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Modelling environmental change in Europe: towards a model inventory (SEIS/Forward)

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In the second phase, the overview of modelling tools and various model descriptions were revised and expanded by the authors of this report together with Stéphane Isoard (EEA), with support from Louise Martinsen (NERI). Also, the detailed model descriptions presented in an Annex to this report were reviewed by the respective modelling teams. In this context, we are thankful for the helpful responses received from:

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Executive summary

Simulation-based models are mathematical representations or computer simulations that attempt to describe the characteristics or relationships of physical events or socio-economic developments, usually in a quantitative manner. Over the past few decades, a myriad of models geared to depicting, simulating and projecting environmental changes have been developed and applied. Modelling tools have become an important cornerstone of environmental assessments, and play a key role in providing the data and indicators needed to describe the state of, trends in and prospects for the environment.

The European Environment Agency (EEA) is responsible for providing timely, targeted, relevant information about the environment — and therefore needs to have a good overview of progress with regard to the development, validation and case applications of different environmental models. This technical report provides a non-exhaustive overview of the modelling tools currently available to simulate environmental change at a European scale, and focuses in particular on those that support forward-looking environmental assessments. Underpinning this overview is a general characterisation of environmental models presented in this report, based on the environmental theme covered, the geographical coverage and the analytical structure of the respective models. Using this classification, a pool of more than 80 models is introduced, a limited number of which are described in more detail. This selection focuses in particular on the characteristics of models that have been used by the EEA in its recent environmental assessments and reviews.

The overview identifies significant gaps in the availability of modelling tools to support forward-looking assessment for some environmental issues at the European scale. Noteworthy gaps include models on key issues such as water quality and biodiversity, and approaches that build on agent-based models or participative, interactive modelling. It is not clear, however, whether such gaps are indicative of an actual lack of modelling tools for these issues, or merely point towards information about modelling tools not being easily accessible, or a combination of both. Either way, further dialogue with relevant research communities is needed to improve the availability of and access to state-of-the-art environmental models at the European scale.

To this end, the report therefore promotes the idea of developing an online model inventory. Such an inventory would have two main uses: first, it would provide an information source about modelling tools that can be used to underpin current and future state of the environment assessments in Europe; second, it can establish an information portal to facilitate interactions between the providers of modelling tools and the users of models and their results. Setting up an online model inventory can play an important role in fostering exchanges between research communities aimed at improving existing or developing new modelling tools that can support forward-looking environmental assessments. It can thus help to further stimulate the development and application of environmental forecasting techniques.

1 Introduction

Environmental policy-makers and others working with environmental issues are facing ever more demanding challenges. The situations they are grappling with are becoming more and more dynamic and complex. Rapid globalisation, for example, has increased the inter-dependencies of countries within Europe and with other global regions. These trends are expected to continue: emerging economies are growing quickly and new political alliances are being formed. Technological development, changes in consumption patterns and growing concerns about social inequity are also examples of areas where rapid and substantial changes are being driven by growing global inter-dependence and improved communication technologies. And while in the 1970s environmental issues barely made it into the public debate, today's discussions about the impacts of climate change and the use of natural resources are prominent topics on political agendas.

This rapid rate of change is increasing the **uncertainties** related to possible future trends and about the effectiveness of policies. Recent projections of environmental trends, in particular, give great cause for concern: climate change, for example, is increasingly recognised as a major threat to our way of life; air pollution is expected to continue to pose significant threats to human health; the observed decline in biodiversity and loss of ecosystem services is not expected to reverse unless new actions are introduced; and the unsustainable patterns of resource use and waste generation are expected to continue to worsen. These diverse issues — dynamic changes, complexity, uncertainty and unfavourable projections — occurring over a range of geographic scales, have triggered a growth in demand for forward-looking information and scenario-based assessments.

It is of crucial importance that forward-looking assessments are well designed, supported by appropriate **information systems**, and fit well into the existing policy-making processes, enhanced by stakeholder participation. It is also important that institutions at different levels develop their capacities to be able to manage these requirements in a coherent way. Recent EEA analyses (EEA, 2007a; EEA, 2008b) show that there are many shortcomings in the current use of forward-looking tools in environmental assessments. There is a need to:

- develop more targeted and sound forward-looking integrated environmental assessments at appropriate geographic scales (integrating social, technological, environmental, economic and demographic issues);
- include future perspectives routinely in regular environment reporting activities and systems (adapting existing information systems to regularly capture data on future perspectives and emerging issues, and including more forward-looking perspectives in national environmental reporting products);
- strengthen national and regional leadership in producing forward-looking assessments to support policy processes (developing more forward-looking studies under the leadership of regional and national institutions);
- strengthen institutional capacity to perform forward-looking assessments at all levels (increasing expertise and resources to build and carry out forward-looking studies) ([1]).
- improving institutional capacities to absorb and better utilise the information generated in processes of strategic political decision-making

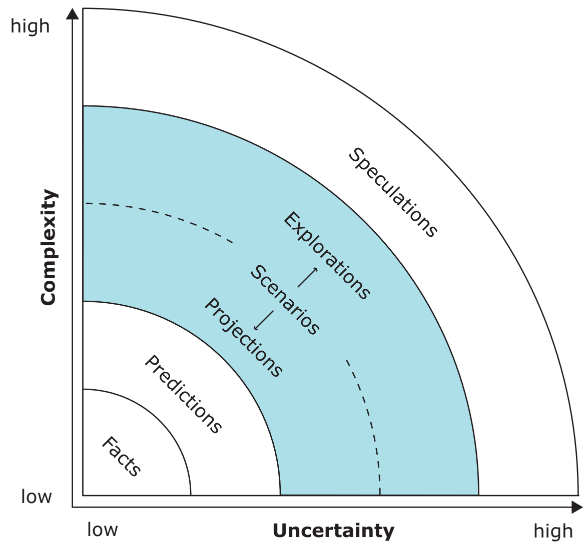
One of the basic requirements for the efficient use of forward-looking assessments is to improve and further develop forward-looking components of environmental information systems and integrate these into existing information systems. Here, the EEA is seeking to fill a gap in this area by developing **forward-looking components of environment**

([1]) A key task outlined in the regulation governing the European Environment Agency is 'to stimulate the development and application of environmental forecasting techniques so that adequate preventive measures can be taken in good time' (see Council Regulation No 1210/90, Article 2 (vii)).

information systems that will ultimately contribute to a Shared Environmental Information System (SEIS) ([2]). Such forward-looking information systems should include both purely quantitative information (such as projections) and combinations of qualitative and qualitative information (such as environmental scenarios). The objective of this forward-looking information system is not to produce better data to reflect a reality that has not yet unfolded, but to produce information that provides deeper understanding and insights into possible future developments (Figure 1.1).

A further requirement, in addition to improving the information base, is to ensure the consistency of assessments related to the past, present and future. There are many **tools and approaches** to support different types of assessment, but they may not provide coherent outputs if not selected and designed so as to complement each other. Such tools and approaches can be used with different effectiveness to deal with complexity and to cope with uncertainties that are increasing with time (Figure 1.2). While projections might effectively support decision processes where uncertainties are not too large, scenario-based analyses become more important in the context of longer-term assessments that deal with a larger degree of uncertainties and complexity, since they allow the combination of the creativity of (stakeholder-based) qualitative analysis and the rigour of modelling.

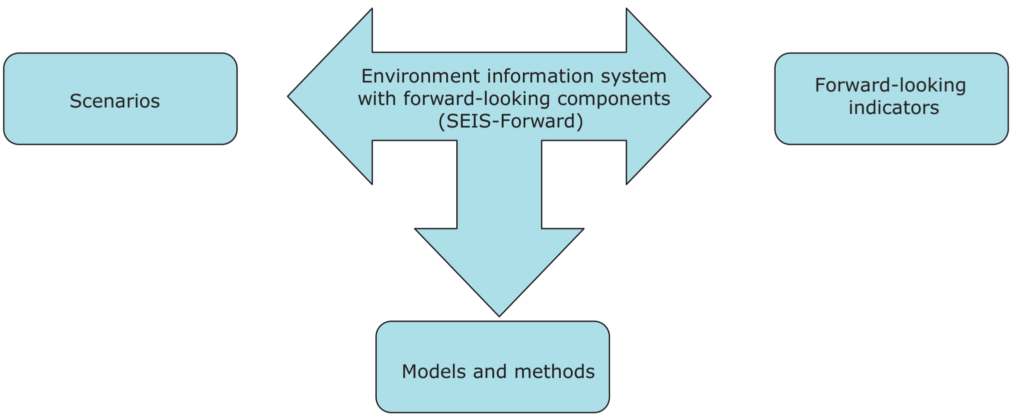
Figure 1.2 Dealing with the uncertainty and complexity of underlying system dynamics in forward-looking assessments



Source: Zurek and Henrichs, 2007.

Whatever the actual approach, models are necessary as soon as you need to quantify. Over recent decades, **models of environmental change** ([3])have thus become an important cornerstone of environmental assessments, and play a key role in providing the

Figure 1.1 Forward-looking information building blocks of environmental information systems for the support of integrated assessments



([2]) The Shared Environment Information System will be a distributed 'system of systems' for environmentally-relevant information, in which current systems for managing information centrally are increasingly replaced by systems based on access, sharing and interoperability (COM(2008)46 final Communication from the Commission to the Council, the European Parliament, the European and Social Committee and the Committee of the Regions/Towards a Shared Environmental Information System (SEIS) and EEA Shared Environment Information System Implementation Plan 2008 with EIONET).

([3]) Models of environmental change are mathematical representations or computer simulations that attempt to describe the characteristics or relationships of physical events or socio-economic developments, usually in a quantitative manner.

data and indicators needed to describe the state of, trends in and prospects for the environment. In particular, forward-looking assessments that aim to provide quantifiable forward-looking indicators about the future state of the environment need to rely heavily on information derived from models of environmental change. As an organisation responsible for providing timely, targeted, relevant information about the environment, the EEA is therefore dependent on having a good overview of progress with regard to the development, validation and case applications of different environmental models and related forward-looking indicators.

To further this, **EEA activities** in the past two years aimed at improving the information base of forward-looking assessment include (see also www.eea.europa.eu/themes/scenarios):

- establishing an inventory of **models** which support environment-related projections (this report);
- cataloguing forward-looking **indicators** relevant to environmental assessments (EEA, 2008a);
- cataloguing **scenarios** and forward-looking studies in Europe (to be published in 2009).

These three activities are being published in the form of a series of EEA technical reports labelled '**SEIS/Forward**'. These aims to reach as broad an audience as possible, and will also be made available on-line and updated regularly.

This technical report, one part of this 'SEIS/Forward' series, sets out to provide a non-exhaustive overview of modelling tools currently available to simulate environmental change at a European scale. It focuses in particular on models that are geared to supporting forward-looking environmental assessments and outlooks, as well as models that provide outlook indicators of environmental trends. Using this nomenclature, a pool of some 150 models is introduced in Chapter 3 and Annex 1. Building on this overview — supplemented by the presentation of a limited number of examples in more detail — some of the strengths and weaknesses of different approaches are discussed, and gaps in the current set of available models are highlighted. Annexes 2 and 3 describe a selection of models in more detail. A final chapter summarises the main findings of the review, promotes the idea of developing an online model inventory and reflects on the use of models in forward-looking environmental assessments.

2 Nomenclature of models of environmental change

There is **no standard nomenclature** for models of environmental change, nor is there a universally agreed classification system to describe key model characteristics. This report describes models of environmental change, grouped along three main dimensions: (i) thematic focus, (ii) geographical scale, and (iii) analytical technique. It also sets out a range of additional characteristics of models of environmental change.

Thematic focus

The first dimension used to group different modelling tools is **thematic focus**: the themes captured by the models and the outputs they produce. Related to this are the key input parameters and main output variables, or indicators, computed by different models. The themes used to group models here correspond to those highlighted in the EEA's Indicator Management Service (IMS, see http://ims.eionet.europa.eu/) see Table 2.1.

While many models have specific thematic foci, several may also address **multiple thematic issues**. In this report, such models are categorised according to their main thematic focus. For example, most models that focus on land use also need to address agricultural issues — but for the purpose of this review they are viewed as having a thematic focus 'land use'.

Nevertheless, there remain several models that cannot be assigned any main thematic focus, as

Table 2.1 Thematic focus of models and examples of corresponding indicators in the IMS

Thematic focus	**IMS category**	**Sample forward-looking indicators** (IMS indicator abbreviations in parentheses)
Agriculture	Agriculture	Fertiliser consumption (AGRI-F01), Fertiliser use (AGRI-F02), Gross nutrient balance (AGRI-F03)
Air quality	Air pollution	Emission of acidifying substances (APE-F01, APE-F02), Emissions of ozone precursors (APE-F03, APE-F04), Emissions of primary particulates (APE-F05, APE-F06)
Biodiversity	Biodiversity	Change in species diversity as a result of climate change (BDIV-F01)
Climate	Climate change	Projections of GHG emissions (CC-F01, CC-F02, CC-F03, CC-F04, CC-F05, CC-F06), GHG concentrations (CC-F07), Global and European temperature (CC-F10)
Energy	Energy	Final energy consumption (EE-F01, EE-F02), Total energy intensity (EE-F03, EE-F04), Total energy consumption (EE-F05, EE-F06), Total electricity consumption (EE-F07, EE-F08), Renewable energy consumption (EE-F09, EE-F11), Renewable electricity (EE-F12)
Land use	Terrestrial	Land cover distribution and change (TELC-F01), Arable land (TELC-F02)
Forest	Terrestrial	n/a
Transport	Transport	Passenger transport demand (TERM-F01, TERM-F02, TERM-F03), Freight transport demand (TERM-F04, TERM-F05, TERM-F06), Car ownership (TERM-F07), Use of cleaner and alternative fuels (TERM-F08)
Waste and material flows	Waste	Municipal waste generation (WMF-F01, WMF-F02, WMF-F03), Generation and recycling of packaging waste (WMF-F04)
Water	Water	Use of freshwater resources (WQ-F01, WQ-F02), Urban wastewater treatment (WWEU-F01), Floods and droughts (WWND-F01)
Demography	(Socio-economic)	Population (SE-F02)
Economy	(Socio-economic)	Gross domestic product (SE-F01), Fuel prices (EE-F13)
Tourism	(Socio-economic)	Tourist arrivals (TOUR-F01)
Integrated	(Socio-economic)	n/a

their explicit objective is to provide an integrated insight across a range of environmental, economic and socio-cultural aspects of sustainability. Such models are listed as '**integrated models**'.

Geographical scale

A second dimension key to characterising models of environmental change is the **geographical scale** they address and whether or not they perform simulations in a spatially-resolved manner. If they do, they are distinguished according to geographical **extent** (i.e. the area covered by the model) or geographical **resolution** (i.e. the details of the modelling processes and outputs within the area covered).

Categories of geographical **extent** relevant to this report range from global (models that cover all or most of the planet, and see Europe as one or several sub-regions), through European (some models cover Europe as a geographical unit, others only address the EU Member States) and national, to the regional scale (including catchment-level models).

The geographical **resolution** of a model refers to the level of detail in its input data and, more importantly, its output data: typically, the geographical resolution correlates with aggregations based either on socio-economic units (e.g. countries, NUTS level) or physio-geographic units (e.g. river basins, ecosystems). Many spatially-explicit models calculate at a grid-level.

This review focuses on models that are spatially explicit and whose geographical extent covers either the global or the European scale. However, selected examples of models that address multiple regions within Europe are also included (especially models which, while producing outputs at the regional scale, can inform European policies in a more general sense).

Analytical technique

There is **no standard classification** for analytical techniques applied to models in the literature. Different classifications have been developed, depending on author and focus, see for example Jørgensen 1994, 2008; Gertsev *et al.*, 2004; or Tamborra, 2002.

For the purpose of this overview, however, **four principal analytical techniques** relevant to models of environmental change are distinguished (see Table 2.2):

Equilibrium models are a class of economic models that use actual economic data to estimate how an economy might react to changes in policy, technology or other external factors. Equilibrium models are often geared towards calculating optimal allocation under a given set of constraints, and thus most models labelled as optimisation models fall into this category. A typical static equilibrium model consists of equations describing model variables and a database consistent with these equations. They can be static — comparing the situation at one or more dates — or dynamic, showing developments from one period to another. This group of models includes computable general equilibrium (CGE) models as well as partial equilibrium models (which, in the literature, are sometimes also referred to as sectoral models). While CGE models calculate a combination of prices such that all the markets of the economy are in equilibrium (implying that resources are allocated efficiently), sectoral models are constructed assuming the equilibrium of only one specific sector of the economy (See also Tamborra, 2002).

Empirical-statistical models commonly include multivariate statistical and/or spatial statistical modelling approaches. This group — which also includes macro-econometric models — is explicitly

Table 2.2 Principal analytical techniques used in this report

Principal analytical technique	Sub-categories of techniques/modelling approaches
Equilibrium models	General equilibrium models, partial equilibrium models or sectoral models, mass balance equation models, optimisation models
Empirical-statistical models	rule-based models, cellular automata, agent-based models, multiple regression models, area-based matrix approaches, stochastic approaches, econometric models
Dynamic system models	Linear/non-linear programming models, population dynamics models, impact assessment models, integrated assessment models
Interactive models	Expert judgement frameworks, decision support systems, educational gaming, information tools

based on statistical relationships (often derived by multiple linear regression analysis), and the parameters of the model equations are commonly estimated by econometric methodologies. Such models thus share the general concept of relying on rule-based algorithms, i.e. behavioural patterns are defined by a set of specific decision rules.

Furthermore, we can distinguish several sub-groups, depending, for example, on whether they are static or dynamic (i.e. comparing the situation at one or more dates or showing developments from one period to another). Cellular automata, for example, are a sub-group of (dynamic) empirical-statistical models that rely on transition rules that take into account the role of neighbouring units when calculating the activities of a specific unit over time. Similarly, agent-based models treat each actor as a separate unit that develops according to a set of decision rules (or transition rules).

Dynamic system models (sometimes also labelled as system theory or systems models) are based on sets of equations, and can be based on either linear or non-linear programming techniques (see Table 2.3). The equations are usually based on causality (although the causality may be derived from an empirical analysis of data). Generally speaking, these equations are used to express levels of stock variables and rates as a measure of change in the stock variables. A sub-group of this analytical technique is population dynamic models.

The group of **interactive models** (including participative models and expert judgement frameworks) includes a somewhat different type of model, i.e. models that rely heavily on user interaction during the course of a model run. Indicatively, interactive models can be sub-grouped into three general categories: (i) information tools (interactive information tools that allow individual users to calculate their personal impact on the environment, (ii) educational games (games designed to teach people about a certain subject, expand concepts, reinforce development, or assist them in learning a skill as they play), (iii) Decision Support Systems (a class of computer-based information systems or knowledge-based systems that support decision-making activities). In addition, expert judgement frameworks that rely on scientists or other professionals to quantify rates of change based on their expertise can also be seen as a type of interactive modelling approach. Finally, in some cases some of the above-mentioned analytical techniques are combined with a graphical user interface which allows them to be used in interactive settings (although often this 'use' is limited to exploring pre-defined model outputs).

In addition to the above four-fold distinction of general modelling types, alternative classifications of analytical techniques of modelling approaches may be useful to further distinguish model types (see Table 2.3).

In most complex models, the above types of analytical techniques are combined and they are *de facto* **hybrid models**. However, while most models apply a combination of different analytical techniques to some degree, the label 'hybrid model' is here reserved for models that do not have a clear guiding analytical technique. For example, a dynamic systems model may be augmented by statistical modelling approaches (i.e. rule-based calculation routines may be employed were causality-based equations are not available), but would still be categorised as a dynamic systems model if the core processes are modelled on differential equations.

Additional characteristics of models of environmental change

In addition to the three main dimensions described above, a number of additional categories can be useful to help characterise models — in particularly

Table 2.3 Alternative classifications of analytical techniques applied (as pairs of model types)

Characterisation of pairs of types of analytical techniques in modelling (based on Jørgensen, 1994)		
Deterministic models (the model outputs are computed exactly)	-or-	**Stochastic models** (the model outputs depend on probability distributions)
Reductionistic models (the model includes as many relevant details as possible)	-or-	**Holistic models** (the model applies generalised principles)
Static models (variables defining the system are not dependant on time)	-or-	**Dynamic models** (variables defining the system are a function of time)
Linear models (first-degree equations are used consecutively)	-or-	**Non-linear models** (one or more equations are not first degree)

in view of developing an online model inventory. A selection of such categories is introduced here, and referred to again in Chapter 4.

Input/output: Key to understanding and applying a specific model is a sound understanding of its main inputs (drivers, parameters) and outputs (indicators, variables). These are commonly directly related to the thematic focus of the respective models.

Temporal coverage: Depending strongly on the issues they address, models vary with regard to the time horizons towards which output is calculated as well as with regard to the time steps for which results are generated. Note that the temporal coverage of the underlying simulations may differ from that used to present model output — we here refer to the temporal coverage of output variables only.

Quality assurance: There are different approaches to determining the quality of a model in producing reliable output. The first is founded on the calibration process of the model, including information on the datasets that have been used to calibrate the model and information on the goodness-of-fit to past data. The second is the validation of model output against independent datasets. Either way, a key element of scientifically-founded models is that they have undergone a transparent and rigorous peer review.

Uncertainty analysis: A key functionality of models is that they are equipped for uncertainty analysis — in the form either of sensitivity analysis or of stochastic model runs, e.g. based on Monte Carlo simulations or variants, or stress testing for boundary conditions.

Level of integration: Another distinguishing feature is the ability to link to other models for an integrated assessment across a broad range of environmental themes. Often, outputs from one model are used as an input to other models, especially in larger assessment processes and research projects. Thus it is relevant to understanding how easily a model can be linked to other models (and to which).

