use issues, or various combinations of these topics. While many of these models have become quite advanced in representing their respective compartment of the Earth system, much work remains to be done with respect to model coupling and the interaction between different sub-systems. So far there have been only a limited number of truly integrated assessment studies with coupled models, e.g. the IMAGE model or the ICLIPS project. Several models were used in the IPCC Special Report on Emission Scenarios (SRES), i.e. IMAGE, MESSAGE, AIM, ASF, MINICAM, MARIA. In the international literature, there is also a group of highly reduced economic climate change models, CETA, DICE, MERGE, RICE, WARM, FUND, MIND and DEMETER. The latter group of models has typically been applied to assess the efficiency and effectiveness of long-term climate change targets, the timing of targets, and the use of various instruments.

Qualitative systems analysis models have been applied in circumstances where the information available is insufficient for detailed quantitative assessments, or where quantitative approaches seem inappropriate. The SYNDROMES approach has been applied for the evaluation of large numbers of case studies, in order to extract overall patterns from specific local conditions. The QSA-SCENE model has been applied to questions of sustainable development in a province in the Netherlands.

These models provide qualitative results, but are nevertheless based on a rigorous mathematical formulation.

Scenario building and planning tools comprise a range of tools that do not attempt to explain actual biophysical or socio-economic processes, but are used to explore possible future paths and scenarios, based on trends and projections derived from other models and external sources. Comprehensive databases provide the information pool, from which model users can define their own model structures and inputs. These tools are used for policy planning purposes, and also as communication tools in stakeholder participation exercises. Examples to be evaluated are QUEST, POLESTAR, THRESHOLD-21 and FAIR.

Table 1 summarises the tools and methods covered in this report. Figure 1 shows the modelling tools in relationship with other tools and methods evaluated in the SustainabilityA-Test project.

**Table 1: Modelling tools for Integrated Sustainability Assessments (ISA)**

| Category                            | Models (Examples)   |
|-------------------------------------|---|
| <b><i>Biophysical models</i></b>    |   |
| Climate                             | <u>GCM</u> (HadCM, ECHAM);<br><u>EMIC</u> (CLIMBER, MAGICC/SCENGEN)   |
| Hydrology                           | WaterGAP, SWIM, IRM-ABM   |
| Biogeochemistry                     | LPJ, VECODE, 4C, WOFOST, ACCESS   |
| <b><i>Socio-economic models</i></b> |   |
| General economy                     | <u>GE</u> (GTAP, WorldScan, GEM-CCGT, GEM-E3, SNI-AGE);<br><u>Macroeconometric</u> (E3ME, NEMESIS, QUEST-II, GINFORS) |
| Partial economic sectors            | <u>Energy</u> (POLES, PRIMES, MARKAL); <u>Agriculture</u> (WATSIM, IMPACT, CAPRI, RAUMIS); <u>Transport</u> (TREMOVE) |
| Demography                          | PHOENIX, IIASA Population Project   |
| Public Health                       | MIASMA, PHSF, TARGET  |
| <b><i>Integrated models</i></b>     |   |
| Land use change                     | FARM, AgLU, MAgPIE, CLUE, SFARMOD, CORMAS   |
| Qualitative systems analysis        | SYNDROMES, QSA-SCENE  |
| Integrated assessment               | IMAGE, ICLIPS, FUND, MIND, DEMETER, RICE-FEEM, GENIE, IMPACT-WATER  |
| Scenario Building and Planning      | QUEST, POLESTAR, THRESHOLD-21, FAIR   |

**Figure 1: Modelling tools and their links to other tools for ISA**



## **2     *The role of modelling tools in ISA***

The computer modelling tools evaluated in this report are simplified representations of complex real-world phenomena. They are based on scientific theory and have a formal, mathematical structure. The formal structure implies that models have well-defined input requirements as well as specific sets of outputs.

Models can be applied to analyse complex chains of argumentation. The model developer is forced to structure the problem to be analysed, in order to facilitate an appropriate formulation in computer code. An important decision of the modeller is about endogenous and exogenous variables and processes in the model. Endogenous processes are described and simulated within the model, while exogenous information has to be taken as an input from external sources, e.g. other models, statistics or expert judgements.

Models have been developed along the lines of specialisation in scientific disciplines. This thematic specialisation is necessary to acquire the appropriate depth of analysis for specific processes, whether they are biophysical or socio-economic. However, strong specialisation has also caused decreasing compatibility between models from different fields of thought. This includes differences in basic structure and methodology, mathematical algorithms and extends to differing software packages to implement the models.

In any comprehensive sustainability assessment, the integrated modelling of nature-society interactions is of special importance and also poses the biggest challenge. Integrated modelling can mean the broadening of the scope of a single model, in order to include processes from neighbouring disciplines and approaches. But it can also mean the coupling of various models from different sources, by developing special coupling algorithms and control methods.

The definition of what is an "integrated model" varies between disciplines and over time. Two decades ago the combination of various approaches from different atmospheric sciences, e.g. atmospheric chemistry and atmospheric physics, would probably have qualified as an integrated research approach. For sustainability and sustainable development research only a true coupling of mechanisms from both biophysical and socio-economic domains would probably be accepted as a form of "integrated modelling".

With the exception of the rather small number of qualitative modelling tools, most models work on the basis of quantitative information, i.e. they require quantitative data as inputs and they provide quantitative data as outputs. Quantitative information is more commonly used in some disciplines than in others.

## **3     *Challenges and limitations for using modelling tools***

Whether or not computer models are useful for the analysis of complex real-world phenomena, especially in an interdisciplinary setting, is subject to debate. Modellers would argue that the application of rigorous mathematical methods provides more structure and transparency to the analysis of complex problems. It also makes it easier in some cases to communicate problem formulation, compared to pure verbal descriptions of a research approach. Critics would argue that models have to make use of simplifications and exogenous assumptions to such an extent that in many cases it renders them useless for saying anything substantial about the problems to be analysed. The choice of the model structure may in many cases predetermine the outcomes to a certain degree. Moreover, while being simplifications of reality, many scientific models remain so complex that they are seen rather as black boxes instead of transparent research machines. Hence, some of what modellers see to be the great strengths of modelling tools are felt by non-modellers to be serious weaknesses.

Complexity vs. simplicity: In order to model complex real phenomena, it is necessary to make simplifying assumptions. This reduces the real problem to the core aspects relevant for the analysis. Models have the strength that they make simplifications in a structured and transparent way. Without

this approach the simulation of complex processes would not be possible. However, oversimplifications and unrealistic assumptions can be a weakness. The acceptance of model results by non-modellers very often depends on the acceptance of basic assumptions.

Quantitative vs. qualitative aspects: The strengths of mathematical representations and simulations of natural or social processes can only be fully exploited if the quantification of these processes is acceptable to the modeller and the model-user. For many phenomena, especially in the social sciences, only insufficient quantitative information is available to describe and analyse the underlying processes. In these cases a quantitative analysis may be misleading. However, most mathematical models are ill-equipped for dealing with qualitative information and usually quantifiable proxy variables are used.

Endogenous vs. exogenous processes: Especially in the field of ISA it becomes apparent that "almost everything depends on everything else", i.e. in a dynamic world there are hardly any exogenous variables. However, most models require a distinction between what to include in the model and what to leave out, in order to keep the involved processes tractable. This important decision during the model development may have strong implications for the model results and their interpretation. A structured discussion about exogenous and endogenous elements of a certain model can also play an important role in structuring and tailoring the problem to be analysed. Hence, this aspect should be made clear and transparent to the model user.

Specialisation vs. integration: There is a clear trade-off between model specialisation and integration. The more focussed a model is on a specific real-world process, the more appropriate the model representation will be with regard to this process, but on the other hand more related external processes have to be ignored or treated as exogenous. Integrated models try to include many linkages between different domains in an explicit way, but in order to keep the overall complexity under control they often have to rely on simplified representations of the single elements involved. Increasing computer power partly helps to make integrated models more sophisticated, but the basic trade-off remains and has to be acknowledged by model developers and model users. There will be no "one-size model that fits all purposes".

## **4 Choice of modelling tools for ISA in MATISSE**

In previous ISA-type exercises the following combinations of thematic elements have been found:

- Economic development and climate change;
- Climate change, impact on vegetation dynamics and hydrological cycles;
- Economic development, agricultural production, land and water use;
- Economic development, nutrient cycles and soil degradation;
- Climate change, land use and land cover change;
- Energy demand, agricultural production, vegetation dynamics.