Accessibility: Any model exhibits a specific degree of complexity that will determine how easily it can be used by others, i.e. those that have not been involved in its development. In this context, it is important to know whether the model can be accessed free of charge and without constraints, and, if not, the restrictions that apply and the conditions for using the model. This also relates to the issue of the transparency of a model, its assumptions and functions (e.g. as described in a user's manual).

Model context: Finally, it is important to understand the context within which different models have been developed. Key to this is clarity about who developed and owns the model, for whom or which target group it has been developed, and the history of the model.

3 An overview of models of environmental change in Europe

3.1 Past reviews of models of environmental change

There have been many reviews of models of environmental change. They either comprise a large number of very different types of model or focus on models for specific thematic areas. Reviews that focus on selected thematic areas and/or analytical techniques allow in-depth comparison of models for the purpose of addressing specific questions. Comprehensive cross-cutting modelling reviews can provide an inventory of available approaches that can be particularly helpful in informing integrated assessments, but such comprehensive reviews may lack the detail and comparability of information that the more focused thematic reviews offer.

However, the broad range of thematic foci and modelling types covered by the various reviews makes it difficult to provide an exact and definite account of existing reviews of models of environmental change. Furthermore, there are no commonly accepted standards for what constitutes a modelling review, and it is difficult to assess the validity of modelling reviews. An important feature of reviews is whether the models are just listed or are analysed, compared and evaluated in more depth in terms of their purpose and usefulness.

For this overview we have considered only reviews that analyse and compare at least two models (ideally more), and we focus on models that have been published within the past ten years. In total we discuss 13 modelling reviews (see Table 3.1); however this list is by no means exhaustive.

An example of a comprehensive modelling review is the *I.Q. tools project* (Bartolomeo *et al.*, 2004) funded under the sixth Research Framework Programme of the European Union (FP6). The project report, together with an overview of the various impact assessment frameworks used in six OECD countries and some analysis of the impact assessment frameworks used by the European Commission, provides a short description of 31 different quantitative models, and assesses whether they can be used within impact assessments. However, only five of the models described are seen to be fit for the purpose of environmental impact assessment ([4]).

Similarly, useful information about different environmental models can be found in the technical annexes of the reports of major cross-cutting environmental assessment exercises. A good example is the EEA's *European environment outlook* report (EEA, 2005) which describes the 13 models that underpin that report in greater detail, although with different levels of information.

More often, however, modelling reviews follow a thematic focus. Such reviews are often constructed, especially in the early phases of larger research projects, with the aim of identifying or justifying which model to use. A typical example is the *Review and literature evaluation of quantification tools for the assessment of nutrient losses at catchment scale* (Schoumans and Silgram, 2003) which was done in the context of the EUROHARP project. The report gives an introduction to eight different models plus a description of the sub-models connected to the eight main models. Fifteen different criteria are used to describe and compare the eight models, and to compare their strengths and weaknesses. Similar examples can be found for other thematic foci and other research projects.

Indeed, many reviews are specific and thus useful primarily within the context in which they have been developed, but do not provide a sufficient overview of the broader range of environmental models available. Thus, with the exception of the cross-cutting reviews mentioned above, comparative and comparable information on different models is not easily accessible. However, even the cross-cutting reviews are often one-off exercises, and the models presented often rapidly become outdated. Although some of the reviews — such as the review of air quality models done by the European Topic Centre on Air and Climate or the review of modelling tools for impact assessment

(4) Another example is the Sustainability A-Test project that was also funded under the sixth Research Framework Programme of the European Union, which provides an overview description of socio-economic, bio-physical and integrated models, but does not display detailed information. This is why it was not formally included in the list of analysed model reviews.

Table 3.1 Selected reviews of models of environmental change

Review in/review by	Thematic focus	Number of models reviewed	Source
European environment outlook	Broad range of themes (i.e. for impact assessments)	13	EEA, 2005
IQ Tools Project	Broad range of themes	31	Bartolomeo *et al.*, 2004
Scenarios for SoEOR	Broad range of themes	7	Bakkes *et al.*, 2002
RIVM	Broad range of themes	16	Bakkes *et al.*, 2000
Cloudy Crystal Balls	Broad range of themes	19	EEA, 2000
VISIONS	Broad range of themes	5	Van Asselt *et al.*, 1998
ETC Air & Climate	Air Quality	83	EEA/ETC, 1996
ETC Water	Agriculture	6	Kristensen *et al.*, 2005
Euroharp	Agriculture (focus on nutrient cycling)	9	Schoumans & Silgram, 2003
DG Research	Energy, climate (focus on GHG)	8	Tamborra, 2002
ESPON project 3.2	Economic, transport, (infrastructure)	2	Fratesi *et al.*, 2006
EEA Land Use Model Review	Land use	5	EEA, 2003
WMO/SWHI	Water	38	Arheimer & Olsson, 2003

done in the I.Q. Tools project — have been prepared as online model inventories, updates of modelling review reports or even regularly updated model inventories are rare. This lack of crosscutting modelling reviews or inventories is an argument for an online modelling inventory (as proposed in Chapter 4).

3.2 Examples of models of environmental change in Europe

This section introduces a number of models that have either been used in recent assessments by the EEA or underpin indicators presented in the Indicator Management Service (IMS). The overview below is thus informed by **two main sources**:

(a) Descriptions of models underpinning forward-looking indicators collected and/or published by the EEA (see EEA, 2008a for an overview of such indicators). Prominent sources of model descriptions here include the most recent European Environment Outlook (EEA, 2005), model reviews performed in the context of the project on prospective analysis of land-use developments in Europe (EEA, 2002, 2007), and the online version of the IMS.

(b) Descriptions of models covered in a dedicated survey of selected modelling tools focussing on models that have not been used in recent assessments published by the EEA — particular in those thematic areas where new or improved models have now become available.

The sample set of models presented focuses on models whose geographical extent covers Europe, or at least large parts of Europe. These are grouped by their **primary thematic focus**, as introduced in Chapter 2. However, this assignment may not always be unambiguous, and several of the models described produce output and indicators for multiple issues.

Nevertheless, a general overview of modelling tools is given for each thematic focus, alongside a description of the corresponding analytical techniques commonly applied to model developments within the respective theme. This is followed by a short description of actual models, again highlighting the general analytical technique that the different models use.

Thematic focus: agriculture

Models that focus on agriculture or agri-environment related issues usually build on a combination of (commonly dynamic) physio-geographic elements (i.e. to simulate growth conditions, such as DAYCENT (Parton, 1996), EPIC (Sharpley and Williams 1990)) and (usually static) economic elements (i.e. to explore assumptions on agricultural trade, such as CAPRI (Britz, 2004), CAPSIM (Witzke & Zintl, 2003) or IMPACT (Rosegrant *et al.*, 2005)).

The **CAPRI** (Common Agricultural Policy Regional Impact) model is an agricultural sector model covering most of Europe at the regional level and global agricultural markets. The objective of the model is to evaluate regional and aggregate impacts of the Common Agriculture Policy and trade policies on production, income, markets, trade and the environment. Its geographical coverage includes the EU-27, and simulations produce most output at the NUTS-II level — although some environmental indicators are downscaled to a 1 km by 1 km grid. The model can be classified as a partial **equilibrium model** — i.e. the model acts as a comparative static equilibrium model, solved by iterating supply and market modules (see Annex 2).

In contrast, the **ELPEN** (European Livestock Policy Evaluation Network) (Wright, 1999) project provides an example of a **static statistical modelling system**, based on a framework within which the economic, environmental and social impacts of changes in policy as they affect livestock systems can be integrated. The ELPEN system builds on EU statistical and geographical data, a reference farm database, and expert knowledge (including simple rules and models based on empirical understanding). This allows a spatial display of the economic, environmental and social impacts resulting from livestock-related policy measures.

Thematic focus: air quality

Modelling approaches applied in the context of air quality are usually dynamic as they generally aim to simulate the evolution of air pollutants in the atmosphere over time. Examples of models that apply dynamic approaches are the RAINS ([5]) model (see below, Amann *et al.*, 2004) or the unified EMEP model (Simpson *et al.*, 2003). However, static approaches can also be used in the context of air pollution modelling, particularly where the aim is to estimate the impacts resulting from pollution patterns or the acidification resulting from particular air pollution levels (see, for example the SMART model, version 2, described by Kros *et al.*, 1995).

The **RAINS** model (Regional Air pollution Information and Simulation, see Annex 2) can be labelled as a linear programming model or **dynamic systems model** that allows analysis of various reduction strategies for air pollutants. It consists of several modules, which contain information on economic activities that cause emissions; emission control options and costs; atmospheric dispersion of pollutants; and sensitivities of ecosystems and humans to air pollution. The model considers emissions of sulphur dioxide, nitrogen oxides, ammonia, non-methane volatile organic compounds and particulate matter. It simultaneously addresses impacts of particulate pollution, acidification, eutrophication and tropospheric ozone on health and ecosystems. The RAINS model covers almost all European countries, including the European part of Russia. It incorporates data on energy consumption for 42 regions in Europe, distinguishing about 24 categories of fuel use in 6 major economic sectors.

Projections based on RAINS are included in the EEA IMS section on forward-looking indicators (EEA, 2008a), namely the indicators for emissions of primary particulates (APE-F05) and for greenhouse gas emissions (CC-A03).

Thematic focus: biodiversity

Models that focus on biodiversity often rely on statistical approaches such as the Euromove (Bakkenes, *et al.,* 2002) or the GLOBIO models (UNEP 2001). On a small scale, dynamic systems models have been developed.

The **Euromove** model, for example, is a species-based static statistical model that uses logistic regression equations to calculate occurrence probabilities for almost 1 400 European vascular plant species. The equations are based on six climatic variables from the IMAGE model (see below) and species data from the Atlas Flora Europaeae (AFE) (Jalas and Suominen 1989; Ascroft 1994). In the Euromove model a threshold probability value for each species has been determined to transform calculated probabilities into absent-present states.

Projections based on the Euromove model are included in the EEA IMS section on forward-looking indicators (EEA, 2008a), namely: change in species diversity as a result of climate change (BDIV-F01).

Another example of a static **statistical model** that focuses on the issue of biodiversity is the **GLOBIO** model, which has been developed to visualise the cumulative impacts on biodiversity and ecosystem function of growth in human resource demand and associated infrastructure development. The

([5]) Note that the RAINS model has now been subsumed by the GAINS model (i.e. Greenhouse gas and Air pollution Interactions aNd Synergies.

model provides a statistical and spatially-explicit risk assessment of the probability of human impacts using buffer zones from infrastructure that vary with type of human activity, density of infrastructure, region, vegetation, climate and ecosystem sensitivity. By linking risk of impact to human expansion in different ecosystems and regions with satellite imagery, possible future impacts of a continued growth in infrastructure can be derived.

Projections based on the GLOBIO model are included in the EEA IMS section on forward-looking indicators (EEA, 2008a), namely: land-cover distribution and change (TELC-F01).

Thematic focus: climate

Climate change projections are typically based on general circulation models (which can be seen as a type of dynamic system model). Prominent European-based examples of such models are the ECHAM model (version 5 is described by Roeckner *et al.*, 2003, 2005) and HADCM model (version 3 is described by Gordon, 2000; Johns, 2003).

Mostly, general circulation models offer results at fairly low geographical resolution: the HADCM3 model, for example provides output at a resolution of 2.75° latitude and 3.75° longitude. To generate climatological output with higher geographical resolutions, either statistical downscaling routines or nested modelling approaches are used (see, for example, REMO described by Jacob and Podzun, 1997, Remmler and Jacob, 2004).

Emission scenarios that feed climate models are usually derived using energy, agriculture, transport or land-use models (described elsewhere in this section).

Thematic focus: energy

A wide range of modelling approaches have been used to simulate energy demand and supply, including static equilibrium models (such as PRIMES (Capros, 2000), WEM), various types of static statistical models (such as PROMETHEUS (Cannon, 2005)), and dynamic system models (such as POLES (Criqui, 1999); TIMER (De Vries *et al.*, 2001)).

The **PRIMES** model is a static **equilibrium model** for the EU energy system. It determines equilibrium by matching the quantities that producers supply to the quantities consumers demand, and thus deducing associated prices, for each of several forms of energy. While the equilibrium is static (within each time period), calculations are repeated in a time-forward path, under dynamic relationships. The model is behavioural but also represents the available energy demand and supply technologies and pollution abatement technologies in an explicit and detailed way. It reflects considerations about market economics, industry structure, energy/environmental policies and regulation. These are conceived so as to influence the market behaviour of energy system agents. The modular structure of PRIMES reflects a distribution of decision-making among agents that decide individually about their supply, demand, combined supply and demand, and prices. The market-integrating part of PRIMES then simulates market clearing.

Projections based on the PRIMES model are included in the EEA IMS section on forward-looking indicators (EEA, 2008a), namely: final energy consumption (EE-F02); total energy intensity (EE-F04); total energy consumption (EE-F06); electricity consumption (EE-F08); renewable energy consumption(EE-F11); renewable electricity (EE-F12); passenger transport demand (TERM-F03); and freight transport demand (TERM-F06).

The IEA's (International Energy Agency) **WEM** (World Energy Model) is another large-scale static **equilibrium model** designed to replicate how energy markets function. It is made up of six main modules: final energy demand; power generation; refinery and other transformation processes; fossil-fuel supply; CO_2 emissions and investment. The WEM is designed to analyse: global energy prospects; environmental impact of energy use; effects of policy actions and technological changes; and effects of investments in the energy sector.

Projections based on the WEM model are included in the EEA IMS section on forward-looking indicators (EEA, 2008a), namely: final energy consumption (EE-F01); total energy intensity (EE-F03); total energy consumption (EE-F05); electricity consumption (EE-F07); renewable energy consumption (EE-F09); fuel prices (EE-F13); and GHG emissions (CC-F02).

In contrast, **PROMETHEUS** is a tool for exploring uncertainties in key energy, environment and technology variables based on a set of stochastic equations (thus being a static **statistical model**). It contains relations and/or exogenous variables for all the main quantities which are of interest in the context of general energy systems analysis as well as technology dynamics regarding power, road transport and hydrogen production and use technologies. The variables cover demographic and economic activity indicators, energy consumption by main fuel, fuel resources and prices, CO_2 emissions, greenhouse gases concentrations, temperature change, technology uptake and two factor learning curves (describing technology improvement in terms of research, and experience gained through their application). All exogenous variables, parameters and error terms in the model are stochastic with explicit representation of their distribution, including in many cases terms of co-variance. It follows that all endogenous variables as a result are also stochastic.

The **POLES** model allows elaboration of long-term energy supply and demand projections for the different regions of the world under a set of consistent assumptions concerning, in particular, economic growth, population and hydrocarbon resources; it can be considered a (partial) **equilibrium model**. The model structure corresponds to a hierarchical system of inter-connected modules and involves three levels of analysis: international energy markets; regional energy balances; and national models of energy demand. The POLES model distinguishes thirty-eight world regions or countries. The dynamics of the model are based on a recursive simulation process, in which energy demand and supply in each national or regional module respond with different lag structures to international price variations in the preceding periods. In each module, behavioural equations take into account the combination of price effects, techno-economic constraints and trends. There are fifteen final energy demand sectors (covering the main industrial branches, transport modes, the residential and service sectors), twelve large-scale power generation technologies and twelve new and renewable energy technologies.

Thematic focus: land use

The issue of land-use change is a cross-cutting one, which requires related models to bring together socio-economic developments and their impacts on the landscape. While most land-use change models are dynamic (as they aim to simulate change over time), the approaches used span all the analytical techniques introduced above. Indeed many models in this area are best classified as hybrid, as they combine several approaches. A host of models are based — at least to a substantial degree — on empirical-statistical modelling approaches, with particular focus on cellular automata and/or agent-based techniques (for example the distribution of land use within the Metronamica and Environmental Explorer models (Engelen *et al.*, 2003); also see Matthews *et al.*, 2007 for an overview of applications of agent-based land-use models). Other models focus to a greater degree on system dynamics approaches at the macro-scale and use rule-based approaches or optimisation routines at higher geographical resolutions (for example CLUE (Verburg *et al.*, 2002), the land use sub/model in IMAGE, or the modelling approaches applied in the ATEAM project (Ewert *et al.*, 2005; Rounsevell *et al.*, 2005; Kankaanpää, Carter, 2004). Also, it should be noted that in the area of land-use change, several models include interactive elements to allow users to explore possible pathways to the future independently (see Table 3.2 and Annex 3 for examples).

The objective of **CLUE** (Conversion of Land Use change and its Effects, Verburg *et al.*, 2002) — a **hybrid model** which combines empirical statistical and dynamic system techniques — is to provide a spatially explicit, multi-scale, quantitative description of land-use changes through dynamic modelling and the quantification of the most important (assumed) bio-geophysical and human drivers, based either on knowledge of the land-use system or empirical analysis of observed land-use patterns. The dynamic simulation model allocates changes in land use of which the aggregate quantity is determined by trend analysis, scenario assumptions or macro-economic modelling. In addition to tracking past or historical land-use changes, the objective is to explore possible land-use changes in the near future under different development scenarios, having a time horizon of about 10-40 years. CLUE focuses on the interaction between spatial policies and restrictions such as natural parks and agricultural development zones, and socio-economic and biophysical factors in different land-use-related sectors.

The **Louvain-la-Neuve model** of land use/cover changes used in the PRELUDE project (EEA, 2007b) is based on the modeling approaches applied in the ATEAM project mentioned above. This model is a **hybrid model** that combines modelling for demand of different land uses at a macro level (largely based on system dynamics analytical techniques) with disaggregation of this demand at the local level (using empirical-statistical modelling techniques). Land-use demand is calculated in three distinct sub-models that focus on urban land use, agricultural land use and forest, respectively.

Thematic focus: forest

As with land-use models, forest models often incorporate rule-based modelling approaches or dynamic statistical models.

EFISCEN (Nabuurs *et al.*, 2006) is a **dynamic statistical model** geared to providing forest resource projections. It is used to gain insight into the future development of European forests regarding issues such as sustainable management regimes, wood production possibilities, nature-oriented management, climate change impacts, natural disturbances and carbon balance. Through its underlying detailed forest inventory database (European Forest Resource Database), the projections provide these insights at varying scales, thus serving forest managers and policy makers at the national and international level. EFISCEN simulates only forest area that is available for wood supply. Unproductive forests and nature conservation areas are excluded from the analysis. The resource projections in EFISCEN are driven by the market demand for round wood, which determines the amount of felling.

Thematic focus: transport

A wide range of different modelling approaches have been used for developing projections in the transport sector, including both partial equilibrium models (such as TREMOVE, De Ceuster *et al.*, 2007) and empirical statistical models (such as the IEA/SMP transport spreadsheet model (Fulton and Eads, 2004).

TREMOVE (De Ceuster *et al.*, 2007) is a static **equilibrium model** geared towards studying the effects of different transport and environment policies on emissions from the transport sector. The model covers both passenger and freight transport. It was developed to compute the effects of various types of policy measures — taken in isolation or as packages — on the key drivers of transport emissions. Currently, TREMOVE consist of 21 parallel country models: each consists of three inter-linked 'core' modules — a transport demand module, a vehicle turnover module and an emission and fuel consumption module.

The **IEA/SMP Transport Spreadsheet Model** (Fulton and Eads, 2004) is an example of a static **statistical model** designed to handle all transport modes and most vehicle types. It produces projections of vehicle stocks, travel, energy use and other indicators. It is designed to have some technology-oriented detail and to allow fairly detailed bottom-up modelling. While the model does not include any representation of economic relationships or changing costs, it is an 'accounting' model, which relates assumptions on activity (passenger and freight travel), structure (travel shares by mode and vehicle type), intensity (fuel efficiency) and fuel type (and CO_2 emissions per unit fuel use) within the transport sector.

Projections based on the IEA/SMP Transport Spreadsheet Model are included in the EEA IMS section on forward-looking indicators (EEA, 2008a), namely: passenger transport demand (TERM-F01); freight transport demand (TERM-F04); car ownership (TERM-F07); use of cleaner and alternative fuels (TERM-F08); emissions of acidifying substances (APE-F02); emissions of ozone precursors (APE-F04); emissions of primary particulates (APE-F06); and GHG emissions (CC-F04).

Thematic focus: waste and material flows

The European Topic Centre on Resource and Waste Management has developed a dynamic **statistical model** (i.e. the **EEA/ETC WMF model**) for projecting waste quantities and estimating greenhouse gas emissions associated with the management of waste at the national level (see Skovgaard *et al.* (2008) for further details). It analyses links between amounts of waste, economic activity and population on the basis of past developments of municipal waste streams, economic activity and the size of population. If the links are shown to have been reliable on the basis of past data, they may be used to generate projections or scenarios for the amounts of waste produced on the basis of assumptions on future economic activity and population size. Using past trends for the amount of municipal waste generated, estimates are made for the development of the management of waste and landfill, incineration and recycling rates.

Projections based on the EEA/ETC WMF model are included in the EEA IMS section on forward-looking indicators (EEA, 2008a), namely: municipal waste generation (WMF-F03); generation and recycling of packaging waste (WMF-F04).

Thematic focus: water

Models that address water resource issues (including water quality, availability, and groundwater) are commonly based on dynamic system modelling approaches (such as macro-scale water balance models presented by Vörösmarty *et al.*, 1989; Arnell, 1999; Alcamo *et al.*, 2003; or Widén-Nilsson, 2007). Also groundwater models typically apply a dynamic systems technique (for example MODFLOW (Harbaugh, 2005) is based on a three-dimensional finite-difference groundwater model).

Conversely, dynamic system modelling approaches are not as easily applied to projecting socio-economic trends that govern water use. Thus, water use is often modelled using empirical-statistical modelling tools, especially agent-based approaches (such as presented by Barthel *et al.*, 2008 — also see Hare and Deadman, 2004, for an overview). Most water resource models, however, are developed for individual catchments or administrative units and are not ideally suited to supporting European-scale assessments.

WaterGAP (Water: global assessment and prognosis; version 2.1) is a **dynamic system model**, and the first global model that computes both water availability and water use on the river basin scale (Alcamo *et al.*, 2003). The model, developed at the University of Kassel, Germany, has two main components: a global hydrology model and a global water-use model. WaterGAP's global hydrology model simulates the characteristic macro-scale behaviour of the terrestrial water cycle to estimate water availability. The global water-use model consists of four main sub-models that compute water use for the WaterGAP model.

Thematic focus: demography, Economy and other socio-economic issues

A wide range of modelling approaches has been used to model socio-economic developments. For demographic change in particular, dynamic system models are often used. Equilibrium models or optimisation models are often used for modelling economic developments (in particular, partial and general equilibrium models are used to depict trade flows), but a wide range of empirical-statistical models have also been developed to assess socio-economic trends.

PHOENIX plus (Hilderink, 2000) provides a population user-support system to explore, develop and analyse different demographic scenarios at various geographical aggregation levels (global, regional, national and grid-cell). PHOENIX provides an integrated modelling framework that allows the description, positioning and analysis of various long-term population issues. A **dynamic system** modelling approach is applied to describe the demographic transition as a composite of its underlying components: the epidemiological and fertility transitions. Future fertility behaviour and mortality patterns in major world regions are explored under varying socio-economic and environmental assumptions by making use of the computer simulation tool.

Integrated models

In addition to the thematic models introduced above, a number of integrated models aim to support international assessments by modelling diverse indicators across a broad range of issues. Commonly, such models are based on dynamic system modelling approaches (which are in this context often combined with statistical modelling elements). Examples of such models include the IMAGE model (MNP, 2006), IFs (Hughes and Hillebrand, 2006) or PoleStar (Raskin *et al.*, 1999).

IMAGE 2 (Integrated Model to Assess the Global Environment; see MNP, 2006) is a multi-disciplinary dynamic systems model, primarily designed to simulate the dynamics of the global society-biosphere-climate system. IMAGE is an ecological-environmental framework that simulates the environmental consequences of human activities worldwide. It represents interactions between society, the biosphere and the climate system to assess sustainability issues like climate change, biodiversity and human well-being. IMAGE 2 combines a number of sub-models: an energy model (TIMER, see DeVries *et al.*, 2001), a population model (PHOENIX, see Hilderink, 2000), sub-models describing land use, agriculture, the carbon and the nitrogen cycle, and a module describing the atmosphere/ocean system. Interactions and several feedbacks between these systems and underlying sub-models are coupled explicitly. In addition, it can be linked to the biodiversity model GLOBIO and the climate policy model FAIR. The IMAGE 2 model is global in application; calculations range from a 0.5° longitude x 0.5° latitude grid (for terrestrial issues) to the world region level, depending on the type of calculation.

Projections based on the IMAGE 2 model are included in the EEA IMS section on forward-looking indicators (EEA, 2008a), namely: GHG emissions (CC-F05); GHG concentrations (CC-F07); global and European temperature (CC-F10).

Another example of a model that addresses issues along a wide range of themes is the **International Futures** model (IFs, see Hughes and Hillebrand, 2006). This is a **dynamic system model** of global systems for classroom or research use. IFs can be used to teach or study demographics, economics, food, energy, the environment, and international politics. It is especially suitable for analysis of sustainable development and examining the human dimensions of global change. IFs is a large-scale integrated global modelling system. It is heavily data-based and also deeply rooted in theory.

It represents major agent-classes (households, governments, firms) interacting in a variety of global structures (demographic, economic, social, and environmental). The system draws upon standard approaches to modelling specific issue areas whenever possible, extending those as necessary and integrating them across issue areas.

3.3 Models geared towards use in interactive settings

Over recent years, a range of models of environmental change have been geared towards or developed specifically for use in interactive settings and participative processes. Such settings include scenario-based approaches like the story-and-simulation approach (EEA, 2001), which aim to inform stakeholder-driven discussions about plausible future developments with the help of modelling tools that allow the quantification of the assumptions and the resulting consequences. While such iteration can often take a few days to weeks (due to the complex nature of models of environmental change), some models are designed to allow 'on-the-spot' interaction. Table 3.2 is an indicative and non-exhaustive list of models suitable for such interactive settings.

This list includes several models designed primarily as **educational tools**. These can be developed as information/educational platforms that allow individual users to calculate their personal impact on the environment. Such tools can also include virtual library and information tools that allow exploration of the results of pre-defined model runs. In contrast, educational games (including video games and 'serious games') are designed to teach people about a certain subject, expand concepts, reinforce development, understand an historical context, or assist them in learning a skill as they play. Here, the assumptions imputed by respective

Table 3.2 Examples of models geared towards interactive settings

Name of model	Type of model	Thematic focus
V GAS (Virtu@alis)	Information/education	Climate (i.e. GHG emissions)
Fishu@lis (Virtu@alis)	Information/education	Other (i.e. fisheries)
Water Domain (Virtu@alis)	Information/education	Water
ViViANE (Virtu@alis)	Information/education	Water, agriculture
ECO2-Privat	Information/education	Energy, transport
Ker-ALARM	Information/education	Biodiversity
World Water Game	Educational games	Water
Flood Ranger	Educational games	Water
NitroGenius	Educational games	Agriculture, transport
Splash!	Educational games	Water
ECO2-Regio	Decision support system	Energy, transport
SimCoast	Decision support system	Land use
MODSIM-DSS	Decision support system	Water
MODULUS-DSS	Decision support system	Land use
mDSS4	Decision support system	Water
WaterWare	Decision support system	Water
COSMO	Models with GUI	Land use
Environment Explorer	Models with GUI	Land use
International Futures	Models with GUI	Integrated
CLUE-S	Models with GUI	Land use
iCity	Models with GUI	Land use
RAINS-Europe	Models with GUI	Air
MAGICC/SCENGEN	Models with GUI	Climate
JCM 5 (java climate model)	Models with GUI	Climate
FAIR	Models with GUI	Climate

Note: More detailed information on the models listed can be found in Annex 3.

players change the settings in underlying modelling processes, making every session unique.

In addition to these, several **modelling approaches** are specifically geared to allow easy interaction with or independent use by potential users. Decision support systems (DSS), for example, are designed to respond directly to the assumptions made, and thus allow exploration of the implications of possible decision pathways. In the context of this overview, only model-driven DSS are included, i.e. those that emphasize access to and manipulation of environmental data, statistical information or quantitative simulation models; other DSS approaches exist, but are not discussed here. Also, several models of environmental change (either full models or simplified versions of larger models) feature a graphical user interface (GUI) which allows them to be used in interactive settings. A graphical user interface allows people to interact with a computer and computer-controlled devices which employ graphical icons or visual indicators along with text labels or text navigation to represent the information and actions available to a user. Examples of this type of model are also included in Table 3.2 and Annex 3.

4 Reflections

This report provides an **extensive overview** of modelling tools available to support forward-looking environmental assessments, corresponding to a growing political interest and demand for this type of study. It illustrates the significant progress made in recent years with regard to the development of tools to simulate environmental change at a European scale. More than 80 models have been identified, and this listing is far from exhaustive. This multitude of available models provides an extensive resource that can be tapped for forward-looking studies.

Although this overview is far from complete, it points to several gaps that warrant further attention. For some **thematic areas** a vast number of modelling tools seem to be available (particularly in the areas of agriculture or energy); for others the choice of well-tested modelling tools appears to be more limited. Thematic areas for which only a limited number of models have been identified here are biodiversity, waste and material flows, and — to a lesser degree — land-use change and water quality. Also, the linkage across thematic themes is often limited, and there are few integrated models.

Generally speaking, a **larger number of modelling tools** within a theme allows for a better comparison of respective modelling approaches and their results. While this is not meant to advocate a 'quantity beats quality' approach, a broad choice of available modelling tools is likely to offer a wider selection of forward-looking indicator calculations. Compiling and comparing a larger number of different model results and structures can help to better analyse uncertainties in the input data and the modelling structures, as it allows a broader range to be covered. As a consequence, uncertainties can be better handled, thus improving the quality of the environmental assessments and the information basis to support decision-making.

A **lack of comprehensive, evaluative and up-to-date information** on the requirements and capacities of specific modelling tools has become apparent in establishing this overview. This makes cross-cutting comparisons of modelling tools, their underlying analytical techniques and degree of reliability difficult — especially for non-modellers and non-experts in the field. This may — and often does — easily lead to a considerable lack of transparency of modelling tools and their outcomes. At the very least it makes the field difficult to navigate for non-experts. The rest of this chapter suggests one possible way of addressing this problem.

4.1 Towards an online model inventory

The lack of transparency and the related shortcomings described above may be overcome by **establishing an online inventory** focused on tools that allow modelling of environmental change in Europe. Such an inventory could help to expand and complete the overview of existing modelling tools initiated here, update this overview as new models or new versions of existing models become available, broaden the perspective of both model developers and model users, point to interesting but currently unknown models, and facilitate interactions between modelling teams.

In particular, an online model inventory can serve **two main purposes**. First, it can provide an information source on modelling tools to underpin future state of the environment assessments — to be used both by those working on environmental assessments and by those using assessment reports that are based on various modelling tools. Second, it can establish an information portal to facilitate interactions between the providers of modelling tools and the users of models and their results.

The main concept behind an online model inventory can best be described as a kind of **web-based encyclopaedia** written collaboratively by the developers and users of environmental models — i.e. following a 'wiki'-inspired approach to knowledge management. In addition, a strong networking component might be considered in order to complement the inventory, allowing users and developers to exchange comment boxes or elaborate discussion blogs. However, the content of such an online model inventory would need to be administered, moderated and quality-controlled by the inventory's host. The host would ideally be an independent entity at the interface between science and policy, in order to avoid a bias towards one or other specific modelling approach and thus ensure a comprehensive and fair assessment of model-relevant information.

An online model inventory should feature **model descriptions** of reasonable detail to allow audiences with a basic understanding of environmental models to arrive at a quick overview and basic comprehension of the respective models' characteristics. Such descriptions might be based on the nomenclature of models of environmental change introduced above (see Chapter 2) — but at the very minimum should address each model's three main dimensions: i.e. its thematic focus, geographical scale, and analytical technique. Annex 2 presents a template that could be used to underpin an online model inventory, and an exemplary set of 14 models is categorised and described using this format.

4.2 Using models in forward-looking environmental assessments

Over the past few decades, a myriad of models geared to depicting, simulating and projecting environmental changes have been developed and applied. Indeed, modelling tools have become a **cornerstone of environmental assessments**, and play a key role in providing data and indicators needed to describe the state of, trends in and prospects for the environment. In particular, forward-looking assessments that aim to provide quantitative estimates about the future state of the environment often rely heavily on information derived from such models.

Thematic assessments are best served by models that capture all the processes relevant to their respective theme. **Cross-cutting environmental assessments**, however, face the challenge of achieving an acceptable degree of consistency in the forward-looking information provided across different thematic areas. This implies higher complexity. In such assessments a risk remains: Using the **best available specialised models** will ensure high quality thematic results, but does not necessarily ensure that results are comparable across themes (especially where underlying assumptions and inputs for models differ). Where this is the case, such inconsistency may undermine the validity of the overall integrated assessment.

An option to ensure consistency across themes is to **link several models** in a 'modelling suite', i.e. in such a manner that the relevant output of some of the models serves as input to others. However, in this type of 'soft link' (i.e. the output from one model is processed and serves as input to another model) between models it is difficult to adequately depict feedbacks between themes. While such feedback analysis can be achieved by carrying out several iterations, it is cumbersome and both time- and resource-intensive.

Alternatively, thematic models can be coupled via a 'hard link' (i.e. the underlying equations of two or more separate models are directly linked) or within **integrated models** that aim from the outset to ensure consistency across assumptions and capture feedbacks — with only minor compromises regarding thematic detail and precision. Thus integrated models are particularly well placed to support cross-cutting assessments that face higher complexity. However, while several global-scale integrated models exist (see above), none of these focus on Europe and they usually only develop outlooks at a rather coarse resolution — somewhat decreasing their usefulness for decision-making.

It should also be stressed here that models need to be understood as support tools for **decision-making**: they cannot replace it. While modelling tools can deal with greater levels of complexity, they are still imperfect representations of the complex dynamics of the environment in which we live, and this has be remembered when interpreting the results across various models. Nevertheless, there seems to be no alternative to making the best-informed use of quantitative simulation models to support decision-making processes relating to future developments.

This makes it all the more important to **increase the quality and transparency** of modelling tools for environmental assessment. The lack of systematic, evaluative information noted above with regard to the development, validation and case applications of different environmental models can be an obstacle — as it reduces confidence in the choice of appropriate and reliable models for authoritative environmental assessments.

As noted above, it is a key task of the European Environment Agency to stimulate the **development and application of environmental forecasting techniques** so that adequate preventive measures can be taken in good time. In this context it is also crucial to facilitate an improved understanding of different models of environmental change. Particularly when considering the myriad of models geared to depicting, simulating and projecting environmental changes, described here, it becomes clear that this is not an easy task. This report is a first step towards an online model inventory that should help increase the understanding of different models, their benefits and their limitations.

References

Alcamo, J.; Döll, P.; Henrichs, T.; Kaspar, F.; Lehner, B.; Rösch, T.; and Siebert. S., 2003. Development and testing of the WaterGAP 2 global model of water use and availability. *Hydrological Sciences*. 48 (3), 317–337.

Amann, M.; Cofala, J.; Gyarfas, F.; Heyes, C.; Klimont, Z.; Mechler, M.; Posch, M.; Schöpp, W., 2004. *The Rains model: Documentation of the model approach prepared for the RAINS peer review*. International Institute for Applied Systems Research, Laxenburg, Austria (www.iiasa.ac.at/rains/review/review-full.pdf).

Arheimer, B. and Olsson, J., 2003. *Integration and coupling of hydrological models with water quality models*. World Meteorological Organisation.

Arnell, N., 1999. A simple water balance model for the simulation of streamflow over a large geographic domain. *Journal of Hydrology* 217, 314–335.

Bakkes, J.; Grosskurth, J.; Idenburg, A.; Rothman, D. and van Vuuren, D., 2000. Descriptions of selected global models for scenario studies on environmentally sustainable development, Global Dynamics and Sustainable development programme, *GLOBO Report series* No 30, RIVM.

Bakkenes, M.; Alkemade, JR.; Ihle, F.; Leemans, R.; Latour, JB., 2002. Assessing effects of forecasted climate change on the diversity and distribution of European higher plants for 2050. *Global Change Biology* 8 (4), 390–407.

Bakkes, J.; Eerens, H.; Nijland, H.; Tuinstra, W.; van Woerden, J.; van Zeijts, H., 2002. Scenarios for the SoEOR (interim report): Implications of using the CAFE baseline as the cornerstone for scenarios in the upcoming EEA State and Outlook Report. European Environment Agency working document.

Barthel, R.; Janisch, S.; Schwarz, N.; Trifkovic, A.; Nickel, D.; Schulz, C. and Mauser, W., 2008. An integrated modelling framework for simulating regional-scale actor responses to global change in the water domain. *Environmental Modelling & Software* 23 (9), 1095–1121

Bartolomeo, M. *et al.*, 2004. *IQ tools: Indicators and qualitative tools for improving the impact assessment process for sustainability — Approaches to Impact Assessment in six OECD countries and at the European Commission*.

Britz, W. (editor), 2004. *CAPRI Modelling System Documentation*, Final report of the FP5 shared cost project CAP-STRAT 'Common Agricultural Policy Strategy for Regions, Agriculture and Trade', QLTR-2000-00394; Bonn University.

Cannon, M.; Kouvaritakis, B. and Huang, G., 2005. 'Modelling and Optimisation for Sustainable Development policy assessment', *European Journal of Operational Research*, 164, 475–490.

Capros P., (guest editor) 2000. 'Technology Evolution and Energy Modelling', special issue of the *International Journal of Global Energy Issues* (IJGEI), Vol. 14-, Nos. 1–4, 2000, Inderscience Enterprises Ltd.

Criqui, P.; Mima, S. and Viguier L., 1999. Marginal abatement costs of CO_2 emission reductions, geographical flexibility and concrete ceilings: an assessment using the POLES model, *Energy Policy*, 27 (10), p. 585–602.

De Ceuster, G.; van Herbruggen, B.; Ivanova, O.; Carlier, K.; Martino, A. and Fiorello D., 2007. *TREMOVE: Service contract for the further development and application of the transport and environmental TREMOVE model* (Final Report to the European Commission: Service Contract 070501/2005/420798/MAR/C1). Transport & Mobility Leuven , Belgium. Available at www.tremove.org

De Vries, B.; Van Vuuren, D.; Den Elzen, M.; Janssen, M, 2001. *The Targets Image Energy Regional (TIMER) Model*. Technical Documentation, Netherlands Environmental Assessment Agency (MNP). Report no. 461502024.

EEA, 2008a. *Catalogue of forward-looking indicators from selected sources: A contribution to the forward-looking component of a shared environmental information system (SEIS/Forward)*. EEA Technical report 8/2008. European Environment Agency, Copenhagen, Denmark.

EEA, 2008b. Using scenarios for decision-support: Current practice and future directions in environmental policy. EEA working paper (forthcoming). European Environment Agency, Copenhagen, Denmark.

EEA, 2007a. *The pan-European environment: Glimpses into an uncertain future.* EEA Report 4/2007. European Environment Agency, Copenhagen, Denmark.

EEA, 2007b. *Land-use scenarios for Europe: Qualitative and quantitative analysis on a European scale (PRELUDE)*. EEA Technical Report 9/2007. European Environment Agency, Copenhagen.

EEA, 2005. *European Environment Outlook*. EEA Report 2/2005. European Environment Agency, Copenhagen, Denmark.

EEA, 2003. *European land use scenarios: Framing the exercise. Proceedings of an Expert Meeting, 25/26 November 2002*. Internal EEA background paper (edited by Henrichs, T.; Hoogeveen, Y. and Ribeiro, T.).

EEA, 2000. *Cloudy Crystal Balls — An assessment of recent European and global scenario studies and models*. EEA environmental issues report 17. European Environment Agency, Copenhagen, Denmark.

Engelen, G.; White, R. and de Nijs, T., 2003. Environment Explorer: Spatial Support System for the integrated Assessment of Socio-Economic and Environmental Policies in the Netherlands. *Integrated Assessment*, 4(2), p.97–105.

Ewert, F.; Rounsevell, M.; Reginster, I.; Metzger, M. and Leemans, R., 2005. Future scenarios of European agriculture land use. I. Estimating changes in crop productivity. *Agriculture, Ecosystems & Environment* 107, 101–116.

Fratesi, U.; Larrea, E. and Ulied, A., 2006. *ESPON project 3.2: Spatial scenarios and orientations in relation to ESDP and cohesion policy: Elements of support for the scenario building process*, Third interim report January 2006.

Fulton and Eads, 2004. *IEA/SMP Model Documentation and Reference Case Projection. International Energy Agency/World Business Council for Sustainable Development*. (www.wbcsd.org/web/publications/mobility/smp-model-document.pdf).

Gertsev, V., and Gertseva, V., 2004. Classification of mathematical models in ecology. *Ecological Modelling* 178, 329–334.

Gordon, C.; Cooper, C.; Senior, C.; Banks, H.; Gregory, J.; Johns, T.; Mitchell, J. and Wood, R., 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.

Harbaugh, A. W., 2005. MODFLOW-2005, the U.S. Geological Survey modular ground-water model — the Ground-Water Flow Process: *U.S. Geological Survey Techniques and Methods* 6-A16, variously p.

Hare, M. and Deadman, P., 2004. Further towards a taxonomy of agent-based simulation models in environmental management. *Mathematics and Computers in Simulation* 64, 25–40.

Hilderink, H. B. M., 2000. *World population in transition: an integrated regional modelling framework*. Amsterdam, Thela Thesis/Rozenberg.

Hughes, B., and Hillebrand, E., 2006. *Exploring and Shaping International Futures.* Paradigm Publishers, Boulder, CO.

Jacob, D., and Podzun, R., 1997. Sensitivity studies with the Regional Climate Model REMO, *Meteorology and Atmospheric Physics* 63, 119–129.

Johns, T.; Gregory, J.; Ingram, W.; Johnson, C.; Jones, A.; Lowe, J.; Mitchell, J.; Roberts, D.; Sexton, B.; Stevenson, D.; Tett, S. and Woodage M., 2003. Anthropogenic climate change for 1860 to 2100 simulated with the HadCM3 model under updated emissions scenarios, *Climate Dynamics* 20, 583–612.

Jørgensen, S., 2008. Overview of the model types available for development of ecological models. *Ecological Modelling*. 215, 3–9.

Kristensen, P.; Lerche, D. and Fribourg-Blanc, B., 2005. *Scenario analysis in relation to agriculture and water quality*, Internal EEA background paper.

Kros, J.; Reinds, G.; Devries, W.; Latour, J. and Bollen, M., 1995. Modelling the response of terrestrial ecosystems to acidification and desiccation scenarios. *Water, Air and Soil Pollution*, 85, 1101–1106.

Matthews, R.; Gilbert, N.; Roach, A.; Polhill, J. and Gotts, N., 2007. Agent-based land-use models: a review of applications. *Landscape Ecology* 22.

MNP, 2006. *Integrated modelling of global environmental change. An overview of IMAGE 2.4*, (edited by A.F. Bouwman, T. Kram and K. Klein Goldewijk).

Netherlands Environmental Assessment Agency (MNP), Bilthoven, The Netherlands.