Models have been coupled as well as combined with other methods and tools in the following ways:

- Models have been used for vision-building and scenario analysis;
- Models have delivered inputs for cost-benefit analyses;
- Data from Material Flow Analysis have been used for modelling purposes;
- Models have been used for evaluating trade-offs between objectives (sometimes represented by Sustainability Indicators);
- Models have been used for vulnerability assessment;

- Models have been applied as communication tools in stakeholder dialogues;
- Transition analysis has been based on modelling tools.

Based on the overview and evaluation of existing modelling tools in the SustainabilityA-Test project, a limited number of especially suitable models were selected for the development of a flexible ISA modelling framework in the MATISSE project. This was done and approved already in the project definition phase. The goal in MATISSE is to improve these models where necessary and to establish links and coupling procedures for ISA related to the MATISSE case studies. In the following sub-sections 4.1-4.4 the selected models are discussed in more detail. Section 4.5 provides a short overview of planned activities in Work Package 8 of MATISSE to improve and link the existing models.

#### **4.1 The Integrated Model for the Assessment of the Global Environment (IMAGE)** (see also Appendix, Section 9)

The IMAGE model is an integrated assessment framework with spatially explicit representation of land-use and land-cover related processes. It includes all major greenhouse gases and pollutants from all sources, including natural sources. Land use, energy production and trade, agriculture and forestry are the main drivers in the model, resulting from socio-economic activities provided in (alternative) scenario projections up to 2100. Climate change and related impacts are calculated and feedbacks to economic sectors are accounted for. Through soft-coupled impact modules the effects on water scarcity, biodiversity and water quality can also be calculated. Climate change mitigation options include land-use related options like bio-energy production and carbon plantations. Mitigation analyses and broader global change studies have been mostly applied at the global scale, addressing single or multiple environmental problems, e.g. for UNEP-GEO, IPCC, the Millennium Ecosystem Assessment and the ongoing Agricultural Assessment. Some assessments have been undertaken at the European scale, e.g. the EURURALIS project with a special focus on sustainable development of rural areas, including livelihood issues. Recently, IMAGE was used to investigate sustainability issues across scales in the context of the Dutch Sustainability Outlook. The process involved various core elements of the ISA approach, like the use of surveys of public preferences and priorities to establish multiple scenarios and identify scenario-specific assessment criteria and liabilities associated with alternative futures.

#### **4.2 The Lund-Potsdam-Jena dynamic global vegetation model (LPJ)** (see Appendix Section 3)

The Lund-Potsdam-Jena Dynamic Global Vegetation Model (LPJ) combines process-based, large-scale representations of terrestrial vegetation dynamics and land-atmosphere carbon and water exchanges in a modular framework. Features include feedback through canopy conductance between photosynthesis and transpiration and interactive coupling between these "fast" processes and other ecosystem processes including resource competition, tissue turnover, population dynamics, soil organic matter and litter dynamics and fire disturbance. Various plant functional types (PFTs) are differentiated by physiological, morphological, phenological, bioclimatic and fire-response attributes. Resource competition and differential responses to fire between PFTs influence their relative fractional cover from year to year. Photosynthesis, evapotranspiration and soil-water dynamics are modeled using a daily time step, while vegetation structure and PFT population densities are updated annually. The LPJ model has been extensively used in global assessments on climate change, especially the third and fourth assessment reports of the IPCC (2001, 2007 forthcoming). Here the model was used to determine the impacts of temperature and CO<sub>2</sub> changes on vegetation cover, changes in different carbon pools (soil, canopy, atmosphere), canopy and land surface albedo as well as hydrological

processes. A new version of LPJ, including agricultural crops, has recently been applied for the derivation of a global map on vulnerability to climate change for the UN. A predecessor of LPJ, the VECODE model, has been used together with the CLIMBER Earth system model of intermediate complexity in order to simulate the interactions between ocean, atmosphere and the land surface. On a European scale, LPJ has contributed substantially to the EU project ATEAM on "Advanced Terrestrial Ecosystem Analysis and Modelling". LPJ was used to analyse the spatially explicit impacts of land use changes on ecosystem services for four different future scenarios.

### **4.3 Global Trade Analysis Project general equilibrium model (GTAP)** (see Appendix Section 4)

The GTAP model<sup>3</sup> is one of the most widely known general economy models with global coverage and belongs to the large group of computable general equilibrium models (CGE). It is maintained and further developed by a global consortium led by Purdue University. The GTAP consortium also provides a consistent global database for all types of global economic analysis, covering international trade, economic development, resource economics and others. The standard GTAP model is a multiregion, multisector, computable general equilibrium model, with perfect competition and constant returns to scale. Bilateral trade is handled via the Armington assumption. The standard model also gives users a wide range of closure options, including a selection of partial equilibrium closures, which facilitate comparison of results with studies based on partial equilibrium assumptions.. The GTAP model has been widely used for analysing WTO negotiations, especially the Uruguay round. The dynamic version GTAP-Dyn is the result of continuing research aimed at extending GTAP's standard modeling framework to incorporate dynamic behaviour. It includes all the special features of the standard GTAP model, such as the sophisticated consumer demands and inter-sectoral factor mobility, as well as incorporating a new treatment of investment behaviour and additional accounting relations to keep track of foreign ownership of capital.

### **4.4 Energy-Environment-Economy Model for Europe (E3ME)** (see Appendix Section 4)

E3ME was originally built by a European team under the EU JOULE/THERMIE programme as a framework for assessing energy-environment-economy issues and policies and has since been maintained and further developed by Cambridge Econometrics. E3ME is designed specifically to address issues of central importance for economic, energy and environmental (E3) policy at the European level. Most conventional macroeconomic models that are operational in government describe short and medium-term economic consequences of policies but with a limited treatment of long-term effects, such as those from the supply side of the labour market, and this limits their ability to analyse long-term policies. In contrast, Computable General Equilibrium (CGE) models have been widely used to analyse long-term E3 policies. CGE models specify explicit demand and supply relationships and enforce market clearing, and are therefore seen as desirable characterisations of long-term outcomes in which markets are assumed to be in equilibrium; for this reason they have been developed particularly in the US for the analysis of environmental regulation. However, CGE models are not generally based on time-series econometric methods and they have not typically been subjected to rigorous historical validation, either in terms of the values of the model's parameters or, more broadly, the underlying assumptions with respect to economic behaviour. They also typically tend to impose the dynamics of the model solution, and so cannot be used for historical validation of the overall model; the analysis of short- and medium-term impacts of policy changes, meanwhile, tends to arise from the assumptions inherent in the model. Their use in forecasting or scenario projections is

<sup>3</sup> This model is well documented in T.W. Hertel (ed.) (1997): *Global Trade Analysis: Modeling and Applications*, Cambridge University Press

therefore more limited. As a result, CGE models are not necessarily the most appropriate vehicle for understanding the processes of dynamic adjustments and structural change at the sectoral level. E3ME combines the features of an annual short- and medium-term sectoral model estimated by formal econometric methods with the detail and some of the methods of the CGE models, providing analysis of the movement of the long-term outcomes for key E3 indicators in response to policy changes. It is essentially a dynamic simulation model estimated by econometric methods. E3ME has been used for general macro analysis and for more focused analysis of policies relating to greenhouse gas mitigation, incentives for industrial energy efficiency and sustainable household consumption. Projects undertaken include:

- Productivity and Environmental Tax Reform in Europe (PETRE) - Anglo-German Foundation
- Development of macro and sectoral economic models aiming to evaluate the role of public health externalities in society (DROPS) - European Commission (DG Research)
- Links between the Environment and the Economy and Jobs - European Commission (DG Environment)
- Economic, social and environmental impacts of possible changes to the EU Emissions Trading Scheme - European Commission (DG Environment)
- Competitiveness Effects of Environmental Tax Reforms (COMETR) - European Commission (DG Tax)
- Modelling the Transition to Sustainable Economic Structures (Transust) - European Commission (DG Research)
- Macroeconomic Analysis of EU Transport Policy (TIPMAC) European Commission (DG TREN)

#### ***4.5 Overview of planned model improvements in MATISSE Work Package 8***

In the first phase (Month 1-18) the common framework conditions for tool development were defined (spatial and temporal coverage, spatial and temporal resolution, scenario assumptions). Major work went into extending and interlinking existing tools to meet requirements for a first application within the case studies and an exchange with the case studies that led to first conclusions about the adequacy of tools and further needs. In the second phase (Month 18-36) the interlinkages between existing tools will be revised and improved, based on the experience from preliminary applications to the case studies in the first phase. The revised set of interlinked tools will be applied to one or more of the case studies in a second iteration.