Nabuurs, G. J.; Pussinen, A.; van Brusselen, J.; Schelhaas, M. J., 2006. Future harvesting pressure on European forests. *European Journal of Forest Research* 10.1007/s10342-006-0158-y

Parton, W. J.; Mosier, A. R.; Ojima, D. S.; Valentine, D. W.; Schimel, D. S.; Weier, K. and Kulmala, A. E., 1996. Generalized model for N_2 and N_2O production from nitification and denitrification, *Global Biogeochemical Cycles,* 10, 401–412.

Petit, S.; Firbank, L.; Wyatt, B. and Howard, D., 2001. Models for Integrated Review and Assessment of Biodiversity in European Landscapes, *Ambio* 30(2), 81–88.

Raskin, P.; Heaps, C.; Sieber, J.; Kemp-Benedict, E., 1999. *PoleStar System Manual*. Stockholm Environment Institute—Boston Tellus Institute. (ISBN: 91 88714 098).

Remmler, T. and Jacob, D., 2004. Modeling extreme precipitation events—a climate change simulation for Europe. *Global and Planetary Change* 44 , 119–127.

Roeckner, E.; Brokopf, R.; Esch, M.; Giorgetta, M.; Hagemann, S.; Kornblueh, L.; Manzini, E.; Schlese, U. and Schulzweida U., 2006. Sensitivity of simulated climate to horizontal and vertical resolution in the ECHAM5 atmosphere model, *Journal of Climate* 19(16).

Roeckner, E.; Bäuml, G.; Bonaventura, L.; Brokopf, R.; Esch, M.; Giorgetta, M.; Hagemann, S.; Kirchner, I.; Kornblueh, L.; Manzini, E.; Rhodin, A.; Schlese, U.; Schulzweida, U.; Tompkins, A., 2003. The atmospheric general circulation model ECHAM5: PART 1 (model description). *Max-Planck-Institute for Meteorology Report 349*, Hamburg. (ISSN 0937-1060).

Rosegrant, M.; Ringler, C.; Msangai, S.; Cline, S., 2005. *International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT-WATER) Model Description*. Int. Food Policy Research Inst, Washington, D.C., 2005.

Rotmans, J. and De Vries, B. (eds.), 1997. *Perspectives on global change: the TARGETS approach*, Cambridge University Press, Cambridge.

Rounsevell, M.; Ewert, F.; Reginster, I.; Leemans, R.; Carter T., 2005. Future scenarios of European agriculture land use. II. Projecting changes in cropland and grassland. *Agriculture, Ecosystems & Environment* 107, 117–135.

Schoumans, O. and Silgram, M. (eds.), 2003. *Review and literature evaluation of nutrient quantification tools*. EUROHARP report 1-2003, NIVA report SNO 4739-2003, Oslo, Norway, 120 pp.

Sharpley, A. N. and J. R. Williams, 1990. EPIC-Erosion/Productivity Impact Calculator: I Model documentation, *Technical Bulletin* No. 1768, 235 pp., US Department of Agriculture.

Simpson, D.; Fagerli, H.; Jonson, J.-E.; Tsyro, S.; Wind, P. and Tuovinen J.-P., 2003. *Transboundary Acidification, Eutrophication and Ground Level Ozone in Europe: PART I (Unified EMEP Model Description)*. EMEP Status Report 2003. Norwegian Metrological Institute. (ISSN 0806-4520).

Skovgaard, M.; Hedal, N.; Villanueva, A.; Andersen, F. M.; Larsen, H., 2008. *Municipal waste management and greenhouse gases*. ETC/RWM working paper 2008/1.

Tamborra, M. (ed.), 2002. *Socio-economic tools for sustainability impact assessment — The Contribution of EU Research to Sustainable Development. European Commission — Directorate General for research*. (http://ec.europa.eu/research/environment/pdf/publication_socio_economic_tools_en.pdf).

UNEP, 2001. GLOBIO: Global methodology for mapping human impacts on the biosphere (drafted by Nelleman, C.; Kullered, L.; Vistnes, I.; Forbes, B. C.; Foresman, T.; Husby, E., *et al.*). UNEP/DEWA/TR.01-3.

van Asselt, M.; Storms, C.; Rijkens-Klomp, N. and Rotmans J., 1998. *Towards visions for a sustainable Europe: An overview and assessment of the last decade in European scenario studies*, Report presented at kick-off meeting of Visions project (ENV4-CT97-0462) 6–7 May 1998, ICIS, Maastricht University.

Verburg, P.; Soepboer, W.; Veldkamp, A.; Limpiada, R.; Espaldon, V.; Sharifah Mastura, S., 2002. Modeling the Spatial Dynamics of Regional Land Use: the CLUE-S Model. *Environmental Management* 30 (3), 391–405.

Vörösmarty, C.; Moore, B.; Grace, A.; Gildea, M.; Melillo, J.; Peterson, B.; Rastetter, E. and Steudler, P., 1989. Continental scale models of water balance and fluvial transport: an application to South America, *Global Biogeochemical Cycles* 3, 241–265.

Widén-Nilsson, E.; Halldin, S. and Xu, C., 2007. Global water balance modelling with WASMOD-M: Parameter estimation and regionalisation. *Journal of Hydrology* 340, 1050118.

Witzke, H. P. and Zintl, A., 2003. *CAPSIM —Complete documentation*, Final Report to Eurostat, Bonn.

Wright, I. A.; Smeets, P. J. A. M.; Elbersen, B. S.; Roos Klein-Lankhorst, J.; Pflimlin, A.; Louloudis, L.; Vlahos, G.; Crabtree, J. R.; Williams, S. M.; Hinrichs, P.; Andersen, A. and Pirringer, H., 1999. *A protocol for building the ELPEN livestock policy decision support system*. MLURI, Scotland, 37pp.

Zurek, M. and Henrichs, T., 2007. Linking scenarios across geographical scales in international environmental assessments. *Technological Forecasting and Social Change*.

Annex 1 Comprehensive list of available modelling tools

Name (short)	Name (complete)	Further information
Thematic focus: agriculture		
AgriPoliS	AGRICULTURAL POLICY SIMULATOR	www.uni-koblenz.de/~juekopp/SemSim/Presentation-Agripolis.pdf
APES	Agricultural Production and Externalities Simulator	www.apesimulator.it/default.aspx
AROPAj		www.grignon.inra.fr/economie-publique/MIRAjE/
CAPRI DYNASPAT	Common Agricultural Policy Regional Impact-The Dynamic and Spatial Dimension	www.agp.uni-bonn.de/agpo/rsrch/dynaspat/dynaspat_e.htm
CAPSIM	Common Agricultural Policy Simulation Model	www.eurocare-bonn.de/profrec/capsim/capsim_e.htm
DSSAT	Decision Support System for Agrotechnology Transfer	http://www.icasa.net/dssat/index.html
ELPEN		www.macaulay.ac.uk/elpen
EPIC	Erosion Productivity Impact Calculator	www.brc.tamus.edu/simulation-models/epicapex.aspx
EveNFlow		www.euroharp.org/toolbox/qtinfo.php?n=EveNFlow&d=1&r=&o=
FARM	Future Agricultural Resources Model	www.ers.usda.gov/publications/aer703/aer703.pdf
EU-FASOM	EU- Forest and Agriculture Sector Optimization Model	
	http://www.mi.uni-hamburg.de/fileadmin/fnu-files/projects/fasom/EUFASOM_and_ENFA.pdf	
FASSET	Farm ASSEssment Tool	www.fasset.dk
FSSIM		
	Farm System Simulator	www.seamless-ip.org/Reports/Report_04_PD3.3.2.1.pdf
IMPACT	International Model for Policy Analysis of Agricultural Commodities and Trade	www.ifpri.org/themes/impact/impactmodel.pdf
MONERIS	MOdelling Nutrient Emissions in RIver Systems	www.umweltdaten.de/publikationen/fpdf-k/1837.pdf
NL-CAT		www.euroharp.org/toolbox/qtinfo.php?n=NL-CAT%20(ANIMO/SWAP/SWQN/SWQL)&d=1&r=&o=
N-LES CAT		www.euroharp.org/toolbox/qtinfo.php?n=N-LES%20CAT&d=1&r=&o=
NOPOLU		www.euroharp.org/toolbox/qt_doc/NOPOLU.doc
SFARMOD		www.geo.ucl.ac.be/accelerates/documents/impel_final_report.pdf, www.geo.ucl.ac.be/accelerates/documents/LandUseModel.ppt
TRK		euroharp.org/pd/pd/models/store/TRK-short.doc
Thematic focus: air quality		
City-Delta	n/a	http://aqm.jrc.it/citydelta/(i.e. compares several models in "An Inter-comparison of long-term model responses [...]")
EcoSense	n/a	www.ier.uni-stuttgart.de/forschung/modmeth/ecosense/ecosense.html
GAINS	Greenhouse Gas and Air Pollution Interactions and Synergies	www.iiasa.ac.at/rains/gains.html
RAINS	Regional Air Pollution Information and Simulation	www.iiasa.ac.at/rains/gains.html
SMART	Simulation Model for Acidification's Regional Trends	www.macaulay.ac.uk/dynamo/smart.htm
Unified EMEP	Unified European Monitoring and Evaluation Programme model	http://emep.int/OpenSource
Thematic focus: biodiversity		
Euromove	n/a	www.rivm.nl/bibliotheek/rapporten/410200032.html
GLOBIO	Global Methodology for Mapping Human Impacts on the Biosphere	www.globio.info
MIRABEL	Models for Integrated Review and Assessment of Biodiversity in European Landscapes	Petit *et al.*, 2001
Thematic focus: climate		
CLIMBER3 EMIC	CLIMBER3 Earth system Model of Intermediate Complexity	www.pik-potsdam.de/climber-3

Name (short)	Name (complete)	Further information
DEMETER	Development of a European Multimodel Ensemble system for seasonal to inTERannual prediction	www.ecmwf.int/research/demeter
ECHAM	European Center HAMburg model	www.mpimet.mpg.de/en/wissenschaft/modelle/echam.html
FAIR	Framework to Assess International Regimes for differentiation of commitments	www.rivm.nl/fair/model_details
HadCM	HADley center Coupled Model	www.metoffice.gov.uk/research/hadleycentre/models/modeltypes.html
MAGICC	Model for the Assessment of Greenhouse-gas Induced Climate Change	http://sedac.ciesin.org/mva/magicc/MAGICC.html
PRECIS	Providing REgional Climates for Impacts Studies	http://precis.metoffice.com
Thematic focus: energy		
DNE 21+		www.iiasa.ac.at/Research/ECS/IEW2005/docs/2005A_Akimoto.pdf; www.rite.or.jp/English/about/plng_survy/todaye/today01e/rt01_systeme.pdf
E3ME	Energy-Environment-Economy Model of Europe	http://www.camecon.com/suite_economic_models/e3me.htm
GINFORS	Global Interindustry Forecasting System	www.gws-os.de/english/modelle-en.htm#ginfors
MESSAGE	Model for Energy Supply Strategy Alternatives and their General Environmental Impact	www.iiasa.ac.at/Research/ECS/docs/models.html#MESSAGE
MESSAGE MACRO		sres.ciesin.org/OpenProcess/htmls/Model_Descriptions.html, www.iiasa.ac.at/Research/ECS/docs/models.html#MESSAGE
MiniCAM		www.globalchange.umd.edu/?models&page=minicam
TIMER	Targets IMage Energy Regional Model	www.mnp.nl/en/publications/2001/TheTargetsIMageEnergyRegionalTIMERModelTechnicalDocumentation.html
TIMES		http://www.etsap.org/Tools/TIMES.htm#intro
WEM	World Energy Model	www.worldenergyoutlook.org/model.asp
Thematic focus: energy/climate		
ETP		www.iea.org/textbase/speech/2004/dgfu_etp.pdf
FUND	Climate Framework for Uncertainty, Negotiation and Distribution	http://www.fnu.zmaw.de/FUND.5679.0.html
GEM-E3	General Equilibrium Model for Energy-Economy-Environment interactions	gem-e3.zew.de/
GMM	Global MARKAL Model	eem.web.psi.ch/Presentations/Barreto_Kypreos_GMM_ETSAP_Florence_2004.pdf
Green-X		www.green-x.at/
MEDEE		http://www.enerdata.fr/enerdatauk/tools/Model_MEDEE.html
MIDAS	Model Integrating Demand And Supply	http://www.e3mlab.ntua.gr/manuals/MIDASman.pdf
NEWAGE		www.ecn.nl/docs/library/report/2005/c05085_policybrief.pdf
POLES	Prospective Outlook on Long-term Energy Systems	
	http://web.upmf-grenoble.fr/iepe/textes/POLES8p_01.pdf	
PRIMES		www.e3mlab.ntua.gr/manuals/PRIMsd.pdf
VLEEM	Very Long Term Energy Environment Model.	http://www.vleem.org/
Thematic focus: forest		
EFISCEN	European Forest Information Scenario Model	http://www.efi.int/portal/virtual_library/databases/efiscen/
EU-FASOM	EU- Forest and Agriculture Sector Optimization Model	http://www.mi.uni-hamburg.de/fileadmin/fnu-files/projects/fasom/EUFASOM_and_ENFA.pdf
Euro-For		http://www.iiasa.ac.at/Research/FOR/INSEA/Presentations/INSEA%20structure.ppt#270,17,Slide%2017
PICUS		www.wabo.boku.ac.at/picus.html
Thematic focus: land use		
CLUE	Conversion of Land Use change and its Effects	www.cluemodel.nl
LLN model	Louvain-la-Neuve Land Use model	http://reports.eea.europa.eu/technical_report_2007_9/en
LOV/BabyLOV	Environment Explorer	www.lumos.info/environmentexplorer.htm
Thematic focus: transport		
ASTRA	ASsessment of TRAnsport strategies	http://cordis.europa.eu/transport/src/astra.htm (Note : The link to the actual model page is dysfunctional)
EXPEDITE	EXpert-system based PrEdictions of Demand for Internal Transport in Europe — meta model	www.rand.org/pubs/monograph_reports/MR1673

Name (short)	Name (complete)	Further information
IEA/SMP model	International Energy Agency and WBCSD's Sustainable Mobility	
Project spreadsheet model	www.wbcsd.org/plugins/DocSearch/details.asp?type=DocDet&ObjectId=MTE0Njc	
KTEN	Known Trans European Network — meta model	www.mcrit.com/espon_scenarios/files/documents/KTEN_MODEL_DESCRIPTION.doc
NEAC	n/a	www.nea.nl/neac
SCENES	SCENES European Transport Forecasting model	www.iww.uni-karlsruhe.de/SCENES
TREMOVE	n/a	www.tremove.org
VACLAV	VACLAV - European Transport Model	http://ec.europa.eu/environment/air/pdf/sat/4_annexes.pdf
MEDEE-Transport		http://www.enerdata.fr/enerdatauk/tools/Model_MEDEE_Transport.html
Thematic focus: waste and material flows		
ETC WMF Model	ETC Waste and Material Flow Model	http://waste.eionet.europa.eu
Thematic focus: water		
ETC UWWT model	ETC nutrients discharge from UWWT plants model	http://water.eionet.europa.eu
MACRO-PDM	n/a	Widén-Nilsson *et al.*, 2007
MAGIC	Model for Acidification of Groundwater In Catchments	www.macaulay.ac.uk/dynamo/magic.htm
MODFLOW	n/a	http://water.usgs.gov/nrp/gwsoftware/modflow.html
SWAT	Soil and Water Assessment Tool	www.brc.tamus.edu/swat
SWIM	Soil and Water Integrated Model	www.pik-potsdam.de/%7Evalen/swim_manual
WASMOD-M	Water And Snow balance MODeling system — Macro-scale	
WaterGAP	Water - Global Analysis and Prognosis	www.usf.uni-kassel.de/usf/forschung/projekte/watergap.en.htm
WDM		Vörösmarty *et al.*, 1989
Thematic focus: demography		
POP	IIASA World Population Program	www.iiasa.ac.at/Research/POP/index.html
CHIMP	Canberra-Hamburg Integrated Model of Population	http://www.fnu.zmaw.de/fileadmin/fnu-files/models-data/chimp/populationwp.pdf
PHOENIX		www.mnp.nl/phoenix/
UNPD World Population Prospects		http://www.un.org/esa/population/publications/wpp2006/wpp2006.htm
Thematic focus: economy		
EspaSim	A micro-simulation model to assess tax-benefit reforms in Spain	selene.uab.es/espasim/eng.htm
EUROMOD	European Tax-Benefit Model	www.iser.essex.ac.uk/msu/emod/
GTAP model	Global Trade Analysis Project	www.gtap.agecon.purdue.edu/
NEMESIS	New Econometric Model for Environmental and Sustainable development and Implementation Strategies	www.nemesis-model.net/
OECDTAX	Tax policy in the OECD economy	www.econ.ku.dk/pbs/diversefiler/OECDTAXfinal.pdf
WARM	WAste Reduction Model	yosemite.epa.gov/oar/globalwarming.nsf/content/ActionsWasteWARMUsersGuide.html
WORLDSCAN		www.cpb.nl/eng/model/worldscan.html
Thematic focus: integrated		
Ifs	International Futures	www.ifs.du.edu
IMAGE	Integrated Model to Assess the Global Environment	www.mnp.nl/en/themasites/image/index.html
GENIE	Grid ENabled Integrated Earth system model	www.genie.ac.uk
PoleStar	n/a	www.polestarproject.org
TARGETS	Tool to Assess Regional and Global Environmental and health Targets for Sustainability	Rotmans and De Vries, 1997
Threshold 21	n/a	www.threshold21.com

Annex 2 Sample entries for model inventory

This annex is based on a recent EEA review of selected modelling tools. The models reviewed were selected based both on the primary model foci and lack of coverage in previous EEA model reviews.

Key to this review has been the description of a limited number of models using so-called 'standardised model descriptions'. For each reviewed model such standardised model descriptions was drafted, based on information available in reports or other publicly available documentation. These draft descriptions were subsequently subjected to a review by the respective model developer teams.

Name of model	Thematic coverage	Geographical scale	Analytical technique
IMPACT	Agriculture	Global	Equilibrium model (partial equilibrium model)
CAPRI-Dynaspat	Agriculture	Europe	Equilibrium model (partial equilibrium model)
CAPSIM	Agriculture	Europe	Equilibrium model (partial equilibrium model)
TREMOVE	Transport	Europe	Equilibrium model (partial equilibrium model)
Euromove	Biodiversity	Europe	Empirical-statistical model (multiple regression model)
CLUE	Land use	Europe	Hybrid model (systems dynamic and empirical-statistical model)
Ifs	Integrated model	Global	Dynamic systems model
EFISCEN	Forest	Europe	Empirical-statistical model (area-based matrix model)
Prometheus	Energy	Global	Empirical-statistical model (stochastic methods)
RAINS	Air quality	Europe	Dynamic systems model (linear programming model)
SMART 2	Air quality	Regional (the Netherlands)	Equilibrium model (mass balance equations)
PHOENIX plus	Demography	Global	Dynamic systems model
ECOSENSE	Air quality	Europe	Hybrid model
WEM	Energy	Global	Equilibrium model (partial equilibrium model)

Template for standardised model descriptions

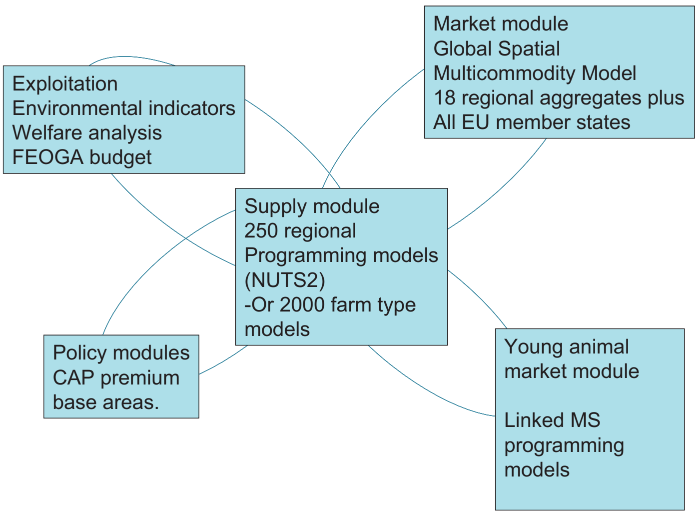
Each model documented in an online model inventory should be described in entries of reasonable detail to allow a quick model overview for audiences acquainted with a basic understanding of environmental models. For this a short and general model summary would ideally be complemented by more detailed information on the model dimension, model development and the use of the model in environmental assessments.

The template below outlines key categories and leading questions to help fill out such template. Not all the categories outlined in this template will be appropriate to describe all models that are featured in a particular model inventory. Nevertheless a suite of core information should be required from any model included: at the very least core information for each model should include details on thematic focus, geographical coverage, and analytical technique.

Model dimension	
Thematic coverage	Which themes (i.e. environmental issues, sectors and activities, or environmental media) does the model address explicitly? (Note: see categories introduced in Table 2.1)
Input (key drivers)	Which are the key driving forces, input data or parameters used by the model?
Output (key Indicators)	Which are the key indicators/primary output variables computed by the model?
Geographical coverage	What spatial coverage/geographical extent does the model operate on and provide output for? And at what spatial resolution?
Temporal coverage	For what time horizon does the model deliver results? And for what time steps?
Analytical technique	What kind of model is it? What is the underlying analytical technique applied? (Note: see categories introduced in Chapter 2)
Model structure	Please add a diagram that summarises the main model structure here (if available)
Information on model development	
Model developers/ owners	Who has developed the model? And who sponsors its development and who owns it?
Model development history	When did model development start, is it still being further developed? Which version of the model is currently used? Which software has been used for the development?
Target group/users	For which audience has the model been developed? Who has used the model and its outputs? Has the model been used for policy purposes?
Calibration	Against which datasets has the model been calibrated? To what goodness-of-fit?
Validation	Has the model been validated against independent datasets? Which?
Uncertainty analysis	Is the model suitable for undertaking uncertainty analysis (such as Monte Carlo simulations, variants, stress testing for boundary conditions)?
Key reference	What is the key (peer-reviewed) publication that describes the model?
Information on use of model in environmental assessments	
Level of integration	What level of integration across environmental themes (see above) does the model allow? Are feedbacks addressed, e.g. between response options and drivers?
Links to other models	Has the model been linked to other models for integrated assessment of environment? Please provide relevant examples of models or projects.
Ease of use // Accessibility	Is the model easy to use for non-developers? Is the model free to access? What restrictions apply? Are results publicly available? Is there a user manual?
Use in participative processes	Has the model - or a simplified versions of the model - been used in interactive settings or participative processes (please give examples)?

CAPRI-Dynaspat (Common Agricultural Policy Regionalised Impact)

CAPRI (Common Agricultural Policy Regional Impact) is an agricultural sector model covering most of Europe at regional level (mostly NUTS II, about 270 regions) and global agricultural markets. The objective of the CAPRI model is to evaluate regional and aggregate impacts of the CAP and trade policies on production, income, markets, trade, and the environment. Scenario analysis using the CAPRI model cover areas cropped and herd sizes along with output and input coefficients and income indicators for each agricultural activity and each region. The model covers prices, supply and demand positions at country level; environmental indicators at regional level. The Project CAPRI-DynaSpat expanded the system from EU-15 to EU-27, adding improved environmental indicators and providing a spatial downscaling of major results for environmental assessment to a 1 x 1 km grid for EU-25.

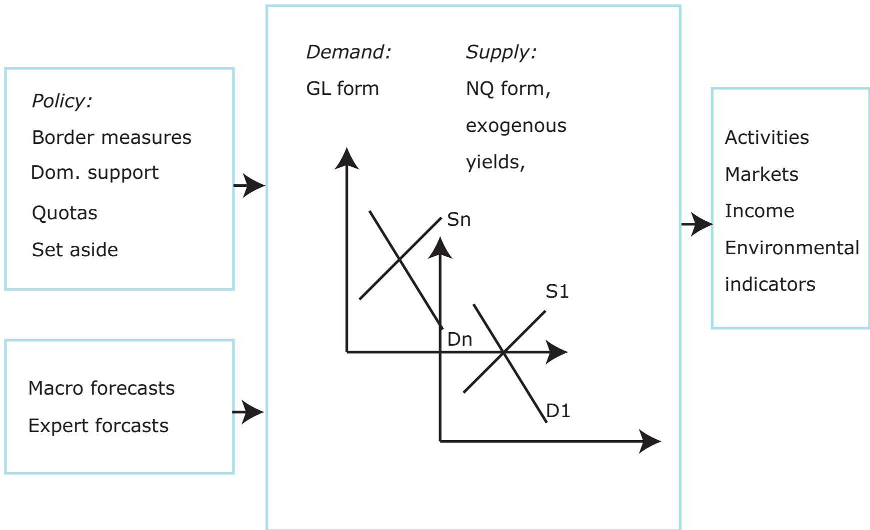
Model dimension	
Themes covered	— Agriculture — Water, air and climate (i.E. Agriculture-related) — Land use (cropping shares at 1 x 1 km grid)
Key drivers (model input)	— Agricultural policies in the CAP — Market prices of agricultural products — Feed, N, P, K fertilizer, diesel or plant protection costs by agricultural activity
Key indicators (model output)	— Areas cropped — Livestock (herd sizes), — Nutrient balances (N, P, K), — Emissions (ammonia, methane and N_2O) PLUS energy use in agriculture
Geographical coverage	— Coverage: EU-27 plus NO plus six Western Balkan countries (note that trade of agricultural products is simulated in global module) — Resolution: regional level (administrative regions, NUTS2) plus 1 x 1 km grid (crop level, animal stocking densities, yields, N balances and further indicators), currently EU-15 (EU-25 foreseen for late spring 2007)
Temporal coverage	— Base-year: 2002 (three year averages 2001–2003), time series at regional level from 1985 onwards (EU-10: 1990, Western Balkans: 1995) — Time horizon: 5 to 10 years, some analysis until 2020 (e.g. SCENAR 2020 study for — DG-AGRI, SENSOR IP), typically final year only
Analytical technique	— Partial equilibrium model (i.e. model described as a comparative static equilibrium model, solved by iterating supply and market modules)
Model structure	

CAPRI-Dynaspat (Common Agricultural Policy Regionalised Impact)	
Information on model development	
Model developers/owners	Institute for Food and Resource Economics, Bonn University (http://www.agp.uni-bonn.de/agpo/rsrch/dynaspat/dynaspat_e.htm. Network approach, several teams contribute and maintain the system besides UBonn as FAL, Braunschweig, NILF Norway, LEI, The Netherland, JRC/IPTS. The Capri-Dynaspat project is funded by the EU Commission (6th FP). The development of CAPRI is mainly funded by DG-RTD, DG-ENV, DG-RTD-JRC/IPTS and DG-AGRI. The model is operationally installed at DG/AGRI.
Model development history	The first version of CAPRI was developed 1997-1999. A master version of the model is distributed along with the data base in the context of yearly training sessions (latest version is from autumn 2006). Currently, development focuses on CAPRI-Dynaspat (scheduled for 2007).
Target group/users	EU commission (DG-AGRI) is using the model for policy impact analysis. Several research institutions (UBONN,NILF, SLI, LEI, FAL, Univ. Galway) use the model for different projects (i.a. for DG-AGRI, DG/ENV, EAA, Norwegian Ag. Council, Ag. Ministry Ireland, seed and biochemical manufacturers).
Calibration	The model is calibrated to the base period (currently 2001-2003) for cropping areas, herd sizes, yields, prices, subsidies, trade flows etc., and lined up ex-ante for 2013 to the current DG-AGRI base line.
Validation	The supply response at regional level is econometrically estimated from time series. External review of the model in 2003.
Uncertainty analysis	A scenario run with the model typically requires between 45 minutes and 1.5 hours, depending on how far the drivers are from the current baselines, which limits classical Monte-Carlo experiments. Rather easy to run different scenarios and compare them.
Key reference	http://www.agp.uni-bonn.de/agpo/rsrch/capri/capri-documentation.pdf
Information on use of model in environmental assessments	
Level of integration	The environmental indicators are all driven by the very same responses of farming practise (cropping shares, yields, animal herds, feeding and fertilizing practise, further input use). The different N-compartments are lined up which each other. N excretions of animals are e.g. in line with the simulated feeding practise.
Links to other models	CAPRI is the basis for CAPRI-Dynaspat. Ammonia emission module in parts sourced by MITERRA (ALTERRA). Link with DNDC in the context of CAPRI-Dynaspat. Link with EPIC under investigation. CAPRI sources in parts RAINS. The two IPs SENSOR and SEAMLESS develop policy impact tools which integrate CAPRI with other economic models and environmental models.
Ease of use//accessibility	Limited (i.e. albeit there is a Graphical User Interface to steer the system, CAPRI is a complex system and takes a great effort and considerable time to master, in the sense that the user is able to understand the response of the model to change in policy or other exogenous drivers. That is mostly due to the fact that prices/supply/demand/cropping shares/herd sizes/yields/feeding/fertilizer use and further use etc. adjust simultaneously across scales – from global to regional scale, not so much from the technical infrastructure. The Bonn team offers training sessions.) Greater network of users which ensure typically that demands from clients are met. CAPRI can be downloaded and used free of charge but users need to buy a GAMS (software) license in order to run the model. An online tool (tables, maps, graphs) allows exploring pre-defined results.
Use in participative processes	
Other comments	Notes from email: CAPRI is basically the same system (CAPRI-Dynaspat is the acronym for a current major FP VI project dealing with CAPRI).

CAPSIM

(Common Agricultural Policy Simulation Model)

CAPSIM is a European partial equilibrium modelling tool with behavioural functions for activity levels, input demand, consumer demand and processing. It is designed for policy-relevant analysis of the CAP and consequently covers the whole of agriculture of EU Member States in the concepts of the Economic Accounts (EAA) at a high level of disaggregation, both in the list of included items (cropping and livestock patterns and animal products per country) and in policy coverage. Technological, structural and preference changes combine with changes in exogenous inputs (e.g. population, prices or household expenditure) to determine the future development of agriculture. For environmental applications CAPSIM may be augmented by a calculation of selected environmental indicators, namely: nutrient balances (N, P, K) and gaseous emissions (NH_3, N_2O, CH_4).

Model dimension	
Themes covered	— Agriculture — Land use on country level — Climate change, water
Key drivers (model input)	— Macro economic development (population, prices or household expenditure) — CAP policies — Output from existing projections (such as FAPRI, CAPRI, DG Agri)
Key indicators (model output)	— Changes in agricultural production level, methods and income — Nutrient balances (N, P, K) — Gaseous emissions (NH_3, N_2O, CH_4),
Geographical coverage	— Coverage: EU-27 (plus Western Balkan countries) — Resolution: country level
Temporal coverage	— Base-year: 2004 — Time horizon: 2025 — Time steps: depending on need, for example five-year time steps
Analytical technique	— Comparative static, partial equilibrium model
Model structure	

CAPSIM **(Common Agricultural Policy Simulation Model)**	
Information on model development	
Model developers/owners	EuroCARE (www.eurocare-bonn.de/profrec/capsim/capsim_e.htm) Model development was funded by EUROSTAT.
Model development history	Model development primarily in 2001-2003 2004 amendments: EU-15 => EU-23, environmental indicators 2005: EU-23 => EU-25, net trade => gross trade model 2006: EU-25 => EU-27 + Western Balkan
Target group/users	CAPSIM has been used as the basis for the agricultural outlook of the EEA Other applications have for agricultural impact analyses of the CAP
Calibration	Free parameters of behavioural functions have been used to reproduce the base-year exactly until 2006. Calibration approach is under revision.
Validation	Ex post fit is checked as of 2007 against historical data as part of the parameter specification.
Uncertainty analysis	Key drivers are varied in scenarios but no further uncertainty analysis.
Key reference	Witzke, H.P., Zintl, A., 2003: CAPSIM — Complete documentation, Final Report to Eurostat, Bonn. http://forum.europa.eu.int/Public/irc/dsis/capsim/library?l=/capsimreportdoc/_EN_1.0_&a=d
Information on use of model in environmental assessments	
Level of integration	Agriculture and related themes (land use, water, climate)
Links to other models	The model allows combining different projections, for example from modelling tools, expert panels or trends forecasts, and finds a compromise between these (under specifiable constraints).
Ease of use//accessibility	Limited. Implementation at JRC, IPTS, Seville in 2007 is under way.
Use in participative processes	Only in form of monitoring by EU Commission steering groups for model development or application.
Other comments	Offers less detail than CAPRI, but can be more easily adapted to particular applications and typically requires less time for applications.

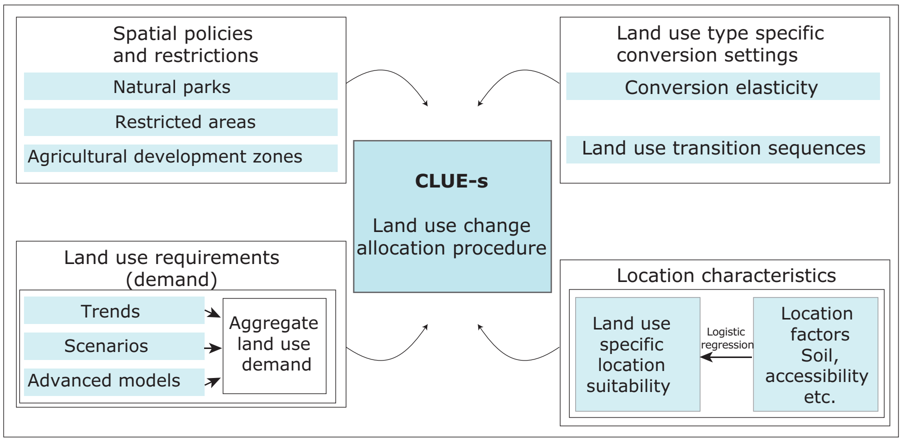
CLUE (including: CLUE, CLUE-s, Dyna-CLUE)

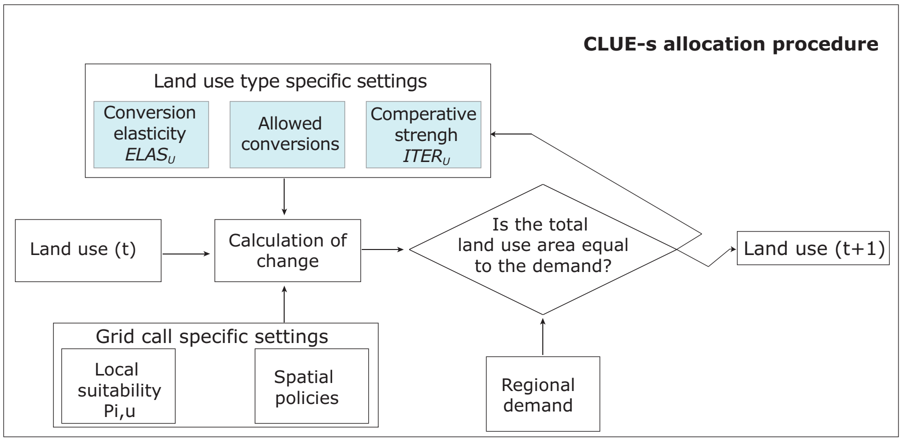
(Conversion of Land Use change and its Effects)

The objective of CLUE is to make a spatially explicit, multi-scale, quantitative description of land use changes through dynamic modelling and the quantification of the most important (assumed) bio-geophysical and human drivers based on either knowledge of the land use system or empirical analysis of observed land use patterns. The dynamic simulation model allocates changes in land use of which the aggregate quantity is determined by trend analysis, scenario assumptions or macro-economic modelling. Besides tracking past or historical land use changes, the objective is to explore possible land use changes in the near future under different development scenarios, having a time horizon of about 10–40 years. CLUE focus on interaction between spatial policies and restrictions, such as natural parks and agricultural development zones, and socio-economic and biophysical factors in different land use related sectors.

Model dimension	
Themes covered	— Land use — Agriculture — Urbanization
Key drivers (model input)	— Land use maps, remote sensing of land cover or census data on land use — Demographic change — Land use requirements (based on trends, scenarios, or macro-economic modelling) — Spatial policies — (Assumed) location factors
Key indicators (model output)	— Land use change
Geographical coverage	— Coverage: EU-27 (in EUruralis, GEO4, SENSOR, NITRO-Europe) — Resolution: 1 km by 1 km grid *Also case studies in a.o. Costa Rica, Ecuador, Honduras, the Netherland, China, Java (Indonesia), Philippines, Malaysia, Vietnam, Kenya, USA etc. with resolutions between 30 meter and 32 km.*
Temporal coverage	— Time horizon: 20–40 years
Analytical technique	— Systems dynamics model (in most cases informed by empirical statistical model of relations between land use and location factors, alternatively a cellular automata mechanism can be used)

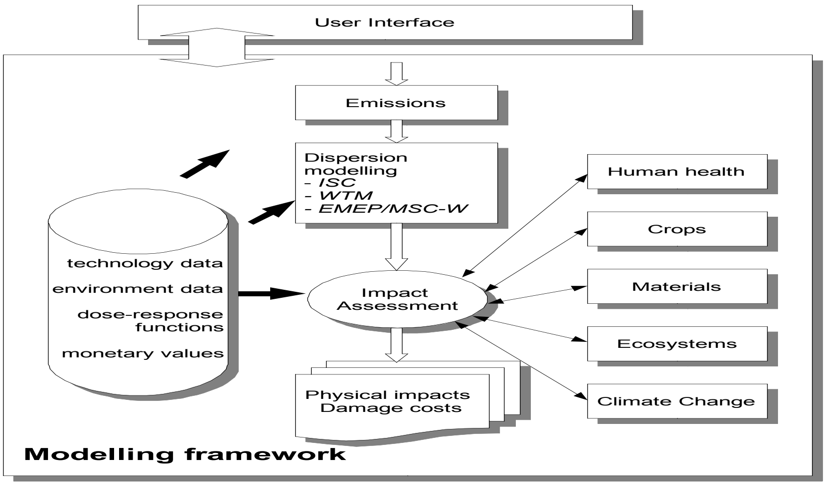
Model structure





CLUE (including: CLUE, CLUE-s, Dyna-CLUE) (Conversion of Land Use change and its Effects)	
Information on model development	
Model developers/owners	Peter H. Verburg, Koen Overmars, Tom Veldkamp and other contributors Department of Environmental sciences Landscape Centre Wageningen University. (www.cluemodel.nl)
Model development history	Mid 1990s — ongoing.
Target group/users	The CLUE model has been used by a large number of both universities and governmental research institutes from all over the world. Case study versions for a variety of regions exists.
Calibration	Calibration is based on observed land use patterns and, if possible, based on historic data. For some case studies calibration is helped by interviews with land managers.
Validation	Validation is based on historic land use changes for various case studies. Pontius, R.G. *et al.*, 2007. Comparing the input, output, and validation maps for several models of land change. Annals of Regional Science. In press.
Uncertainty analysis	Has been performed for some parameters in a number of case studies including the use of monte-carlo techniques.
Key reference	A wide range of scientific publications (full list at www.cluemodel.nl): e.g. Verburg, P.H., Soepboer, W., Veldkamp, A. Limpiada, R. Espaldon, V., Sharifah Mastura S.A. 2002. Modeling the Spatial Dynamics of Regional Land Use: the CLUE-S Model. Environmental Management 30(3): 391–405.
Information on use of model in environmental assessments	
Level of integration	High level of integration among land use sectors and spatial-temporal dynamics including path-dependence and spatial interactions. Feedbacks with environmental indicators can be addressed by tight coupling of the model with indicator models.
Links to other models	In many projects, including EURURALIS and SENSOR the land requirements are based on macro-economic modelling results from models such as GTAP, NEMESIS or IMAGE.
Ease of use//accessibility	Full version with technical support of the model is only available for collaborative projects. Others may use the model signing a memorandum of understanding excluding the commercial use of the model and requirement of proper referencing.
Use in participative processes	The model is used to simulate scenarios resulting from participatory processes. Results of the model have been used in participatory process. The model itself is not suitable for direct use by stakeholders.
Other comments	

EcoSense
EcoSense was designed for the analysis of single energy sources (electricity and heat production, transport processes) in Europe. It can also be used for analysis of multiple emission sources in certain regions. EcoSense was developed to support the assessment of priority impacts resulting from the exposure to airborne pollutants, namely impacts on human health, crops, building materials and ecosystems. The ExternE methodology includes also Impact Assessment due to emission of greenhouse gases (included in the current version EcoSense-Web). EcoSense-Web covers the emission of 'classical' pollutants SO_2, NO_x, primary particulates, and NMVOC, as well as some of the most important heavy metals. Impacts are calculated on different spatial scales, i.e. local (50 km around the emission source), regional (= Europe-wide) and (northern) hemispheric scale. EcoSense-Web does also assess impacts from radioactive nuclides, and chemical transformation from primary pollutants to secondary pollutants like nitrates, sulphates and ozone is also taken into account. The version EcoSense-Web has a web-based user interface and was developed for the European Commission project NEEDS.