Work Package 8.1: The work here centers around the E3ME model, which represents the European economy in high structural detail and provides a short- and medium-term approach to the modelling of dynamic economic processes. This is an alternative approach to Computable General Equilibrium models, such as GTAP. In the first phase WP8.1 produced a scoping report looking at the position of externalities in ExternE and in E3ME and how the latter might be improved with additional sources and a greater number of GHGs. Previous work was extended by obtaining data on pollutants, emission sources and damage estimates. In the second phase, the following linkages will be established between WP8.1 and the case study in WP7.2 (Sustainable environmental technology - economic transition). E3ME is the core model being used in this case study. Scenarios have been calculated using E3ME to investigate the impact of the development/use of environmental technologies in the EU25 on the basis of the national environmental technology action plans (ETAP scenario). The results from the model development undertaken for MATISSE will be used in further case study work. In addition, the scenarios for E3ME and associated calculations of material use are being provided to WP5.1 (Dematerialization).

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Work Package 8.2-3: The work here focuses on the IMAGE integrated assessment model. The existing agricultural economic module of IMAGE will be partly replaced by the GTAP general economy model, which will improve the representation of economic processes, especially the agricultural sector and international trade. The existing biogeochemical module of IMAGE will be replaced by the LPJ model, which will improve the representation of carbon and water cycles. The following activities will be carried out: (1) Improving links between existing models IMAGE/GTAP (derivation of land supply curves, modelling of trade flows, implementation of policy instruments) and IMAGE/LPJ (improvement of crop model, link between carbon and water cycles, calculation of Net Primary Production (NPP)); (2) Conducting joint model runs, based on scenarios (provided by MATISSE Common Scenario Group and Global Environmental Outlook); (3) Applying joint models to two case studies WP5.1 (Dematerialization) and WP7.1 (Sustainable Technology Development). The focus here will be on future biomass energy scenarios for Europe, the contribution to a hydrogen-based transport sector and related environmental impacts (e.g. biodiversity loss) within and outside Europe.

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## **APPENDIX**

### **Evaluation results for model categories (including references for specific models)**

#### **1 *Biophysical models: Climate***

##### **1.1 *Introduction***

Climate models simulate long-term changes in atmospheric conditions, like temperature, precipitation and atmospheric concentrations of various gases. They are used both to reconstruct climate conditions in the past and produce scenarios of future trends. Drivers of climate changes can be natural or anthropogenic. Most climate models have a global focus and cover very long time scales, from several decades to millions of years. "General circulation models" (GCM) are sophisticated representations of the coupling of processes between the atmosphere and the oceans. "Earth system models of intermediate complexity" (EMIC) are attempts to link climate processes with simplified representations of vegetation and other land-based biogeochemical cycles.

##### **1.2 *Methodology***

Major dynamic processes of atmospheric physics and atmospheric chemistry are represented with mathematical equations. For historic reconstructions, the equations are combined to simulate and match existing data on atmospheric gas concentrations in the past, e.g. from ice cores or sediments. For scenarios, assumptions about the trends in major driving forces, e.g. anthropogenic greenhouse gas emissions, are fed into the model and the climate impact is derived.

##### **1.3 *Process***

Data generation and processing includes creating appropriate time series from available sources (sediments, ice cores, records). For scenarios, trends are created for future drivers, e.g. emissions. The scenario to be modelled is defined, e.g. emissions path and a check is made of the standard model parameters to determine whether these have to be adapted to certain problem conditions. Model simulations are run and, if appropriate, sensitivity analysis is conducted for the most important model assumptions and parameters.

##### **1.4 *Review***

###### **1.4.1 *Evaluation results***

Climate models provide valuable representations of the climate system, with a special focus on long-term changes. They usually have a global focus and are strong with regard to the biophysical components of the Earth system. The links to socio-economic processes are often limited. There is a certain level of disagreement on important outcomes, e.g. spatial precipitation patterns, which are important for other processes, especially those related to economics. Model coupling for the purpose of more appropriate sustainability assessment has to be further improved. Climate models are most demanding with regard to computer power.

### **1.4.2 Experience**

Climate models have been applied to reconstruct and explain past climate conditions and variability, as systematic climate observations only exist for about 100 years. This has helped to distinguish between naturally occurring climate change and anthropogenic change. Certain discrete events in the past, like species extinctions, could be explained with climate effects. The models have also been used for climate scenarios, depending on various assumptions for future human behaviour. The work of IPCC and UNFCCC has been largely based on climate modelling results.

### **1.4.3 Combinations**

Climate models are integral parts of all Integrated Assessment models. Many links exist with models on biogeochemistry, hydrology, economy, and health. Model results have been used in scenarios, vulnerability analysis, and cost-benefit-analysis. IPCC reports on climate change, impacts and adaptations are the prime example of combinations of these tools.

Climate models provide inputs for: biogeochemistry models, hydrology models, economy models; scenario analysis; cost-benefit-analysis; vulnerability analysis.

Especially for scenarios, climate models need inputs from economy models and demography models.

### **1.4.4 Strengths and weaknesses**

#### Strengths:

- Strong biophysical representation of climate processes
- GCM: most advanced coverage of atmosphere/ocean coupling
- EMIC: consistent integration between atmosphere, ocean, land surface
- High flexibility in temporal scale and coverage, ranging from few decades to many millennia
- Global coverage
- Good representations of past climate trends
- Most models agree on future trends in average global climate conditions

#### Weaknesses:

- Limited coverage of anthropogenic processes
- High complexity
- Extreme demand for computer power
- Not appropriate for short-term forecasts
- Coarse spatial resolution
- Disagreement between models on scenarios for regional climate conditions, e.g. precipitation patterns
- Uncertainty analysis very difficult

### **1.4.5 References**

**HadCM3**

Collins, M.; Tett, S.F.B., and Cooper, C. (2001). "The internal climate variability of HadCM3, a version of the Hadley Centre coupled model without flux adjustments". *Climate Dynamics* 17: 61-81.

Gordon et al. (2000). "The simulation of SST, sea ice extents and ocean heat transports in a version of the Hadley Centre coupled model without flux adjustments". *Climate Dynamics* 16: 147-168.

### **HadAM3**

Pope, V.D.; Gallani, M.L., Rowntree, P.R., and Stratton, R.A. (2000). "The impact of new physical parameterizations in the Hadley Centre climate model — HadAM3". *Climate Dynamics* 16: 123-146.

### **ECHAM4**

[http://cera-www.dkrz.de/IPCC\\_DDC/SRES/ECHAM4/echam4opyc3.html](http://cera-www.dkrz.de/IPCC_DDC/SRES/ECHAM4/echam4opyc3.html)

[http://www-pcmdi.llnl.gov/projects/modeldoc/amip1/26mpi\\_ToC\\_b.html](http://www-pcmdi.llnl.gov/projects/modeldoc/amip1/26mpi_ToC_b.html)

Roeckner et al. 1992: Simulation of the present-day climate with the ECHAM model: Impact of model physics and resolution. MPI Report No. 93, ISSN 0937-1060, Max-Planck-Institut für Meteorologie, Hamburg, Germany, 171 pp.

### **ECHAM5**

Roeckner et al. 2005: Sensitivity of simulated climate to horizontal and vertical resolution in the ECHAM5 atmosphere model, *J. Climate*, accepted, 2005.

Roesch, A., and E. Roeckner, Assessment of snow cover and surface albedo in ECHAM4 and ECHAM5, *J. Climate*, accepted, 2005.

Wild, M., and E. Roeckner, Radiative fluxes in ECHAM5, *J. Climate*, accepted, 2005.

Hagemann, S., K. Arpe and E. Roeckner, Validation of the hydrological cycle simulated by the GCM ECHAM5, *J. Climate*, accepted, 2005.