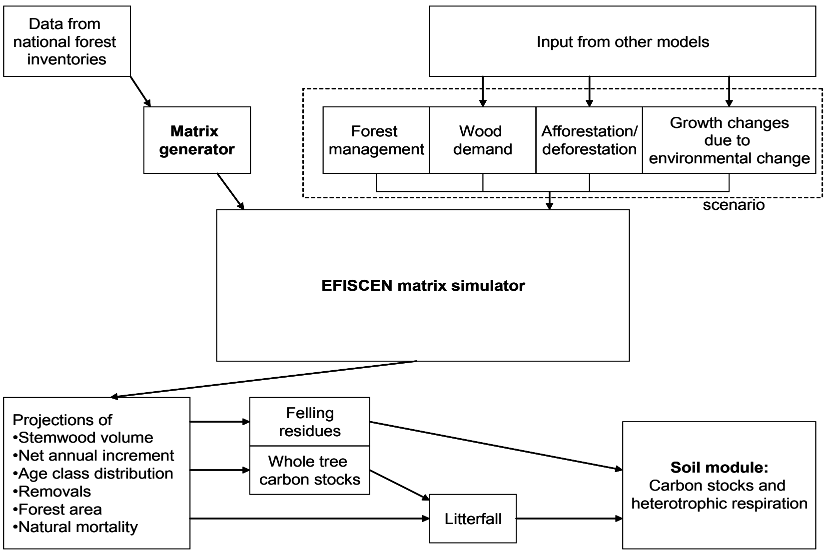
Model dimension	
Themes covered	— Air pollution — Energy (i.e. related to air pollution from energy use) — Environment and health (i.e. related to air pollution)
Key drivers (model input)	— Information on power plants (e.g. location, type of technology) — Emissions, e.g. NO_x, SO_2, $PM_{2.5}$, PM_{10}, NMVOC, GHG, heavy metals *EcoSense-Web contains a model to generator site depending local meteorological data*
Key indicators (model output)	— Concentration levels of primary and secondary particles and ozone — Receptor exposure (i.e. population, crops, building material) — Physical impacts resulting from exposure to airborne pollutants — (Damage) costs due to impacts on human health, crops, building materials, ecosystems, and due to climate change.
Geographical coverage	— Coverage: Europe including North Africa (EcoSense-Web). EcoSense can be/has been used in other regions, e.g. China, Brasil, Russia — Resolution: local scale: (polar-stereographic) grids with resolutions of 10 km x 10 km; regional scale: (polar-stereographic) grids with resolutions of 50 km x 50 km; hemispheric scale: (polar-stereographic) grids with resolutions of 100 km x 100 km covering the Northern Hemisphere.
Temporal coverage	— No time-steps/time horizon The EcoSense model is an impact assessment model without forecasts) — Yearly average values
Analytical technique	— Modelling framework combines and links various modelling and impact assessment approaches (notably: air transport models: Industrial Source Complex Model (ISC, a Gaussian plume model), the Windrose Trajectory Model (WTM, a user-configurable trajectory model), and the parameterised Eulerian model EMEP/MSC-W)
Model structure	

EcoSense	
Information on model development	
Model developers/owners	Institut für Energiewirtschaft und Rationelle Energieanwendung (Universität Stuttgart) for the European Commission project series ExternE (Externalities of Energy). (www.externe.info)
Model development history	EcoSense 2.0 (1999), EcoSense-Transport, EcoSense 4.01 (2004), Latest version is EcoSense-Web.
Target group/users	ExternE project partners; policy makers and researcher dealing with air pollution in Europe. Currently being applied in NEEDS (New Energy Externalities Development for Sustainability) project.
Calibration	
Validation	Validation of the models implemented in EcoSense versions (2002): Work package 5 of ExternE-Pol (http://www.externe.info/exterpol.html) Validation of the WTM dispersion model: comparison with measurement data (Rainer Friedrich, Peter Bickel (Eds.), Environmental External Costs of Transport, Springer 2001, ISBN 3-540-42223-4, pp.30–33) Validation of the EMEP/MSC-W dispersion model: comparison of the model with other dispersion models and comparison of the results with measured data.
Uncertainty analysis	See chapter 11 in Methodology 2005 Update, NEEDS project RS1b, WP7: 'Deliverable D7.2 Report on the methodology for the consideration of uncertainties' Jan, 2007.
Key reference	Externalities of Energy, Methodology 2005 Update. Edited by Peter Bickel and Rainer Friedrich (http://www.externe.info/brussels/methup05.pdf), www.externe.info
Information on use of model in environmental assessments	
Level of integration	Required models for dispersion modelling, exposure modelling, calculation of physical impacts and associated monetary values are integrated and interlinked. Most of the relevant input data are included in the EcoSense databases (environmental data, exposure-response functions, monetary values).
Links to other models	Interface for import of concentration fields from other dispersion models is in preparation.
Ease of use//accessibility	Access to EcoSense-Web can be obtained for a small handling fee after signing a licence agreement (www.externe.info/tools.html). A simplified version of the EcoSense model is available free of charge online http://ecoweb.ier.uni-stuttgart.de/ecosense_web/ecosensele_web/frame.php
Use in participative processes	
Other comments	EcoSense-Web operational April 2007; public access planned for later in 2007.

EFISCEN

(European Forest Information Scenario Model)

EFISCEN is a forest resource projection model. It is used to gain insight into the future development of European forests for issues such as sustainable management regimes; wood production possibilities; nature oriented management; climate change impacts; natural disturbances; and carbon balance issues. Through its underlying detailed forest inventory database (i.e. European Forest Resource Database), the projections provide these insights at varying scales, thus serving forest managers and policy makers at the national and international levels. EFISCEN simulates only forest area that is available for wood supply. Unproductive forests as well as nature conservation areas are excluded from the analysis. The resource projections in EFISCEN are driven by the market demand for round wood, which determines the amount of felling.

Model dimension	
Themes covered	— Forestry — Biodiversity (i.e. forestry related) — Climate change (i.e. forestry related)
Key drivers (model input)	— EFISCEN inventory database (i.e. forest types can be separated based on administrative unit, ownership, tree species and site class; see http://www.efi.int/databases/efiscen/intro.php). — Forest management (tree mortality, yield, and felling regime) — Market demand for round wood
Key indicators (model output)	— Tree species distribution — Area, growing stock, increment, harvest level and age class distribution — Information on carbon stocks in biomass and soil
Geographical coverage	— Coverage: EU-27 + CH, NO — Resolution: national to provincial level (depends on inventory database)
Temporal coverage	— Base-year: depends on inventory database — Time horizon: 50 to 60 years — Time steps: 5 years
Analytical technique	— Forest model, described as area-based matrix modelling approach (i.e. EFISCEN is an area-based matrix model, for each forest type that is distinguished in the input data a separate matrix is set up)
Model structure	

EFISCEN (European Forest Information Scenario Model)	
Information on model development	
Model developers/owners	EFISCEN has been jointly developed and applied at the European Forest Institute (EFI) and Alterra (see www.efi.int/projects/efiscen)
Model development history	Model structure developed in late 1980's, database updated regularly. In parallel to maintain the current model, new development directions are currently investigated, aiming at higher resolution and integration with land use models. Current version used: 3.1.3.
Target group/users	The model is designed to be used by various users such as policy and decision makers, researchers as well as the general public. Currently being used in the EU FP6 projects EFORWOOD and ADAM.
Calibration	Calibration is done separately for each country, based on inventory database.
Validation	Validated against independent Finnish and Swiss long term inventory series.
Uncertainty analysis	An uncertainty analysis is currently being done and will be available shortly in the new manual (Schelhaas *et al.*, in prep.)
Key reference	A detailed description will be available shortly with the manual (Schelhaas *et al.*, in prep.). Many peer-reviewed publications are available on the website. Most recent: Nabuurs, G.J., Pussinen, A., van Brusselen, J., Schelhaas, M.J., 2006. Future harvesting pressure on European forests. European Journal of Forest Research. 10.1007/s10342-006-0158-y
Information on use of model in environmental assessments	
Level of integration	Model assesses consequences of environmental change, but there are no feedbacks within the model. However, output can be used to feed to other models (for example carbon sequestration).
Links to other models	Within the projects LTEEF-II and NitroEurope EFISCEN was/is used to upscale consequences of environmental change as assessed by detailed process based models. Within the EFSOS project, EFISCEN was used to assess consequences of projected wood demand as assessed by an economic model. Within the project ADAM-IP, EFISCEN will be linked with economic (wood demand) and landuse (forest area changes) models, including feedbacks to those models and to a climate model as well. Within SENSOR-IP EFISCEN is linked to an econometric model and a landuse model.
Ease of use//accessibility	Model executable is available on request. Requires some training before use.
Use in participative processes	
Other comments	

Euromove

In the EUROMOVE model nearly 1400 plant species with a known European distribution are correlated with climate data (i.e. from IMAGE model) using multiple logistic regressions. These calculations result in climate envelopes.

EUROMOVE integrates the calculated regression equations to analyse the effects of climate change on the European flora. With EUROMOVE, response curves and maps can be drawn for plant species diversity and species distributions for various climate scenarios. With EUROMOVE it is also possible to calculate for each European grid cell the expected changes in occurring plant species due to changes in regional and seasonal climate patterns.

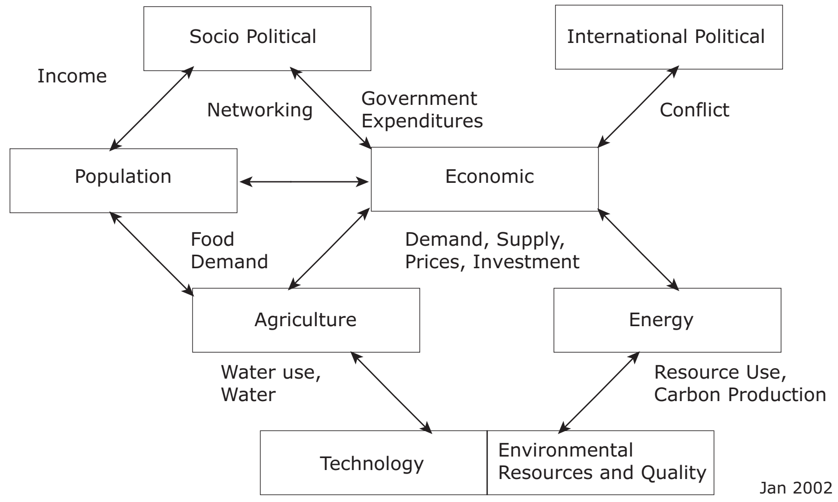
Model dimension	
Themes covered	— Biodiversity — Climate change (i.e. biodiversity related)
Key drivers (model input)	— Climate parameters — Current plant distribution data
Key indicators (model output)	— Changes in diversity and distribution of nearly 1400 plant species
Geographical coverage	— Coverage: EU-27 plus NO, IS, CH, UA, MD, BY (and 'European' part of RU) — Resolution: roughly a 50 by 50 km^2 grid
Temporal coverage	— Base-year: 1990 (approximated) — Time horizon: 2050/65 (depends on climate data input)
Analytical technique	(i.e. the EUROMOVE model uses logistic regression equations to calculate the occurrence probability for 1400 plant species in Europe.
Model structure	Climate variables for 1990 were related to the presence–absence data for the 1397 plant species derived from the 'Atlas Florae Europaeae' using multiple logistic regression. Logistic regression is a special case of generalised linear models in which the outcome variable is assumed to have a binomial distribution, and the logit function is used to link the expected values with the explanatory variables. The expected values that resulted from the model calculations can be interpreted as estimates of occurrence probabilities of plant species. To obtain uni-model response functions, both linear and quadratic terms of each explanatory variable were included in the model (Gaussian logit model).

Euromove	
Information on model development	
Model developers/owners	Netherlands environmental assessment agency (MNP) (see www.rivm.nl/bibliotheek/rapporten/410200032.html)
Model development history	First published in 2002
Target group/users	Used to support climate change impact research at European level; including applications for the European Environment Agency.
Calibration	Calibrated on 1990 data — all multiple logistic regression analyses resulted in statistically significant models ($\alpha = 0.01$). On average, the deviance explained (D) was 42 %, indicating a relatively high predictive power.
Validation	
Uncertainty analysis	
Key reference	M. Bakkenes, *et al*., 2002. Assessing effects of forecasted climate change on the diversity and distribution of European higher plants for 2050. Global Change Biology 8 (4), 390–407. Bakkenes, M., Eickhout, B. and Alkemade, R., 2006. Impacts of different climate stabilisation scenarios on plant species in Europe. Global Environmental Change, 16(1): 19-28.
Information on use of model in environmental assessments	
Level of integration	
Links to other models	EUROMOVE uses climate data from IMAGE model.
Ease of use//accessibility	Model not available online.
Use in participative processes	
Other comments	

IFs

(International Futures)

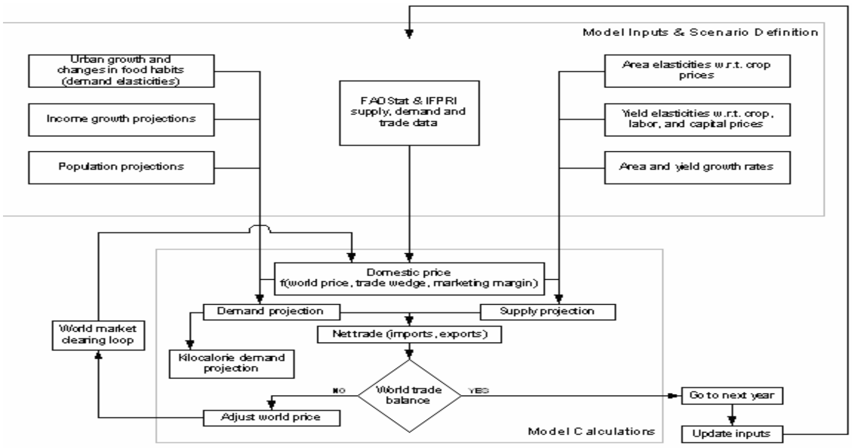
International Futures (IFs) is a computer simulation of global systems for classroom or research use. IFs can be used to teach or study demographics, economics, food, energy, the environment, and international politics. It is especially suitable for analysis of sustainable development and for examining the human dimensions of global change. IFs is a large-scale integrated global modelling system. IFs is heavily data-based and also deeply rooted in theory. It represents major agent-classes (households, governments, firms) interacting in a variety of global structures (demographic, economic, social, and environmental). The system draws upon standard approaches to modelling specific issue areas whenever possible, extending those as necessary and integrating them across issue areas.

Model dimension	
Themes covered	— Climate change — Energy — Agriculture — Other (such as demography, economy, political) *With respect to themes covered, it would be possible to add to the other list: education, human-well-being including poverty*
Key drivers (model input)	— Current situation describing demography, economic, agricultural, energy, socio-political, international political, environmental situation. — The relationship functions between and within modules can be altered, depending on scenario assumption
Key indicators (model output)	— Future situation describing demography, economic, agricultural, energy, socio-political, international political, environmental situation.
Geographical coverage	— Coverage: global — resolution: 182 regions/countries
Temporal coverage	— Base-year: 2000 — Time horizon: 2100 — Time steps: annual
Analytical technique	Global system dynamics model (i.e. the system combines various types of modelling approaches, including partial equilibrium modelling and multiple agent approaches). The economic model uses CGE within the framework of a social accounting matrix.
Model structure	IFs is a modelling system that includes several modules: demography, economic, agricultural, energy, socio-political, international political, environmental, and an implicit technology modules. 

IFs (International Futures)	
Information on model development	
Model developers/owners	Barry Hughes, Graduate school of international studies University of Denver (www.du.edu/~bhughes/ifs.html). Model development is supported by a range of different foundations and funding sources.
Model development history	The first version of International Futures was developed in 1980. The fifth version of IFs is currently in use (i.e. in 2006).
Target group/users	IFs began as an educational tool and is mainly used for educational purposes. Nevertheless, the model is increasingly being used in policy analysis and international assessments (e.g. UNEP).
Calibration	With respect to calibration, the model is initialized with data primarily from the 1995–2005 period and a very large data associated data base (nearly 1000 series) from a wide range of sources, especially World Bank World Development Indicators, Global Trade and Analysis Project, UN Population Division, WRI Earthtrends, British Petroleum annual energy report, and UN FAO.
Validation	With respect to validation, runs of the model from 1960 through 2000 have been compared with data series from the same sources for key model variables (report is on the IFs web site).
Uncertainty analysis	
Key reference	Barry B. Hughes and Evan E. Hillebrand, Exploring and Shaping International Futures. Boulder, CO: Paradigm Publishers, 2006. Specifically, see chapter 4.
Information on use of model in environmental assessments	
Level of integration	
Links to other models	
Ease of use//accessibility	Ease-of-use is high. No special permission is needed. Model is available online: www.ifs.du.edu
Use in participative processes	With respect to use in participative processes: the model is routinely used in many university classrooms, and has been used collaboratively in a variety of presentations and workshops.
Other comments	

IMPACT **(International Model for Policy Analysis of Agricultural Commodities and Trade)**

IMPACT, the International Model for Policy Analysis of Agricultural Commodities and Trade, is a state-of-the-art model developed by IFPRI (International Food Policy Research Institute) to generate projections to the year 2020 and 2050 on global and regional food supply, demand, trade, and malnutrition. IMPACT covers 32 commodities (which account for virtually all of world food production and consumption), including all cereals, soybeans, roots and tubers, meats, milk, eggs, oils, meals, vegetables, fruits, sugar and sweeteners, and fish in a partial equilibrium framework. It is specified as a set of country-level supply and demand equations where each country model is linked to the rest of the world through trade. Food production is also made a function of water availability (from both precipitation and irrigation). IMPACT has been used in several important research publications, which examine the linkage between the production of key food commodities and national-level food demand and security, under alternative global scenarios of environmental and economic change.

Model dimension	
Themes covered	— Agriculture — Water (as related to agriculture)
Key drivers (model input)	— Income, and population growth (to determine food and non-ag water demand) — Crop productivity (depends on various drivers, incl. ag research, etc.) — Change in available agricultural area over time — Climate parameters, plus irrigation and water supply information — Trade policies
Key indicators (model output)	— Crop area, yield, production, demand for food, feed and other uses, prices — Livestock numbers, yield, production, demand, prices — Net trade in 32 agricultural commodities (virtually all global food trade) — Percentage and number of malnourished preschool children — Per-capita calorie availability from foods
Geographical coverage	— Coverage: global — Resolution: 115 regions and countries (incl. EU-15 and Eastern Europe) intersected with 126 river basins — gives a total of 281 spatial units globally.
Temporal coverage	— Base-year: 2000 — Time horizon: 2020/2025/2050 — Time steps: annual
Analytical technique	— Partial equilibrium model (i.e. IMPACT is a sectoral agricultural model)
Model structure	IMPACT is specified as a set of country or regional sub-models within each of which supply, demand, and prices for agricultural commodities are determined. The country and regional agricultural sub-models are linked through trade. The model uses a system of supply and demand elasticities incorporated into a series of linear and nonlinear equations to approximate the underlying production and demand functions. A descriptive diagram is shown below. 

IMPACT (International Model for Policy Analysis of Agricultural Commodities and Trade)	
Information on model development	
Model developers/owners	International Food Policy Research Institute (IFPRI) of the CGIAR Network. (www.ifpri.org/themes/impact.htm)
Model development history	Early 1990's to 2000. The original IMPACT model was enhanced to include linkages with water (IMPACT-Water) in 2002, and has been further expanded in 2005 to give greater spatial resolution.
Target group/users	Has been used in numerous international environmental assessments (such as World Water Vision, Millennium Ecosystem Assessment). Currently being used in UNEP's Global Environmental Outlook (GEO-4) and the International Assessment of Agricultural Science and Technology for Development (IAASTD).
Calibration	Model uses the UN Medium Variant Population growth projections, and follows the global hydrology patterns embodied from the climate data provided by the Climate Research Unit of the University of East Anglia. The streamflow and runoff data has been calibrated to WaterGAP of the University of Kassel.
Validation	IMPACT has been used in a historical counterfactual analysis that accurately produced the historical record of agricultural production and consumption from 1970 to 2000.
Uncertainty analysis	Climate uncertainty is explored with the use of alternative GCM scenarios, which are downscaled to the spatial units of IMPACT.
Key reference	Rosegrant *et al*. (2005) International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT-WATER): Model Description (available at www.ifpri.org/themes/impact/impactwater.pdf)
Information on use of model in environmental assessments	
Level of integration	Water is the key environmental component which is directly integrated into the model structure. Response to water availability is measured in terms of yield loss (relative to full potential).
Links to other models	The IMPACT model has been linked to a range of models in international assessments, such as GTEM (AustraliaBARE), IMAGE (MNP, Netherlands), AIM (Nat'l Inst for Env Studies, Japan) and WaterGAP (Univ. of Kassel).
Ease of use//accessibility	Ease-of-use is very limited (i.e. referring to the full version of IMPACT). IFPRI has developed a distributional version (IMPACT-D) that can be downloaded free of charge (www.IFPRI.org/themes/impact/impactd.asp).
Use in participative processes	
Other comments	

PHOENIX plus

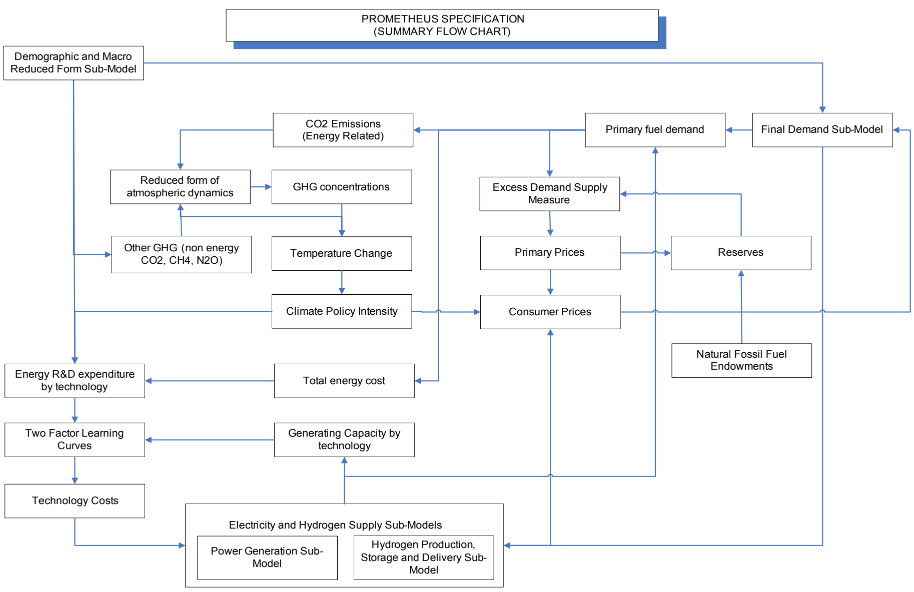
PHOENIX plus provides a population user support system to explore, develop and analyze different demographic scenarios at various geographical aggregation levels (global, regional, national and grid-cells). PHOENIX provides an integrated modelling framework that allows to describe, position and analyze various long-term population issues.
A systems dynamic modelling approach is applied to describe the demographic transition as a composite of its underlying components: the epidemiological and fertility transitions. Future fertility behaviour and mortality patterns in major world regions are explored under varying socio-economic and environmental conditions by making use of the computer simulation tool.

Model dimension	
Themes covered	— Demography
Key drivers (model input)	— Assumptions on fertility, mortality and migration (from previous studies)
Key indicators (model output)	— Demography
Geographical coverage	— Coverage: global (in Europe 40 countries detailed) — Resolution: country level, disaggregated to 0,5 x 0,5 degree grid cells
Temporal coverage	— Base-year: 1950/2000 (i.e. latest population data) — Time horizon: 2100 — Time steps: annual
Analytical technique	— Systems dynamic modelling approach
Model structure	PHOENIX consists of three components: Demographic Core — The population submodel uses an integrated systems approach, in which the results of the fertility and mortality submodels are structured into pressure (e.g. health determinants), state (e.g. fertility behaviour and population dynamics for disease and disease-specific mortality), impact (e.g. burden of disease and life expectancy, and the size and structure of the population) and response (e.g. population/health policies influencing the fertility behaviour and disease processes). Fertility Model — The fertility model calculates the total fertility rate (TFR), based on an index of marriage, an index of contraceptives, an index of postpartum infecundity and an index of abortion. Mortality Model — The mortality model simulates the number of persons exposed to various health risks and the number of deaths related to these exposures.

PHOENIX plus	
Information on model development	
Model developers/owners	Netherlands environmental assessment agency (see www.mnp.nl/phoenix/)
Model development history	Model developed in the late 1990s.
Target group/users	The PHOENIX model has been used, among others, in the IMAGE model, in National Environmental Outlooks, in UNEP's Global Environmental Outlook, IPCC SRES and EUruralis.
Calibration	Model calibrated on data from 1950 to 2000.
Validation	
Uncertainty analysis	
Key reference	Hilderink, H. B. M. (2000) World population in transition: an integrated regional modelling framework, Thela Thesis/Rozenberg, Amsterdam. Hilderink, H.B.M., Population & Scenarios, Worlds to win? 2004, Netherlands Environmental Assessment Agency (RIVM-MNP): Bilthoven, the Netherlands. Hilderink, H.B.M., People in the Pixel: Towards grid-based population modelling. Sustainable Planning and Development, 2005. 1(1). Hilderink, H.B.M., People in the Pixel: grid-based population dynamics using PHOENIX, in Integrated modelling of global environmental change. An overview of IMAGE 2.4, A.F. Bouwman, T. Kram, and K. Klein Goldewijk, Editors. 2006, Netherlands Environmental Assessment Agency (MNP).
Information on use of model in environmental assessments	
Level of integration	
Links to other models	Close ties to the IMAGE model (Phoenix provides demographic input)
Ease of use//accessibility	Free download (permission is granted automatically when the user accepts the terms of usage)
Use in participative processes	
Other comments	

Prometheus

PROMETHEUS is a tool for exploring uncertainties on key energy, environment and technology variables. It is a self-contained energy model consisting of a set of stochastic equations. It contains relations and/or exogenous variables for all the main quantities which are of interest in the context of general energy systems analysis as well as technology dynamics regarding power, road transport and hydrogen production and use technologies. The variables cover demographic and economic activity indicators, energy consumption by main fuel, fuel resources and prices, CO_2 emissions, greenhouse gases concentrations, temperature change, technology uptake and two factor learning curves (describing technology improvement in terms of research and experience gained through their application). All exogenous variables, parameters and error terms in the model are stochastic with explicit representation of their distribution including in many cases terms of co-variance. It follows that all endogenous variables as a result are also stochastic.

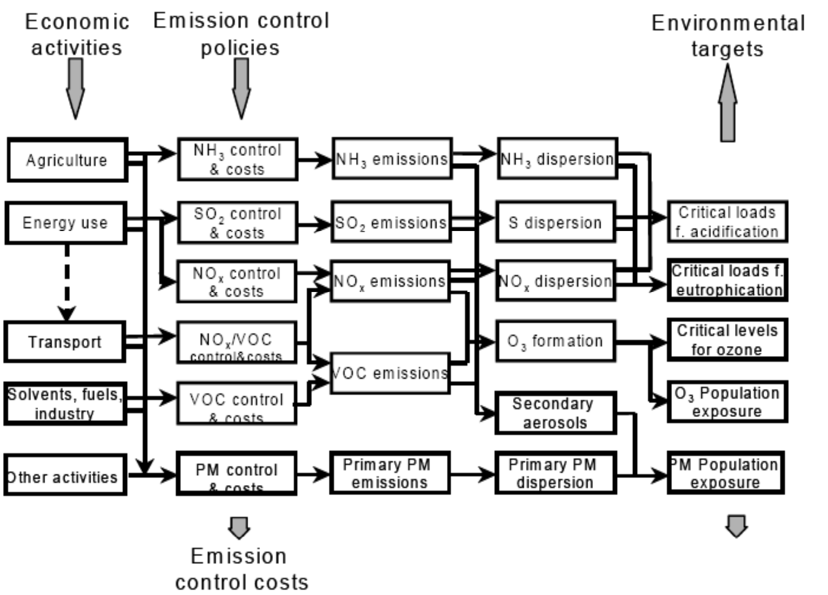
Model dimension	
Themes covered	— Energy — Climate change — Transport
Key drivers (model input)	Joint distributions of parameters and autonomous deviations related to: — GDP — R&D activity — Resource endowments — Fuel prices
Key indicators (model output)	Joint Probability distributions for all the variables in the model: energy supply and demand, macro-economic aggregates, total system costs, technology uptake, international fuel prices, reserves for oil and gas, GHG emissions and concentrations, world temperature, power plant capacities, electricity generation by technology, technology investment costs
Geographical coverage	— Coverage: Global — Resolution: 4 main world regions: — OECD 90 Europe (includes EU-15, Norway and Switzerland) — Other OECD 90 (includes USA, Canada, Japan, Australia and New Zealand) — The 12 New Member States of the European Union — Rest of the World (Less Developed countries)
Temporal coverage	— Base-year: 2004 — Time horizon: 2050 — Time steps: yearly
Analytical technique	— Statistical methods, Monte Carlo simulations
Model structure	

Prometheus	
Information on model development	
Model developers/owners	Developed by the Energy-Economics-Environment Modelling Laboratory (E3M-Lab) (www.e3mlab.ntua.gr) of the Institute of Communication and Computer Systems of National Technical University of Athens
Model development history	PROMETHEUS has been initially developed for the European Commission SAPIENT project (Contract no. ENG2-CT1999-0003). During a series of subsequent EU-funded projects the model has been extended to incorporate: — Wider technological description (additional power generation technologies, detailed representation of the transport sector, hydrogen production, storage and delivery infrastructure technologies CO_2 capture and sequestration) — A detailed stochastic climate change module calculating CO_2, N_2O and CH_4 emissions from different sources, their atmospheric concentrations and committed global average temperature change. — Stochastic relations (two factor learning curves) describing technology improvement dynamics (both learning by research and by experience) — Additional regional coverage (New EU Member States) — Longer time-horizon (2050) The model is implemented using the E-views econometric software.
Target group/users	Major applications are in environmental risk, security of supply assessment, assessment and investment risk analysis. Emphasis on policy analysis
Calibration	The model has been calibrated using EUROSTAT, IEA and ENERDATA time series data. It also uses TECHPOL for technology and R&D statistics and USGS for geological uncertainties.
Validation	Over historical period: EUROSTAT, IEA
Uncertainty analysis	PROMETHEUS has been specifically designed to perform uncertainty analysis. The basic output of PROMETHEUS is a data set of Monte Carlo simulations providing strategic and analytical information on risks and probabilities with regard to all the variables incorporated in the model or any predetermined function involving them.
Key reference	Cannon, M., Kouvaritakis, B., and Huang, G., 2005, 'Modelling and Optimisation for Sustainable Development policy assessment', European Journal of Operational Research, 164, 475–490 Systems Analysis for Progress and Innovation in Energy Technologies (SAPIENT) Final Report, European Commission ENG2-CT1999-00003 Systems Analysis for Progress and Innovation in Energy Technologies for Integrated Assessment (SAPIENTIA) Final Report, European Commission ENK6-CT-2002-00615 EEA, European Environment Outlook (2005), Short model description
Information on use of model in environmental assessments	
Level of integration	Impacts of R&D on Sustainability objectives, Impact of Technology promoting policies (Renewables, Carbon Capture and Sequestration, Fuel Cells, Hydrogen)
Links to other models	ISPA integrated decision tool for R&D strategy exploration
Ease of use//accessibility	Limited
Use in participative processes	
Other comments	

RAINS **(Regional Air pollution Information and Simulation)**

The regional air pollution information and simulation (RAINS) model provides a tool for analysis of reduction strategies for air pollutants. The model combines information on economic and energy development, emission control potentials and costs, atmospheric dispersion characteristics and environmental sensitivities towards air pollution. The model addresses threats to human health posed by fine particulates and ground-level ozone as well as risk of ecosystems damage from acidification, excess nitrogen deposition (eutrophication) and exposure to elevated ambient levels of ozone. The RAINS model framework makes it possible to estimate, for a given energy— and agricultural scenario, the costs and environmental effects of user-specified emission control policies.

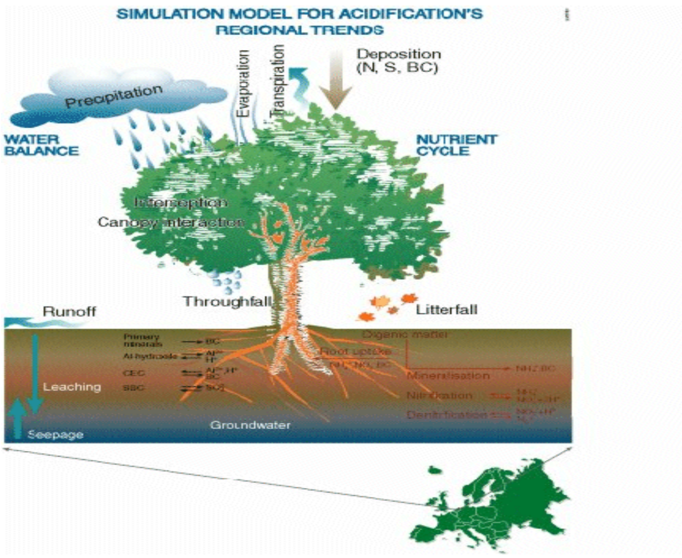
RAINS-Europe has recently evolved to GAINS (Greenhouse Gas and Air Pollution Interactions and Synergies).

Model dimension	
Themes covered	— Air — Energy (as related to air) — Transport (as related to air) — Agriculture (as related to air)
Key drivers (model input)	— Economic development — Sectoral activity (for agriculture, transport, energy, fuels and others)
Key indicators (model output)	— Emissions of sulphur dioxide (SO_2), nitrogen oxides (NO_x), ammonia (NH_3), non-methane volatile organic compounds (NMVOC), particulate matter (PM) — Air pollution effect of energy consumption, transport and agriculture — Health impact and acidification
Geographical coverage	— Coverage: almost all European countries, incl. the European part of Russia — National versions available for Italy and the Netherlands (also RAINS versions for other regions, e.g. Asia, available) — Resolution: country-level (can be linked with finer resolution dispersion models)
Temporal coverage	— Base-year: 2000 — Time horizon: 2020 — Time steps: 5 year time steps
Analytical technique	— Linear programming model/impact assessment model
Model structure	

RAINS (Regional Air pollution Information and Simulation)	
Information on model development	
Model developers/owners	IIASA (International Institute for Applied Systems Analysis) a non-governmental Vienna based research institute (www.iiasa.ac.at/rains)
Model development history	Developed in the period from 1983 to 2005. Recently extended to explore synergies and trade-offs between the control of local and regional air pollution and the mitigation of global greenhouse gas emissions (GAINS model).
Target group/users	European Commission (e.g. the model was used in preparation of the 1998 EU directive on air quality and emissions). The model is also used by a large number of governments, universities, and research institutes.
Calibration	
Validation	
Uncertainty analysis	A methodology to estimate uncertainties of emission calculations based on uncertainty estimates for the individual parameters of the calculation is included. Also several sensitivity analyses have been conducted.
Key reference	Amann *et al.*, 2004. The RAINS model: Documentation of the model approach prepared for the RAINS peer review. http://www.iiasa.ac.at/rains/review/review-full.pdf
Information on use of model in environmental assessments	
Level of integration	
Links to other models	— RAINS is the basis for the GAINS model. — Atmospheric dispersion processes over Europe for air pollutants are modelled on the basis of results of RAINS and the European EMEP model. — Strong links to PRIMES, TREMOVE and CAPRI models have been established (e.g. in the EC's CAFE 2030 programme).
Ease of use//accessibility	Simulations can be run free of charge from the online version of the RAINS model. Basic forecasts can be calculated by lay people using the online version of RAINS.
Use in participative processes	— RAINS has been used as the central modelling tool for the EU Clean Air For Europe (CAFE) programme, for the EU emission ceilings directive in 1999 and is currently applied for the revision of the EU emission ceilings directive. — RAINS has been used i.a., for the Gothenburg Protocol of the Convention on Long-range Transboundary Air Pollution — National versions for Italy and the Netherlands have been developed and are used for national assessments.
Other comments	

SMART 2 (Simulation Model for Acidification's Regional Trends)

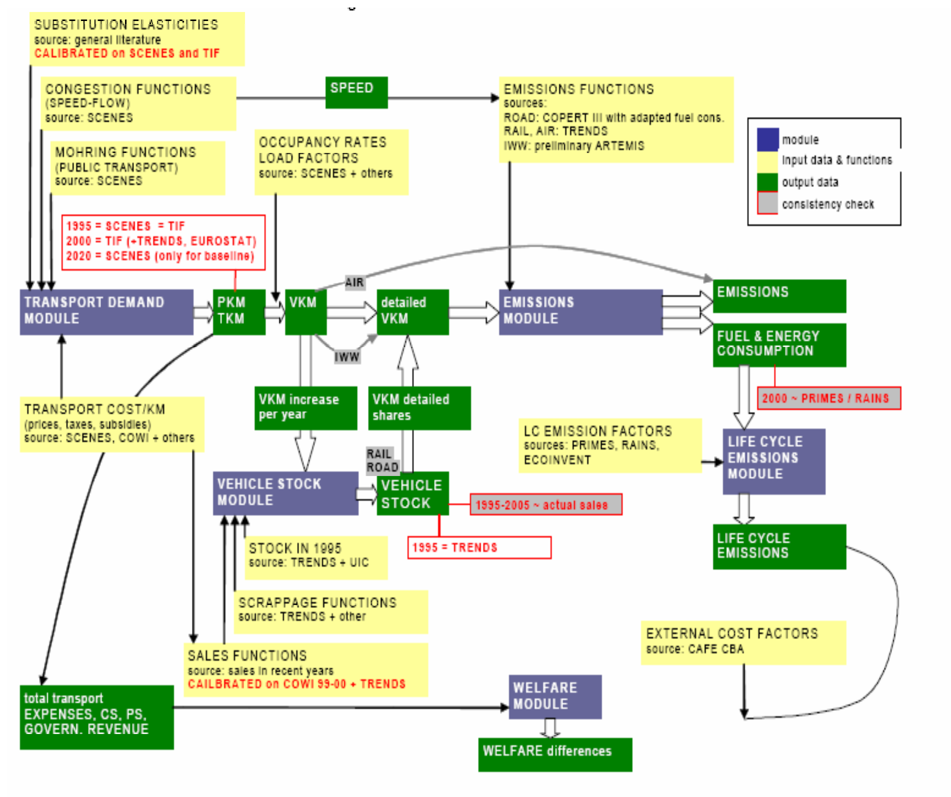
Changes in vegetation are often caused by changes in abiotic site factors, such as pH, nitrogen availability and soil moisture. It has been recognized that abiotic site factors are affected by atmospheric deposition and groundwater-table changes. In order to evaluate the effects of eutrophication, acidification and desiccation on site factors, the model SMART2 has been developed. SMART2 (Simulation Model for Acidification's Regional Trends) is a simple one-compartment soil acidification and nutrient cycling model that includes the major hydrological and biogeochemical processes in the vegetation, litter and mineral soil. Apart from pH, the model also predicts changes in aluminium (Al^{3+}), base cation (BC), nitrate (NO_3^-) and sulphate (SO_4^{2-}) concentrations in the soil solution and solid phase characteristics depicting the acidification status, i.e. carbonate content, base saturation and readily available Al content.

Model dimension	
Themes covered	— Acidification/soil — C and N sequestration — Biodiversity change
Key drivers (model input)	— Atmospheric deposition — Water balance — Soil type — Vegetation type — Nutrient cycle
Key indicators (model output)	— Soil solution concentrations of Al, Ca + Mg, Na, K, NH_4, SO_4, NO_3 — Concentration of the soil water leaving the root zone — Nutrient availability
Geographical coverage	— Coverage: Netherlands potential to cover the entire EU (depends on the data availability) — Resolution: GIS application, between 1 km x 1 km to 20 km x 20 km grid cells
Temporal coverage	— Base-year: 1990 — Time horizon: 2050 — Time steps: annual
Analytical technique	— Set of mass balance equations, describing the soil input-output relationships
Model structure	

SMART 2 (Simulation Model for Acidification's Regional Trends)	
Information on model development	
Model developers/owners	ALTERRA (Wageningen University, NL) see also: http://www.macaulay.ac.uk/dynamo/smart.htm
Model development history	The dynamic soil acidification SMART model was developed in the late 1980s/early 1990s. The SMART2 model is an extension of SMART and was developed in the mid 1990s.
Target group/users	Research
Calibration	Mol-Dijkstra, J.P., G. J. Reinds, J. Kros, B. Berg, W de Vries (in prep) Modelling soil carbon sequestration in forest soils on intensively monitored plots in Europe in response to N deposition
Validation	Kros, J., J.P. Mol-Dijkstra and E.J. Pebesma, (2002). Assessment of the prediction error in a large-scale application of a dynamic soil acidification model. Stochastic Environmental Research and Risk Assessment 16, 279–306.
Uncertainty analysis	Kros, J., E.J. Pebesma, G. J. Reinds, P.A. Finke (1999) Uncertainty in Modelling Soil Acidification at the European Scale, A case study, Journal of Environmental Quality 28/2: 366–377 Jansen, M.J.W., E.P.A.G. Schouwenberg, J.P. Mol-Dijkstra, J. Kros and H. Houweling (2000). Variance-based regression-free uncertainty analysis for groups of inputs applied to a model chain in nature conservation, in: Cottam, Harvey, Pape & Tait (eds), Balkema, Rotterdam: 1127–1131.
Key reference	Kros, J., Reinds, G.J., Devries, W., Latour, J.B., and Bollen, M. Modelling the response of terrestrial ecosystems to acidification and desiccation scenarios. Water Air and Soil Pollution 85:1101-1106, 1995.
Information on use of model in environmental assessments	
Level of integration	Comprises soil, vegetation, soil water, biogeochemistry
Links to other models	To be linked with output from atmospheric deposition models and hydrological models Dynamically linked with a vegetation succession model SUMO: Output to be linked with the NTM model See also: Van Dobben, H.F., Wamelink, G.W.W., Schouwenberg, E.P.A.G., Mol, J.P., 2002. Use of coupled models to predict biodiversity in managed ecosystems. Reports in ecology and environmental engeneering 1, 76–86 E.C. Rowe, G.W.W. Wamelink, S. Belyazid, J.P. Mol-Dijkstra, C. D. Evans, S. M. Smart (in prep) Comparing models of acid and nitrogen pollution effects on plant diversity on European sites.
Ease of use//accessibility	Model not available online. Ease of use is limited. An executable with user manual is obtainable from the developers
Use in participative processes	
Other comments	

TREMOVE

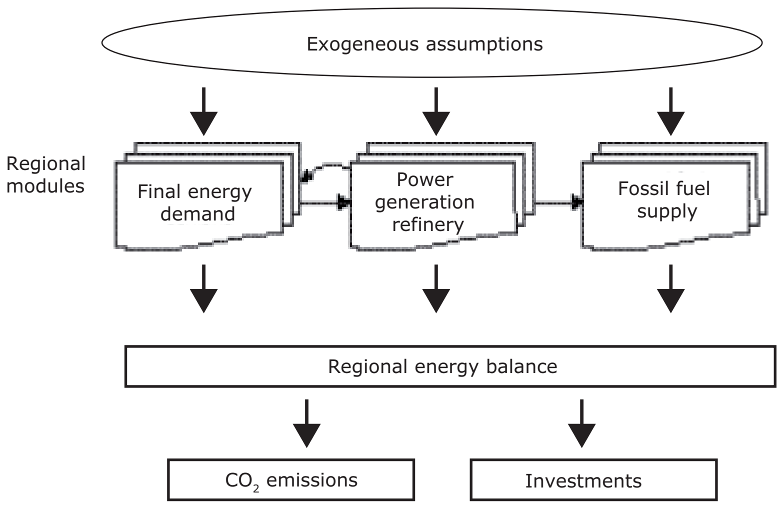
TREMOVE is a policy assessment model to study the effects of different transport and environment policies on the emissions of the transport sector. The model covers passenger and freight transport. TREMOVE was developed to compute the effects of various types of policy measures — taken in isolation or as packages — on the key drivers of transport emissions (such as size/composition of the vehicle stock and usage). Currently, TREMOVE consist of 21 parallel country models. Each country model consists of three inter-linked 'core' modules: a transport demand module, a vehicle turnover module and an emission and fuel consumption module, to which a welfare cost module and a well-to-tank emissions module have now been added. Currently a project is ongoing to extend TREMOVE to 31 countries and a 2030 time horizon.