### **CLIMBER-3**

<http://www.pik-potsdam.de/climber-3/>

<http://www.pik-potsdam.de/emics/>

Marisa Montoya et al. (2005) "The earth system model of intermediate complexity CLIMBER-3a." Springer-Verlag

<http://www.pik-potsdam.de/research/research-domains/earth-system-analysis/climber3/publication.html>

### **MAGICC/SCENGEN**

Hulme, M., Jiang, T. and Wigley, T.M.L., 1995: SCENGEN, a climate change scenario generator, a user manual. Climatic Research Unit, University of East Anglia, Norwich, U.K., 38 pp.

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Wigley, T.M.L., 1995: MAGICC and SCENGEN: Integrated models for estimating regional climate change in response to anthropogenic emissions. (In) *Climate Change Research: Evaluation and Policy Implications-Proceedings of the International Climate Change Research Conference*, Maastricht, The Netherlands, 6-9 December 1994 (eds. S. Zwerver, R.S.A.R. van Rompaey, M.T.J. Kok and M.M. Berk), Elsevier Science B.V., Amsterdam, The Netherlands, 93-94.

## **2 Biophysical models: Hydrology**

### **2.1 Introduction**

Hydrology models contain mathematical descriptions of the major elements of the water system, i.e. rivers, lakes, oceans, soil, atmosphere. They describe the impact of natural (e.g. climate change) and/or anthropogenic (e.g. water withdrawals) disturbances on water flows and water cycles. They can be applied on different scales, ranging from local to global. Some models cover water quality aspects.

### **2.2 Methodology**

Mathematical descriptions of the major water stocks and water flows between the different compartments of the water system are the backbone of hydrology models. Scenarios on natural and anthropogenic disturbances are fed into the models and the resulting changes in water flows and stocks are calculated. Results are usually presented based on Geographic Information Systems (GIS).

### **2.3 Process**

The major elements of the water sub-system under investigation have to be identified (river basin, sub-basin, or hydrotope). Scenarios on relevant disturbances (e.g. climate change, irrigation needs) have to be derived from other models or other external sources. Modelling results have to be related to their geographical location using GIS.

### **2.4 Review**

#### **2.4.1 Evaluation results**

The water cycle provides an important link between human activities and environmental processes. Hence, hydrology models represent a very important compartment of the Earth system. They are very flexible with regard to spatial disaggregation. There are many important links to other natural and socio-economic phenomena. However, most hydrology models have a strong natural scientific bias, anthropogenic processes are often under-represented. Model coupling with socio-economic models has to be improved, but this is a huge challenge, as hydrology models in themselves already deal with very complex systems. The demand for computer power is high.

#### **2.4.2 Experience**

Changes in the water cycle have been analysed on the global level, the river-basin level, and the sub-basin level. Aspects of global climate change, irrigation demand for food production, and river management options have been important research topics.

#### **2.4.3 Combinations**

Various Integrated Assessment studies on the impact of climate change and population growth have been carried out.

#### **2.4.4 Strengths and weaknesses**

##### Strengths:

- Consistent representations of the water cycle, one of the basic requirements of life
- Highly flexible in temporal and spatial scaling
- Strong relationship with many other natural and social processes
- Provide crucial links between environment and anthroposphere

##### Weaknesses:

- Limited coverage of anthropogenic processes
- High complexity
- Highly non-linear behaviour possible
- High demand for computer power

#### **2.4.5 References**

##### **WaterGAP**

<http://www.usf.uni-kassel.de/usf/forschung/projekte/watergap.en.htm>

Döll, P., Kaspar, F., Lehner, B. (2003): A global hydrological model for deriving water availability indicators: model tuning and validation. *Journal of Hydrology*, 270: 105-134.

Döll, P., Alcamo, J., Henrichs, T., Kaspar, F., Lehner, B., Rösch, T., Siebert, S. (2003): The global integrated water model WaterGAP2.1. In: *EuroWasser, Kassel World Water Series*, 5, pp. 18. University of Kassel, Kassel.

Alcamo, J., Henrichs, T., Rösch, T. (2000): *World Water in 2025: Global modeling and scenario analysis for the World Commission on Water for the 21st Century*. *Kassel World Water Series*, 2. Center for Environmental Systems Research (CESR), University of Kassel.

Available at: <http://grdc.bafg.de/servlet/is/5071/>

##### **SWIM**

[http://www.pik-potsdam.de/~valen/swim\\_manual/](http://www.pik-potsdam.de/~valen/swim_manual/)

Post, J., Habeck, A., Hattermann, F.F., Krysanova, V., Wechsung, F. and Suckow, F., 2006. Evaluation of water and nutrient dynamics in soil-crop systems using the eco-hydrological catchment model SWIM (Soil and Water Integrated Model). *Environmental Modelling and Assessment*, in revision.

Krysanova, V., F. Wechsung & F. Hattermann, 2005. Development of the ecohydrological model SWIM for regional impact studies and vulnerability assessment. *Hydrological Processes*, 19, 763-783.

Hattermann, F., V. Krysanova, F. Wechsung & M. Wattenbach, 2005. Runoff simulations on the macroscale with the ecohydrological model SWIM in the Elbe catchment - validation and uncertainty analysis. *Hydrological Processes*, 19, 693-714.

##### **IRM-ABM**

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Valkering et al. 2005: Simulating Stakeholder Support in a Policy Process: An Application to River Management” in *Simulation*; 81: 701-718.

### **3 Biophysical models: Biogeochemistry**

#### **3.1 Introduction**

Biogeochemistry (BGC) models explain vegetation growth and related natural exchange processes, based on climate conditions, soil quality, nutrient and water supply. Some models focus on natural vegetation, while others deal with agricultural crops or forestry only. They can be used to simulate external effects, e.g. climate change, on vegetation growth and related material fluxes, e.g. change in soil carbon, water balances. They can also be used to simulate potential natural vegetation, e.g. for reconstructing past vegetation cover or for demonstrating current anthropogenic disturbance.

#### **3.2 Methodology**

Major plant growth functions, e.g. photosynthesis, and exchange processes with the environment, i.e. through carbon or water fluxes, are simulated with mathematical equations. Vegetation growth depends on temperature, radiation, water supply, nutrient supply. This can be applied to a single plant or vegetation type, but also to larger areas (grid cells, regions) that are populated by representative plant types. Vegetation is classified in certain functional types which can be treated as homogeneous (e.g. grass, tropical trees, boreal trees, a certain crop type). Each of these types is calibrated according to stylised empirical conditions.

#### **3.3 Process**

Data generation and processing includes creating appropriate time series from available sources (temperature, precipitation, nutrient supply). For scenarios, trends are created for future drivers, e.g. climate change, the scenario to be modelled is defined, e.g. in terms of temperature rise, a check is made whether standard model parameters have to be adapted to certain problem conditions, model simulations are run and, if appropriate, sensitivity analysis is conducted with respect to most important model assumptions and parameters. For past reconstructions spatial vegetation patterns are validated with observations, e.g. satellite images.

#### **3.4 Review**

##### **3.4.1 Evaluation results**

The representation of biogeochemical cycles is in itself a highly integrative task. BGC models are flexible with regard to thematic and spatial coverage. Some of them, especially on larger scales, are very resource intensive (manpower, computer power). Some ecological functions, especially on larger scales, still lack a good theoretical foundation. The links to important socio-economic processes are still limited. Limited data availability constrains model validations. But improved supply of satellite remote sensing information will strengthen these modelling applications. BGC models are key components of Integrated Assessment exercises with links to many important parts of the Earth system.

##### **3.4.2 Experience**

BGC models have been used to reconstruct past vegetation patterns, depending on climate model results. This can range back from several decades to several millennia. BGC models can cover single

plants, but also regions and the global scale. Crop models have been used to simulate the impact of climate change or changed nutrient supply on crop growth, which is important for food security questions. IPCC reports on climate impacts and adaptation have been based upon this. Vegetation cover has an influence on the degree of energy absorption of the land surface and hence an impact on climate.

### **3.4.3 Combinations**

BGC models have been used in some Integrated Assessment models. There are many links with models on climate and hydrology. Model results have been used in scenarios and vulnerability analysis. IPCC reports on climate change, impacts and adaptations are the prime example of the use of these tools. There are also examples of regional impact studies of climate change on vegetation, hydrology, agricultural production, and regional economic development.

BGC models provide inputs for: Hydrology models, climate models (EMIC), land use models, agricultural sector models; scenario analysis; vulnerability analysis.

BGC models require inputs from climate models.

### **3.4.4 Strengths and weaknesses**

#### Strengths:

- Strong biophysical representation of vegetation and related processes
- High flexibility in temporal scale and coverage, ranging from days to millennia
- Flexible in spatial coverage, ranging from single plants to global
- Good representations of past vegetation trends
- Provide crucial links between biophysical conditions and human activities, especially crops and forestry

#### Weaknesses:

- Limited coverage of anthropogenic processes
- High complexity
- High demand for computer power
- Difficult to validate, limited data availability
- Ecological functions not always clear
- Uncertainty analysis very difficult

### **3.4.5 References**

#### **LPJ**

<http://www.pik-potsdam.de/lpj/>

Sitch et al. (2003), *Global Change Biology*, 9, p. 161-185

Sitch et al. (2003) "Evaluation of ecosystem dynamics, plant geography and terrestrial carbon cycling in the LPJ Dynamic Vegetation Model". *Global Change Biology* 9: 161–185

Gerten et al. (2004) "Terrestrial vegetation and water balance: hydrological evaluation of a dynamic global vegetation model". *Journal of Hydrology* 286: 249–270

### **WOFOST**

Boogaard et al. (1998). User's guide for the WOFOST 7.1 crop growth simulation model and WOFOST Control Center 1.5. DLO-Winand Staring Centre, Wageningen, Technical Document 52, 144 pp.

Supit I., A.A. Hooijer, C.A. van Diepen (eds.), 1994. "System description of the WOFOST 6.0 crop simulation model implemented in CGMS. Volume 1: Theory and Algorithms", EUR 15956, Office for Official Publications of the European Communities, Luxembourg. 1994-146 pp. catno: CL-NA-15956-EN-C

Hijmans R.J., I.M. Guiking-Lens, C.A. van Diepen, 1994. "WOFOST 6.0: User's guide for the WOFOST 6.0 crop growth simulation model". Wageningen, DLO Winand Staring Centre, Technical Document 12. 1994-146 pp.-48 figs.- 78 ref. ISSN 0928-0944

Kraalingen D.W.G. van, 1991. " The FSE system for crop simulation " Simulation reports CABO-TT 23, CABO-DLO, WAU-TPE Wageningen, 77 pp.

### **4C ("FORESEE")**

<http://www.pik-potsdam.de/topik/t6scs/safe/home/4c.html>

Bugmann, H., Grote, R., Lasch, P., Lindner, M. & Suckow, F., 1997: A new forest gap model to study the effects of environmental change on forest structure and functioning. In: Mohren, G.M.J. & Kramer, K. (eds.), *Global Change Impacts on Tree Physiology and Forest Ecosystems*. *Forestry Sciences* Vol.52, Kluwer Academic Publishers, 255-261.

Schaber, J., F.-W. Badeck, P. Lasch (1999). Ein Modell der Sukzessionsdynamik europäischer Wälder - Forest Ecosystems in a changing Environment (4C). Deutscher Verband forstlicher Versuchsanstalten - Sektion forstliche Biometrie und Informatik. 11. Jahrestagung und Internationale biometrische Gesellschaft. Deutsche Region. Arbeitsgruppe Ökologie, Herbstkolloquium. (D. R. Pelz, O. Rau and J. Saborowski, Hrsg.). Freiburg: 212-217.

Suckow, F.; Badeck, F.-W.; Lasch, P.; Schaber, J. 2001: Nutzung von Level-II-Beobachtungen für Test und Anwendungen des Sukzessionsmodells FORESEE. *Beitr. Forstwirtsch. u. Landschaftsökol.*, 35, 84-87.

Lasch, P., F. Badeck, M. Lindner and F. Suckow. 2002. Sensitivity of simulated forest growth to changes in climate and atmospheric CO<sub>2</sub>. *Forstw. Cbl.* 121, Supplement 1, 155-171.

### **GAIM Model Intercomparison**

<http://gaim.unh.edu/Structure/Intercomparison/EMDI/models/index.html>

Schunk, R.W., L. Scherliess, and J.J. Sojka, Ionospheric Specification and Forecast Modeling, *Journal of Spacecraft and Rockets*, 39, 314, 2002.

Schunk, R.W., L. Scherliess, J.J. Sojka, and D. Thompson, Global Assimilation of Ionospheric Measurements (GAIM), *Radio Science*, 39, RS1S02, doi:10.1029/2002RS002794, 2004.

<http://ccmc.gsfc.nasa.gov/models/gaim.php#pubs>

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## **4 Socio-economic models: General economy**

### **4.1 Introduction**

General economy models (GEM) are aggregated representations of an economic system, usually a nation state (or a group of nations). They are "closed" in a sense that they are based on a consistent accounting framework that covers the whole economy. GEM can be highly stylised, consisting of only one or very few sectors, but focussing on the complex dynamic processes of investment, innovation and economic growth, especially in the longer run. Others, like general equilibrium models or multi-sector econometric models can cover a large number of economic sectors, but have to be more restricted with respect to dynamics, structural flexibility, and time horizon.

### **4.2 Methodology**

Major economic processes, like production, consumption, or government activities, are represented by mathematical equations. Behavioural patterns of the agents involved are usually based on some form of utility maximisation. Markets and sectors are linked through prices of goods and services. The models are driven either by external shocks, e.g. demographic changes, government interventions, environmental conditions, or by internal dynamic processes that partly depend on initial conditions, e.g. investment behaviour. The impacts of these changes are measured in terms of economic output (e.g. GDP), employment, trade balance, and state budget.

### **4.3 Process**

The process includes generation of an appropriate database, usually taken from national accounts and other statistics. For equilibrium models model parameters are collected or calibrated. For econometric models model equations are fitted to past observations. External shocks and drivers of change are defined, especially for forecasts, e.g. demographic change, different policy options and climate change. Standard models are adapted to specific problems, e.g. parameter choices. Model scenarios are run and sensitivity analysis is conducted with respect to critical model assumptions and parameters.

### **4.4 Review**

#### **4.4.1 Evaluation results**

GEM provide consistent representations of the economic system as a whole. This is important for the analysis of important economic processes, stocks and flows. It is also crucial to evaluate certain policies, especially macroeconomic steering, which provide the background for all other economic activities. There is some methodological dispute about equilibrium and dis-equilibrium concepts as well as the representation of dynamics. Most GEM lack detail with regard to certain economic sectors, and the links to biophysical environmental conditions are especially weak. So far there are limited attempts in the area of model coupling, with the exception of climate change studies.

#### **4.4.2 Experience**

GEM are used for macroeconomic forecasting as well as national and international policy evaluations, i.e. tax reforms, labour market reforms, energy policies, trade negotiations, effects of foreign investment and other forms of globalisation. GEM are standard tools for the support and analysis of macroeconomic policy-making. They have also been used for assessing the economic welfare effects of climate change.

### **4.4.3 Combinations**

GEM provide inputs for all tools that depend on macroeconomic trends and forecasts, e.g. demographic models, partial sector models, climate models, land use models. The first generation of Integrated Assessment models were basically combinations of climate models with general economy models. GEM are also used for scenario analysis and cost-benefit-analysis.

GEM can provide inputs for: climate models, land use models, economic sector models; scenario analysis; cost-benefit analysis.

For some types of analysis GEM use inputs from climate models.

### **4.4.4 Strengths and weaknesses**

#### Strengths:

- "Closed" representation of whole economy
- Close relationship to official statistics and accounting
- Immediate link to policy formulation and implementation
- Flexible in structural representation of the economy
- Growth models: good coverage of economic dynamics and long time scales
- Multi-sector models: good coverage of intra-sectoral links and structural aspects
- Econometric models: strong link to past observations

#### Weaknesses:

- Limited coverage of biophysical processes and constraints
- Limited coverage of institutional settings
- Usually constrained to time scales of a few years (but regularly applied to much longer time scales)
- Insufficient empirical base for many model parameters
- Strongly simplified behavioural patterns of economic agents
- Insufficient understanding of dynamic processes related to technological change, human preferences, and institutions
- Usually non-spatial

### **4.4.5 References**

#### **E3ME**

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#### **GTAP**

<http://www.gtap.agecon.purdue.edu/>

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Hertel, T. W. and M. E. Tsigas (1997). *Structure of GTAP. Global Trade Analysis: Modeling and Applications*. T. W. Hertel. Cambridge, Cambridge University Press.

### **GEM-CCGT**

<http://ccgt.zew.de>

Böhringer, C., Löschel, A. (eds.) (2004), *Climate Change Policy and Global Trade*, ZEW Economic Studies 26, Physica, Heidelberg.

### **GEM-E3**

<http://gem-e3.zew.de>

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### **SNI-AGE**

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### **NEMESIS**

<http://www.nemesis-model.net>

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### **QUEST II**

Giudice, G., Turrini, A., In't Veld, J. (2003), *Can Fiscal Consolidations be Expansionary in the EU? Ex-post Evidence and ex-ante Analysis*. In: European Commission (ed.), *European Economy*, No. 195, Brussels.

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## **5 Socio-economic models: Partial economic sectors**

### **5.1 Introduction**

Economic sectors are important descriptive units of an economic system. Partial economic sector models (PEM) have a focus on a certain sector of the economy, for which they provide much more structural detail than multi-sectoral general economy models can do. Sector models work on the simplifying assumption that major feedbacks between the specific sector and the economy as a whole, e.g. effects on employment and growth, can be neglected. Taking macroeconomic conditions and certain prices as given, the allocation and distribution effects within the sector can therefore be looked

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at more realistically. Moreover, specific environmental conditions and constraints can be taken into account.

## **5.2 Methodology**

Most sector models are either partial equilibrium models or mathematical programming models, which optimise a certain sectoral goal function. Consumption, production and prices of sector-specific goods and services are represented through mathematical equations. Model parameters are either derived from statistical time series data or calibrated to the conditions of a certain base year. The model can be driven through macroeconomic changes, policy changes or environmental changes. Depending on the structural detail of the model, a wide range of sector-specific policy instruments can be defined and implemented.

## **5.3 Process**

The process includes: generation of an appropriate database, mostly taken from official statistics, in some cases supplemented by surveys; collection and/or calibration of model parameters; definition of external shocks and drivers of change, especially for forecasts, e.g. macroeconomic conditions, different policy options, climate change; adaptation of standard model to a specific problem, e.g. parameter choices; running model scenarios; conducting sensitivity analysis with respect to critical model assumptions and parameters.

## **5.4 Review**

### **5.4.1 Evaluation results**

PEM can be very rich in sectoral detail and specifics of certain economic activities, while they have to neglect macroeconomic consistency. PEM are very flexible in their structure and are better prepared to consider explicit links to environmental conditions and constraints than GEM, which supports more integrative approaches. PEM are usually poor in covering dynamics of economic decisions, and they often focus on short- to medium-term changes. PEM have been used as important building blocks in many IA studies.

### **5.4.2 Experience**

PEM are used for the analysis of sector-specific national and international policies, i.e. taxes and subsidies, trade negotiations, energy policies, agricultural policies, transport policies. PEM are standard tools for the support and analysis of sector-specific policy-making and distributional aspects for certain economic groups. They have been used for assessing the effects of climate change on food production and alternatives for future energy mixes.

### **5.4.3 Combinations**

Sector models depend on inputs from macroeconomic models for basic conditions. Agricultural sector models are partly overlapping with land use models. Energy models provide important links to the climate system. PEM are also used for scenario analysis and cost-benefit-analysis in a sector-specific context. Sector models with a focus on environmental-economic linkages can be linked with biogeochemistry or hydrology models.

Sector models can provide inputs for climate models, land use models; scenario analysis; cost-benefit analysis.

Sector models require inputs from general economy models and optionally from all types of biophysical models.

#### **5.4.4 Strengths and weaknesses**

##### Strengths:

- Detailed representation of specific economic sector
- Immediate link to policy formulation and implementation
- Flexible in structural representation of the sector, including distributional aspects between agent groups
- Links between economic decisions and environmental constraints
- Relatively simple structure
- Some spatial representation of economic activities possible

##### Weaknesses:

- Limited feedback with macroeconomic system
- Limited coverage of institutional settings
- Usually constrained to time scales of a few years due to structural rigidities
- Insufficient empirical base for many model parameters
- Strongly simplified behavioural patterns of economic agents
- Biophysical constraints usually taken as exogenous

#### **5.4.5 References**

##### **POLES (Energy sector model)**

<http://www.upmf-grenoble.fr>

Russ P., Criqui P. (2007). Post-Kyoto CO2 emission reduction : the soft landing scenario analysed with POLES and other world models. *Energy Policy*, vol. 35, n° 2, p. 786-796.

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Capros et al. (1999) European Energy and CO2 Emissions Trends to 2020: PRIMES model v.2 *Bulletin of Science Technology Society*.1999; 19: 474-492

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##### **WATSIM (Agricultural sector model)**

[http://www.agp.uni-bonn.de/agpo/rsrch/watsim/wats\\_ov\\_e.htm](http://www.agp.uni-bonn.de/agpo/rsrch/watsim/wats_ov_e.htm)

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**IMPACT (Agricultural sector model)**

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[http://www.agp.uni-bonn.de/agpo/rsrch/capri/capri\\_e.htm](http://www.agp.uni-bonn.de/agpo/rsrch/capri/capri_e.htm)

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[http://www.agp.uni-bonn.de/agpo/rsrch/raumis\\_e.htm](http://www.agp.uni-bonn.de/agpo/rsrch/raumis_e.htm)

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**TREMOVE (Transport sector model)**

<http://www.tremove.org>

## **6 Socio-economic models: Demography**

### **6.1 Introduction**

Demography models provide long-term projections of future population changes, based on external scenarios about natural and anthropogenic influences. Major driving forces are changes in environmental conditions, fertility, epidemiology, mortality, and more general socio-economic conditions.

### **6.2 Methodology**

Demographic changes and transitions are described with mathematical functions, based on statistical techniques, and partly on system dynamics approaches. Populations are usually disaggregated into various age cohorts with different properties, in order to make forecasts more reliable.

### **6.3 Process**

External scenarios and/or model results on major environmental and economic pressures and conditions have to be collected. The resulting demographic changes are usually presented using tables and graphs.

### **6.4 Review**

#### **6.4.1 Evaluation results**

Demographic changes are long-term processes that are key drivers of many socio-economic as well as environmental changes. Demography models provide the relevant background for many other modelling and scenario exercises in other thematic areas. Hence, they are important building blocks for all IA studies. However, problems and inconsistencies may arise due to the fact that demography models themselves rely on input from other disciplines. This may cause cyclical relationships in model coupling and scenario studies and should be treated more carefully in future applications, especially in the realm of ISA.

#### **6.4.2 Experience**

Demography models are regularly being used for national and global population projections, based on various future scenarios (see Population project at IIASA). Projections of future global population size have been revised downwards several times in recent years. However, considerable uncertainties remain about the speed of the demographic transition on the global scale, and especially in many poor countries.

### **6.4.3 Combinations**

Demography models have provided essential inputs for long-term economic projections with regard to climate change, e.g. SRES scenarios for IPCC. Demographic forecasts are also essential for projecting future developments of national pension systems.

### **6.4.4 Strengths and weaknesses**

#### Strengths:

- Strong representation of socio-economic sub-system
- Description of a key driver for social and environmental change
- Suitable for long-term projections

#### Weaknesses:

- Rather narrow thematic focus
- Limited integration of environmental processes
- Reliance on socio-economic conditions, which may cause cyclical relationships between various model types (i.e. demographic projections depend on economic projections, which in turn depend on demographic projections)

### **6.4.5 References**

#### **PHOENIX**

<http://arch.rivm.nl/ieweb/ieweb/index.html?tools/phoenix.html>

Hilderink, H.B.M. (2000): World Population in Transition: An Integrated Regional Modelling Framework, PhD Thesis University Groningen, pp 256, Thela Thesis/Rozenberg, Amsterdam.

#### **IIASA Population project**

<http://www.iiasa.ac.at/Research/POP/index.html>

W. Lutz, W.C. Sanderson, and S. Scherbov (eds.), The End of World Population Growth in the 21st Century. New Challenges for Human Capital Formation and Sustainable Development, London, Earthscan, 2004.

## **7 Socio-economic models: Public Health**

### **7.1 Introduction**

The population health paradigm places the traditional medical model of individual care within the context of multiple determinants of health. There are various health models available for a wide range of purposes. Some explore future health scenarios (PHSF model; TARGETS model), others place human health in an ecosystem context (Butterfly Model of Health; Mandala of Health model). The MIASMA model focuses on the health impacts of atmospheric pollutants. The model is driven by scenarios of population figures and atmospheric changes, superimposed on baseline data regarding disease incidence, climatic conditions, and ozone-layer thickness.

## **7.2 Methodology**

The objective of most of these models is to provide a better understanding of the dynamics underlying the health impacts of environmental changes, e.g. climate change and ozone depletion, and the sensitivities and uncertainties surrounding these impact estimates. In this context, the instructive and educational value of models presented can strongly increase our awareness of the potential health impacts of environmental changes. Another goal of the modelling framework is to help identify gaps in our knowledge of the processes underlying the impacts studied, which may help to set the agenda for further research.

## **7.3 Process**

First, external scenarios on socio-economic and environmental conditions have to be specified or taken from other models. Then, baseline data on the health situation have to be defined. The models can then be used to derive the health impacts, based on a large number of health determinants from various combined scenarios of external drivers.

## **7.4 Review**

### **7.4.1 Evaluation results**

Models on public health have a special status, as they are neither strongly linked to economic models nor to most biophysical models. However, they have to take relevant socio-economic as well as environmental conditions into account. The number of public health models for ISA is still limited, although the importance of health issues for economic processes and the impact of environmental conditions on public health is high. In the future, public health considerations have to play a stronger role in ISA.

### **7.4.2 Experience**

Several models have been used either to analyse the link between biophysical and environmental conditions and human health, or to provide future scenarios on health impacts of environmental changes. The MIASMA model has been used successfully in various educational settings. Individual scientists have used the tool and experiments with it have been discussed in international 'assessment'. This tool is less useful to for policy analysts.

### **7.4.3 Combinations**

Newer versions of the MIASMA model have successfully been coupled to newer GCM models and the SRES scenarios. Output of the tool has been aggregated and used in other models, like FUND, IMAGE and TARGETS. Some health models are integrated into a modular framework of other socio-economic and biophysical models for consistent feedbacks. Health models require either scenario inputs or model inputs on key socio-economic and biophysical conditions. For example, the MIASMA model relies on global and GCM climate change scenarios, as well as on input regarding population development.

### **7.4.4 Strengths and weaknesses**

#### Strengths:

- Comprehensive list of health determinants
- Covering different levels of causality

- Usually closely linked with other modules
- First IA model on health-climate relationship
- Straightforward user interface with self-explaining help files (MIASMA)
- Useful for educational purposes (MIASMA)

Weaknesses:

- Complex models
- Distinction between direct and indirect health determinants
- Limited response variables
- Not easily adaptable for different regions
- Limited possibility to change settings

## **7.4.5 References**

### **MIASMA**

- Martens, P. (1998). *Health and Climate Change: Modelling the impacts of global warming and ozone depletion*. Earthscan Publications Ltd., London.
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### **TARGETS**

- Rotmans, J. and H. J. M. de Vries, Eds. (1997). *Perspectives on Global Change: The TARGETS approach*. Cambridge, UK, Cambridge University Press.

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## **8 Integrated models: Land use**

### **8.1 Introduction**

Land use change models (LUC) are integrated models that link important economic activities like agriculture, forestry, transport or energy production, with environmental processes. Land use activities represent some of the most intensive and closest links between society and nature. Some LUC focus more on biophysical determinants of human land use activities, while others are more closely linked to economic decision models that treat biophysical conditions as decision constraints. LUC have been applied on very different spatial scales, ranging from single farms to global coverage.

### **8.2 Methodology**

LUC comprise a wide variety of methodological approaches. They include rather descriptive approaches which try to derive spatial land use patterns using GIS tools. There are also spatial econometric models, which try to determine causal effects of land use changes and their spatial distribution, based on spatially explicit exogenous variables. Finally, there are simulation models that try to represent (parts of) the economic decision process as well as related biophysical processes, in order to simulate the combined outcome. All these models can also be used, to a certain extent, to make predictions about future land use patterns.

### **8.3 Process**

The level of spatial coverage has to be determined. The relevant economic and biophysical processes to be modelled explicitly have to be selected, including the distinction between endogenous and exogenous processes. Most importantly, the model interfaces between these processes have to be defined and developed. External conditions with regard to the natural and the socio-economic part of the model have to be defined, in many cases scenarios have to be applied. A suitable application for the joint modelling framework has to be defined and analysed.

### **8.4 Review**

#### **8.4.1 Evaluation results**

Land use models include a wide variety of approaches. Aspects of land use change are at the core of many society-nature interactions. Hence, the relevance of land use modelling has been recognised in recent years, especially in the area of IA studies. LUC are highly integrative and can provide important links to many other thematic issues, e.g. water, soil, carbon, energy, food, transport. Most LUC are well prepared to provide consistent links between economic decision-making and biophysical processes and constraints. However, many of these interfaces are not straightforward to simulate, and a number of paradigmatic and methodological challenges arise while coupling economic and biophysical process models. Data availability for many LUC applications is still limited, but improving. LUC will remain to play a key role in ISA, but efforts for further development have to be made.

#### **8.4.2 Experience**

LUC have been used for explaining land use changes in the past in many parts of the world. As land use is determined by many different factors, the representation and explanation of spatial land use patterns in the past is a huge task. Some LUC have also been applied for scenarios of future land use patterns, which is even more difficult, especially for a long time scale. Future land use is influenced for example by climate change as well as economic development, but at the same time land use itself

has an impact on climate and the economy. Important questions related to the endogeneity of important processes arise.

### **8.4.3 Combinations**

Land use models are crucial parts of many Integrated Assessment exercises. Land use models depend on coupling with economic decision models, especially partial economic sector models and agent-based models. But they also need the links to models of biogeochemical and climatic processes. GIS tools are important for data management and representation of land use modelling activities. Land use models rely on a number of external scenarios to reduce their complexity.

### **8.4.4 Strengths and weaknesses**

#### Strengths:

- Highly integrative by definition
- Combine economic decision-making with biophysical processes and constraints
- Cover some of the closest links between nature and society
- Can cover a wide variety of processes and aspects (soil, water, carbon, biodiversity, economy)
- Focus on spatially explicit processes

#### Weaknesses:

- Very complex
- Methodological and paradigmatic challenges
- Demanding task to link socio-economic and biophysical processes
- Distinction between exogenous and endogenous processes not always clear
- Highly demanding with respect to data and external scenarios
- Often limited data availability

### **8.4.5 References**

#### **AgLU**

Sands, R., Leimbach, M. (2003): Modelling agriculture and land use in an integrated assessment framework. *Climatic Change*, 56, 1/2, pp. 185-210.

#### **FARM**

Darwin, R. F. (1999). "A FARMer's View of the Ricardian Approach to Measuring the Effects of Climatic Change on Agriculture." *Climatic Change* 41(3-4): 371-411.

#### **MAGPIE/LPJ**

Lotze-Campen et al. (2005): "How tight are the limits to land and water use? – Combined impacts of food demand and climate change" *Advances in Geosciences*, 4, 23–28, 2005.

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### **SFARMMOD (ACCELERATES project)**

<http://www.geo.ucl.ac.be/accelerates/documents/LandUseModel.ppt>

Audsley (1981) An arable farm model to evaluate the commercial viability of new machines or techniques. *Journal of Agricultural Engineering Research*, 26 (2) 135-149

### **CLUE**

<http://www.cluemodel.nl/>

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### **Agent-based approaches**

Parker, D.C., Berger, T., Manson, S.M. (2002): Agent-based models of land-use and land-cover change. LUCR Report Series No. 6.

## **9 Integrated models: Integrated assessment**

### **9.1 Introduction**

Integrated assessment models (IAM) try to link, within a single modelling framework, main features of society and economy with the biosphere and climate systems. Starting with a focus on the connection between anthropogenic greenhouse gas emissions and climate change, the agenda of IAM now includes aspects of land use, biogeochemistry, hydrology, demography and health. The goal is to make more and more parts of the "Earth system" endogenous to the modelling framework. This is an ongoing process, in which major methodological barriers between scientific disciplines have to be overcome. For example, the optimisation mode of most economic models has to be linked with process-based, time-step models in climate or biogeochemistry research.

Integrated Assessment is a useful way of approaching highly complex issues like climate change, which involve a range of problems, disciplines, stakeholders and time and spatial scales. Climate change is very much a multi-actor problem; those involved include emitters of greenhouse gases, those who make climate change policy and those who will be affected directly and indirectly by climate change.

## **9.2 Methodology**

The major building blocks of IAM are well-established models from specific disciplines, e.g. climate models, biogeochemistry models, general economy models, demographic models. These sub-models or modules communicate through the exchange of well-specified input and output data sets. Many feedback loops may be required to make outputs of two modules from different domains consistent. In some cases shortcuts and simplifications have to be applied, often simplified versions of specific modules have to be developed. Earlier IAMs were built as single entities with the different representations of the component parts of the problem interacting within the one model. More recently, there has been a move towards a modular representation, in which the IAM is actually a grouping of a number of separate modules, each with a user interface, which can be added or removed as necessary to address different questions. The great advantage of this approach is its flexibility and greater transparency. This requires effort in creating clear user interfaces.

## **9.3 Process**

Original sub-models from relevant disciplines are select and modified. ; Appropriate input and output interfaces between sub -models are defined. Work flow for integrated modelling is designed. Joint scenarios are defined and model simulations are run.

## **9.4 Review**

### **9.4.1 Evaluation results**

Integrated assessment models are still the most ambitious approaches to integrative modelling and assessment. They provide important examples of how model coupling and integration can work across very different disciplines. While many IAM still lack some detail in their separate parts, this will improve over time. So far, most IAM have been confined to studies on climate change. This scope will be widened as the experience with model coupling continues to grow. But new challenges will also arise in this process. IA is still in an early stage, and many questions regarding interactions between different compartments of the Earth system are still unresolved. IAM provide the most promising approach to quantitative sustainability impact assessments.

### **9.4.2 Experience**

The first IAMs have been developed for climate impact studies. The Special Report on Emission Scenarios (SRES) summarises the modelling results of a range of prominent IAM for global scenarios on future climate change due to anthropogenic greenhouse gas emissions. These provided the basis for the IPCC third and fourth assessment reports. Applications in areas other than the economy/climate domain are still in an early stage.

### **9.4.3 Combinations**

Integrated Assessment models have been used in scenario analysis, vulnerability analysis and cost-benefit-analysis. IPCC and SRES reports on climate change, impacts and adaptation are the prime examples of these combinations.

IAM provide inputs for scenario analysis; cost-benefit-analysis; and vulnerability analysis

### **9.4.4 Strengths and weaknesses**

Strengths:

- Consistent integration between economy, climate and biosphere
- Operational modelling and model development in an interdisciplinary setting
- Puts specific schools of thought and methods into a broader perspective
- Global coverage
- Long time scales

Weaknesses:

- Necessary trade-off between specialisation (depth of coverage) and integration (breadth of coverage)
- Extreme complexity
- Extreme demand for computer power
- Not appropriate for short-term forecasts
- Whole modelling framework depends on "weakest link", e.g. in terms of spatial resolution
- Uncertainty analysis very difficult
- Problems of combining qualitative and quantitative research
- Credibility with users

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# **10 Integrated models: Qualitative systems analysis (QSA)**

## **10.1 Introduction**

QSA approaches structure and analyses socio-economic processes and their environmental implications based on qualitative influence (system) diagrams and additional information linked to these. The required information (only directions of change, no numerical measures) is less demanding for data providers and can be used in circumstances where quantitative assessments are not available, or where quantitative information is not strictly comparable. Nevertheless, QSA is based on mathematical functions and hence retains a rigorous approach. This assures that consistent chains of argumentation can be derived even from relatively vague initial statements.

## **10.2 Methodology**

The concept of qualitative differential equations (QDE) is applied in QSA. QDEs can use information from a wide variety of sources, e.g. a number of unrelated case studies, and filter out underlying mathematical patterns. Even complex chains of qualitative arguments ("if x rises and y falls, then z will ...") can be analysed in a structured way. As a result, qualitative changes in key indicators are obtained.

## **10.3 Process**

Basic information on relevant actors and realistic reactions has to be collected from a series of case studies, interviews and surveys, and/or other forms of stakeholder participation. Based on very simple table and matrix calculations, one can transparently derive the role of different elements in a system, identify policy levers, potential bottlenecks and ways to stabilize a system. The information has to be condensed, if one wants to apply QDEs. The qualitative evolution of the described system is then represented in mathematical and graphical form.

## **10.4 Review**

### **10.4.1 Evaluation results**

While all other modelling categories discussed here are based on quantitative approaches, QSA provide an alternative where either a quantitative model is not appropriate or its application is not possible. QSA can lead to highly complicated models. However, while many other models remain

"black boxes" to non-expert model users, QSA are especially suitable for interactive stakeholder participation. The focus on qualitative aspects of important processes is a strength and a weakness at the same time. While qualitative changes are often sufficient to get a broad overview and impression of certain developments, for many practical policy purposes additional quantitative assessments will still be demanded. QSA with rigorous mathematical foundations are still in an early stage of development and seem promising tools for future ISA, especially in combination with some quantitative tools.

#### **10.4.2 Experience**

QSA has been applied to derive so-called "Syndromes" of global environmental change, i.e. similar patterns of environmental degradation under certain critical conditions in very different parts of the world. This was possible through systematic evaluation of a large number of originally unrelated regional case studies. QSA has also been applied to the analysis of resource management options for fish stocks and to participatory methods for regional economic planning. Moreover, QSA has been applied in the Dutch Province of Limburg to derive policy options for sustainability, in a transport case study to derive innovative policy options, in a river-bed management case, and in a future study by the Ministry of the Flemish Region, Belgium.

#### **10.4.3 Combinations**

QSA has been used for scenario analysis; stakeholder dialogues; transition analysis.

QSA requires some stakeholder participation for generation of necessary inputs.

#### **10.4.4 Strengths and weaknesses**

##### Strengths:

- Facilitates mathematical modelling without quantitative information
- Appropriate in certain decision processes where quantitative figures are not available or not appropriate
- Useful for integrating knowledge from natural and social sciences
- Applicable to a wide range of issues
- Operational modelling and model development in an interdisciplinary setting
- Puts specific schools of thought and methods into a broader perspective
- Valuable enrichment for participatory processes

##### Weaknesses:

- Mathematically demanding
- Early development stage
- Broader acceptance by model users still open
- Results not always clear
- Can be demanding in terms of input generation

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### **10.4.5 References**

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## **11 Integrated models: Scenario building and planning (SBP)**

### **11.1 Introduction**

SBP models are highly integrative tools that are capable of representing a wide variety of social and natural compartments of the Earth system. They can be used to develop and structure complex scenarios, and also for analysing these scenarios in interactive stakeholder participation settings. They can be easily applied to analyse various policy measures and other human activities, e.g. environmental management.

### **11.2 Methodology**

SBP tools usually do not contain formal models of the actual processes involved. They work with large databases containing external information like statistics, time series, formal model results and scenario analyses. These different types of information can be combined in a customised manner. The analytical approach is often based on systems dynamics approaches. Convenient user interfaces are provided for a wide range of user groups, including non-experts.

### **11.3 Process**

Measures and scenarios to be analysed have to be defined in a structured way. Very often this is done with strong stakeholder involvement. Actors and their activity spaces have to be defined in the SBP tool. Interactions and feedback loops between various elements and actors have to be defined. As most SBP tools are not too demanding with respect to computer power, scenario and model refinement can be done in an iterative way.

### **11.4 Review**

#### **11.4.1 Evaluation results**

Scenario building and planning tools provide the link between process-based, formal modelling and broader scenario analysis. Most SBP are based on information derived from external sources, including other models and scenario studies, which can be combined to create new scenarios or pose new questions. Most SBP are equipped with convenient user interfaces and are especially suited for stakeholder participation activities. They are very flexible in their structural features, thematic and spatial focus. Some SBP are based on system dynamics approaches, which provides the possibility of non-linear effects and surprising results, but makes it sometimes difficult for non-experts to interpret the outcomes.

### **11.4.2 Experience**

SBP tools have been applied to a wide range of local to regional planning exercises. Moreover, future scenarios of society-nature interactions, with a focus on policy interventions, have been analysed.

### **11.4.3 Combinations**

SBP tools are closely related to all kinds of modelling tools and scenario analysis approaches.

### **11.4.4 Strengths and weaknesses**

#### Strengths:

- Highly integrative
- Very flexible structure
- Able to represent non-linear behaviour, feedback loops and surprises
- Requires limited computer power
- Usually equipped with convenient user interfaces

#### Weaknesses:

- Demanding with respect to input data
- No underlying process understanding
- Internal relationships not very transparent, results might not be plausible

### **11.4.5 References**

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#### **FAIR**

<http://www.mnp.nl/fair/>

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