Model dimension	
Themes covered	— Transport — Air (i.e. transport-related emissions) — Energy (i.e. transport-related energy consumption and WTT emissions)
Key drivers (model input)	— BAU transport activity forecast (currently from SCENES model) — BAU transport prices forecast — Road pricing, public transport pricing — Size and composition of vehicle stock in the baseyear(s) — Policies on emission standards, subsidies for cleaner cars etc.
Key indicators (model output)	— Demand for passenger km (pkm)/ton km (tkm) per transport type — Total fleet and number of km for each year according to vehicle type and age — Fuel consumption and emissions from transport — Cost to society associated with emission reduction scenarios
Geographical coverage	— Coverage: EU-15 member states plus Czech Republic, Hungary, Poland, Slovenia + Switzerland, Norway ; extension ongoing to Cyprus, Estonia, Latvia, Lithuania, Slovenia, Malta, Slovakia, Bulgaria, Croatia, Romania, Turkey. — Resolution: output by country, each country is split up in three regions — One metropolitan city — An aggregate urban region (all other cities) — Non-urban region
Temporal coverage	— Base-year: 1995 — Time horizon: 2020 (extension to 2030 ongoing) — Time steps: annual
Analytical technique	— Partial equilibrium model (i.e. sectoral model for the transport market)
Model structure	

TREMOVE	
Information on model development	
Model developers/owners	Developers : Transport & Mobility Leuven (TML) and the K.U. Leuven The model development was funded by the EU commission. Owners : EU commission Software : GAMS (general algebraic modelling software) Website (by TML): (www.tremove.org)
Model development history	TREMOVE 1: 1997-1999. TREMOVE 2.0 to 2.4: 2002–2006. TREMOVE 2.5 is now under development. The most recent version is the TREMOVE 2.44 model. Further development of the model is scheduled in the FP6 iTREN-2030 project in coordination with EU JRC-Sevilla
Target group/users	TREMOVE 1 was primarily used in the EU Auto-Oil II programme. TREMOVE 2.0 to 2.4 were used in the EU CAFE programme (Euro 5 emission standards, maritime policies, etc.) and for the EU policy on car CO_2 emissions. Also some national applications and applications in cooperation with automobile manufacturers (FP5 projects).
Calibration	The demand module has been calibrated towards European statistics and additional national transport demand estimates towards national vehicle fleet statistics, and towards national fuel consumption statistics (detailed description of calibration in model documentation).
Validation	
Uncertainty analysis	
Key reference	Final report TREMOVE 2 (Service Contract 070501/2004/387327/MAR/C1) www.tremove.org/documentation/index.htm
Information on use of model in environmental assessments	
Level of integration	
Links to other models	Links to SCENES and PRIMES models for the BAU scenario development. Joint scenario analysis with TREMOVE, SCENES, CGE in the ASSESS project (DG TREN project coordinated by TML for the mid-term assessment of the White paper on transport policy).
Ease of use//accessibility	Ease-of-use is limited. Both public and in-company training sessions are available. Model description and user manual available at http://www.tremove.org/model/index.htm Online access to the model with a login code (available free of charge from the EU DG Environment : www.tremove.org/model/index.htm (model coordination will be transferred to EU JRC after March 2007) Various different pre-defined runs can be downloaded from the website, www.tremove.org/runs/index.htm.
Use in participative processes	
Other comments	

WEM (IEA's World Energy Model)	

The IEA's (International Energy Agency) WEM (World Energy Model) is a large-scale mathematical construct designed to replicate how energy markets function. The model, which has been developed over many years, is made up of six main modules: final energy demand; power generation; refinery and other transformation processes; fossil-fuel supply; CO_2 emissions and investment. The development and running of the WEM requires access to huge quantities of historical data on economic and energy variables. Most of the data are obtained from the IEA's own databases of energy and economic statistics. The World Energy Model is updated constantly. The WEM is designed to analyse: global energy prospects; environmental impact of energy use; effects of policy actions and technological changes; and effects of investments in the energy sector.

Model dimension	
Themes covered	— Global energy prospects — Environmental impact of energy use — Effects of policy actions and technological changes — Effects of investments in the energy sector — Assessment of energy and environment policies enacted/under consideration — Evaluation of impact of technological progress and learning
Key drivers (model input)	— Economic growth — Demographics — International fossil fuel prices — Technological developments — Energy and environmental policy assumptions
Key indicators (model output)	— Final energy demand by region and sector (Industry, transport, residential, services and agriculture) — International trade and energy balances by sector and by fuel — Power generation, refinery and other transformation processes — Fossil-fuel supply availability and constraints by region and fuel — CO_2 emissions from fuel combustion by region and sector — Investment by region and sector
Geographical coverage	— Coverage: global — Resolution: 21 world regions
Temporal coverage	— Base-year: 2005 (updated annually), based on time series data from 1971. — Time horizon: flexible (fixed at 2015 and 2030 in the latest World Energy outlook (WEO) 2006. — Time steps: annual
Analytical technique	Partial equilibrium model with six sub-modules.
Model structure	

WEM (IEA's World Energy Model)	
Information on model development	
Model developers/owners	International Energy Agency (IEA) http://www.worldenergyoutlook.org/model.asp
Model development history	The model was initially developed in 1993 and has been gradually expanded and refined. The current version (2006) is the tenth version of the model and comprises about 16 000 equations.
Target group/users	The World Energy model is used to produce the IEA publication World Energy Outlook. The World Energy Model also provides the basis for most other IEA analyses.
Calibration	The parameters of the equations of the demand-side modules are estimated econometrically, usually using data for the period 1971–2004. Technical and cost parameters for the supply and investment modules are based on the IEA large internal datasets supplemented by expert judgement of the IEA sectorial experts.
Validation	IEA internal experts as well as a large network of external experts from academia, international organisations, governments, and private companies participate in the peer-reviewing process and validation of the WEM projections.
Uncertainty analysis	The six sub-modules can be isolated and simulations run separately (e.g. final energy demand; power generation; refinery and other transformation processes; fossil-fuel supply; investment. Sensitivity analyses, as well as probabilistic analyses can be run either at the sub-module or at the aggregate level to study the impact of uncertainty on some technical or cost parameters.
Key reference	A detailed description can be found in the IEA (2006) World Energy Outlook. (see http://www.worldenergyoutlook.org/annex_c.pdf)
Information on use of model in environmental assessments	
Level of integration	
Links to other models	EAD has developed in collaboration with the CIRED a General Equilibrium Model (called WEM-ECO) with a detailed representation of the energy sector, by coupling EAD's WEM model with CIRED's IMACLIM — R model.
Ease of use//accessibility	Model not available online
Use in participative processes	
Other comments	

Annex 3 Overview of participative models

This annex reports some of the findings of the recently concluded EEA project review of modelling tools.

An objective of the project was to provide an extended overview of computer models suitable for interactive meetings and stakeholders participation. The information presented in this annex is based on information provided online by the respective modelling teams — the respective sources are noted under 'key reference'.

V GAS (Virtu@alis)	
A computer-based learning tool developed to organise current scientific knowledge about environmental issues for non-scientific audiences. Includes: **Personal barometers** — The V GAS Build Profile aims at accounting personal emissions of the 3 greenhouse gases considered in this product, based on personal consuming patterns and regional or national energy and others; **Scenario generators** — The V GAS What If Explorer aims at exploring alternative lifestyles scenarios; **Virtual visits** — The V GAS Virtual Library aims at showing further information about climate change related issues, namely scenarios developed by institutions such as the IPCC; **Multi-player games** — The V GAS Game is a single and multi-player game whose objective is to attain a better 'sustainable score' by adjusting lifestyles after a launcher of events triggers some variations in the user's profile that require action in order to re-establish at least previous patterns of consumption).	
Model dimensions	
Thematic focus	Climate change (GHG emissions)
Geographical scale	Coverage: Europe; Resolution: individuals
Analytical technique	Interactive model (i.e. information tool and educational game)
Key reference	http://alba.jrc.it/vgas (also www.virtualis-eu.com/index.php)

Fishu@lis (Virtu@alis)	
A computer-based learning tool developed to organise current scientific knowledge about environmental issues for non-scientific audiences. Includes: **Personal barometers** — The Fishu@lis Personal Barometer prototype serves to relate the consumption and lifestyle choices of users with impacts in the marine environment. **Scenario generators** — Users can explore the effects of patterns of governance and socio-economics on the sustainability of fisheries, examine sets of future scenarios, and explore ways to resolve diffrences in priorities. **Virtual visits** — The Fishu@lis Virtual Visit prototype is designed as a learning tool in which users adopt the roles of actors operating in the marine environment. **Multi-player games** — Inside the game, players must face dangers and carry on tasks in order to survive and prosper. In the initial version of the game 3 types of characters (migratory fish, predator and fisherman) share a persistent 3D underwater environment and interact in a variety of situations involving cooperation, combat and negotiation.	
Model dimensions	
Thematic focus	Fisheries
Geographical scale	Coverage: United Kingdom, Portugal, Norway; Resolution: individuals
Analytical technique	Interactive model (i.e. information tool and educational game)
Key reference	http://alba.jrc.it/fishualis (also www.virtualis-eu.com/index.php)

Water Domain (Virtu@alis)	
A computer-based learning tool developed to organise current scientific knowledge about environmental issues for non-scientific audiences. Includes: **Personal barometers** — A stand-alone application designed to calculate per capita and whole household domestic water consumption and provide feedback on the impact of consumption levels based on water use data entered. **Scenario generators** — The SG focuses on the effects of different surface water abstraction licences in terms of their spatial distribution, what use the water is put to, the volume licensed, the volumes actually taken in recent years. **Virtual visits** — The VV presents the context of real geographically located 'stations' from a particular catchment representing either points (e.g. sewage discharge point) or areas (e.g. a stretch of river or a wetland habitat) **Multi-player games** — In the mobile-phone based game the aim is to get your marker out of the maze before your opponent by successfully answering a question or completing challenges.	
Model dimensions	
Thematic focus	Water
Geographical scale	Coverage: Spain, France, UK & Germany; Resolution: individuals (PB), household or farms (MPG)
Analytical technique	Interactive model (i.e. information tool and educational game)
Key reference	www.virtualis-eu.com/index.php

ViViANE (Virtu@alis)	
A computer-based learning tool developed to organise current scientific knowledge about environmental issues for non-scientific audiences. Includes: **Personal barometers** — Multi-scale hyper- AMOEBA permitting appraisal of Fertiliser, water and pesticide use, relative to local or regional 'carrying capacity' as well as a farm's energetic 'ecological footprint'; **Scenario generators** — Evaluation of technological and sectoral options for a more sustainable (less emissions of fertiliser and pesticide residues) agricultural production on regional scales; **Virtual visits** — Educational/tourist visit to regions where intensive agriculture is raising sustainability problems due to fertiliser and pesticide residues and perhaps other forms of land 'stress' such as compaction, salinisation and erosion; **Multi-player games** — Key choices of farming units: (1) Type of crop and cultivation, and (2) Regional decisions for policies and goals of agriculture sector economic, social and environmental performance;	
Model dimensions	
Thematic focus	Water, agriculture
Geographical scale	Coverage: abstract (based on Bretagne, France); Resolution: individuals, abstract farming village, farming unit
Analytical technique	Interactive model (i.e. information tool and educational game)
Key reference	http://viviane.c3ed.uvsq.fr/(also www.virtualis-eu.com/index.php)

ECO_2-Privat	
ECO_2-Privat is an online software tool that calculates annual personal energy consumption and associated CO_2 emissions (for Switzerland). The tool differentiates between direct and indirect energy consumption. ECO_2-Privat shows the user, how much energy and how much CO_2 are consumed, also in comparison to people in other countries. The tool also highlights options to reduce energy and CO_2 consumption.	
Model dimensions	
Thematic focus	Energy, transport, households
Geographical scale	Coverage: Switzerland/European/World average; Resolution: households
Analytical technique	Interactive model (i.e. information tool)
Key reference	http://eco2.ecospeed.ch/ecospeedhome/index.html?sc=1015&cenr=28

Ker-ALARM	
Ker-ALARM describes itself as an interactive multimedia deliberation support tool allying science and stakeholder dialogue processes for Europe biodiversity management and risk governance. It does not feature any interactive modelling approaches or DSS modules. Ker-ALARM is linked to the FP6 project ALARM (Assessing Large-scale environmental Risks for biodiversity with tested Methods), which seeks to develop an integrated large scale risk assessment for biodiversity as well as terrestrial and freshwater ecosystems as a part of environmental risk assessment.	
Model dimensions	
Thematic focus	Biodiversity
Geographical scale	Coverage: N.A.; Resolution: N.A.
Analytical technique	Interactive model (i.e. information tool)
Key reference	http://keralarm.c3ed.uvsq.fr

World Water Game	
The WWG is a computer game with a double purpose. One, to be played as a game in the spirit of challenge, tension and fun. Two, to show students and other non-professionals the relationship between four extremely important elements: population growth; water supply (and use); food demand and production; and measures taken and investments made to avoid hunger, and even starvation, situations in the coming century. WWG players become World Water Managers with incalculably more power and responsibility than any single person will ever have in the real world. They have to manage the world's precious water resources and public funds sensibly and ensure that the 19 World Water Regions remain reasonably self-sufficient in food production.	
Model dimensions	
Thematic focus	Water
Geographical scale	Coverage: global; Resolution: 19 world regions
Analytical technique	Interactive model (i.e. educational game)
Key reference	www.wldelft.nl/soft/wwg/index.html

Floodranger	
FloodRanger is an educational game about managing flood defences along rivers and coasts. It is aimed at flood defence practitioners, local authorities, insurers, universities and schools. The objective of the game is to defend urban areas and sites of special scientific interest while maintaining levels of housing and employment for an expanding population. The game uses a virtual terrain loosely based on the east coast of England. The user can select between two world future scenarios in combination with four climate change scenarios.	
Model dimensions	
Thematic focus	Water
Geographical scale	Coverage: abstract (based on East coast of England); Resolution: river basin
Analytical technique	Interactive model (i.e. educational game)
Key reference	www.discoverysoftware.co.uk/FloodRanger.htm

NitroGenius	
NitroGenius is a multi-stakeholder, simulation game about (solving) nitrogen problems. The game is designed to illustrate in a simple way the complex relations within the nitrogen pollution situation. Combining agriculture, industrial and transportation influences, the game aims to improve understanding of nitrogen's movement in the environment. This game contains an integrated nitrogen model that calculates all the N-flows on the relevant scale in the Netherlands of all sectors and all compartments. Each individual model is tested with measurement data. Furthermore, the models use databases containing relevant data on plot scale in the Netherlands. These data are detailed and not available for other areas in the world. Therefore, at this time the models can only be run for the Netherlands situation. The multi-player version of the game can be played by 4 players. Just as in a real society four different representatives of target groups will work together to solve the nitrogen problems. The goal of the team of four players is to solve the Dutch nitrogen problems against the lowest costs and social consequences. However, each player also has its own targets.	
Model dimensions	
Thematic focus	Nitrogen (transport, agriculture, industry)
Geographical scale	Coverage: Netherlands; Resolution: regions
Analytical technique	Interactive model (i.e. educational game)
Key reference	www.serc.nl/play2learn/products/nitrogenius/frameset.htm

Splash!	
Splash! is described as a game broadly based on the idea of SimCity that aims to interactively teach both kids and adults how to reduce runoff pollution to protect our water resources. The player is manager of a river basin area and can decide on spatial planning (e.g. allocate land for farming, nature, housing, industry and recreation). Hereby, the player has to take account of socio-economic, hydrological and ecological processes. These processes are described by simulation models. The player is watched by different stakeholders (e.g. farmers, the industry and environmental activists) and the player's score is determined by all stockholders satisfaction.	
Model dimensions	
Thematic focus	Water
Geographical scale	Coverage /resolution: abstract region (with suburb, city, agriculture)
Analytical technique	Interactive model (i.e. educational game (for children))
Key reference	www.epa.gov/owow/nps/kids/splash/webpage2/

ECO_2-Regio	
ECO_2-Regio is an accounting and decision support tool for energy consumption and associated CO_2 emissions on a regional scale. Regions can be flexibly defined, depending on the user's needs. A region may be a community, a city, a metropolitan region, a state or a nation. The tool is tuned to the needs of persons working in institutions and organisations dealing with energy and climate issues, e.g. energy planning or greenhouse gas emission inventories. The tool calculates sectoral consumptions of households, economy and transportation. Users can define scenarios by varying regional population, workforce, floor-space and transportation (mileage) dynamics. Allows simulating the impact of policy measures on regional energy consumption. Furthermore, effects of restoration activities in the building sector and of increases in the energy efficiency of household, industry and transportation technologies can be assessed. Against that background, users can also model medium — and long-term impacts of measures of climate and energy policies.	
Model dimensions	
Thematic focus	Energy, transport, households
Geographical scale	Coverage: municipality, city, province; Resolution: municipality, city, province
Analytical technique	Interactive model (i.e. DSS (Decision Support System))
Key reference	http://eco2.ecospeed.ch/ecospeedhome/index.html?sc=3&cenr=20

SimCoast	
SimCoast is a fuzzy logic rule-based expert system designed to enable researchers, managers and decision-makers to create and evaluate different policy scenarios for coastal zone management. It is interdisciplinary and multi-sectoral. It aims to combine traditional and advanced specialist knowledge about coastal zones with a set of reasoning and analytical tools. Experts involved include engineers, natural and social scientists, law-makers, administrators, community and national leaders. Via workshops and consensus discussions, sensitive issues such as transboundary pollution and cross-sectoral socioeconomic effects can be translated into rules for policy formulation and decision-making. The conceptual basis of SimCoast is a two-dimensional multi-zoned map onto which key features such as ports, legal regimes and different habitats and activities such as shipping, tourism, and aquaculture are mapped. Activities are often associated with different zones and processes to which they are linked (e.g. land tenure, erosion). The effects of activities on features are evaluated in relation to defined policy targets (e.g. water quality, ecosystem integrity) as measured in particular units. This evaluation is the result of developing a set of expert rules.	
Model dimensions	
Thematic focus	Coast and seas
Geographical scale	Coverage: abstract (based on UK); Resolution: coastline
Analytical technique	Interactive model (i.e. DSS (Decision Support System))
Key reference	www.discoverysoftware.co.uk/SimCoast.htm

MODSIM-DSS	
MODSIM-DSS is a generalized river basin decision support system and network flow model designed specifically to meet the growing demands and pressures on river basin managers today. It was designed for this highly complex and constantly evolving river basin management environment. MODSIM-DSS has been linked with stream-aquifer models for analysis of the conjunctive use of groundwater and surface water resources. Also MODSIM-DSS has also been used with water quality simulation models for assessing the effectiveness of pollution control strategies. MODSIM-DSS can also be used with geographic information systems (GIS) for managing spatial data base requirements. MODSIM-DSS is structured as a decision support system, with a graphical user interface (GUI) allowing users to create any river basin system topology. Data structures embodied in each model object are controlled by a data base management system, which is also queried by simple mouse activation. Formatted data files are prepared interactively and a highly efficient network flow optimization model is automatically executed from the interface without requiring any direct intervention by the user. Results of the network optimization are presented in useful graphical plots.	
Model dimensions	
Thematic focus	Water
Geographical scale	Coverage: river basins; Resolution: river basins (non-spatial)
Analytical technique	Interactive model (i.e. DSS (Decision Support System))
Key reference	http://modsim.engr.colostate.edu/index.html

MODULUS	
MODULUS developed a generic spatial decision support system for integrated environmental policy-making at the regional level (on average 2 000 km square). Models from past or ongoing EU-projects were adapted and integrated that represent the physical, economic and social aspects of land degradation and desertification in Northern Mediterranean coastal watersheds. MODULUS reviewed the existing models and adapted them in view of their integration into a multi-scale, multi-temporal dynamic modelling framework. The MODULUS DSS system enables the end-user to gain access to state of the art knowledge about the case regions, and provides him with appropriate tools for the design and evaluation of integrated policies in an iterative, direct and user-friendly manner. The MODULUS DSS is developed as a very interactive, transparent and (geo)graphical instrument. (Note that Modulus uses the GEONAMICA Model-/DSS-Generator.)	
Model dimensions	
Thematic focus	Land Use
Geographical scale	Coverage: Northern Mediterranean (case studies); Resolution: variable
Analytical technique	Interactive model (i.e. DSS (Decision Support System))
Key reference	www.riks.nl/projects/MODULUS

mDSS4	
The mDSS4, originally developed in the context of the MULINO project (MULti-sectoral, INtegrated and Operational Decision Support System for Sustainable Use of Water Resources at the Catchment Scale) and further developed and applied with a contribution of several other projects is a generic DSS developed to assist water authorities in the management of water resources. It can help you: • to better understand or explain (to stakeholders) the problem at hand; • to facilitate public participation required by the WFD; • to take the edge of the conflict related to alternative water uses; • to extend collaboration with and within different stakeholder groups. mDSS4 integrates models (e.g. hydrological, ecological, socio-economic) with multi-criteria decision methods. The DPSIR framework helps to organise possible cause-effect relationships.	
Model dimensions	
Thematic focus	Water
Geographical scale	Coverage: different case study regions; Resolution: riverbasin
Analytical technique	Interactive model (i.e. DSS (Decision Support System))
Key reference	http://www.netsymod.eu/mdss/

WaterWare	
WaterWare is an integrated, model-based information and decision support system for water resources management. The system is designed to support the implementation of the Water Framework Directive or similar national legislation, and has been developed through a series of applications to various river basins. WaterWare is implemented in an open, object-oriented client-server architecture, fully web-enabled and Internet based, supporting the seamless integration of databases, GIS, simulation and oiptimization models, and analytical tools into a common, easy-to-use framework. This includes a multimedia user interface with Internet access (using a standard web browser as the only client software required), a hybrid GIS with hierarchical map layers, object data bases, time series analysis, reporting functions, an embedded expert system for estimation, classification and impact assessment tasks, and a hypermedia help-and-explain system.	
Model dimensions	
Thematic focus	Water
Geographical scale	Coverage: has been applied to various river basins (e.g. Thames, UK; Gediz, Turkey, Dhiarizos River, Cyprus); Resolution: river basin
Analytical technique	Interactive model (i.e. DSS (Decision Support System))
Key reference	www.ess.co.at/WATERWARE/

COSMO	
COSMO demonstrates the main steps in the design, analysis and evaluation of coastal zone management plans. The program is an interactive tool that allows coastal zone managers to explore the impacts of development projects and environmental and coast protection measures. COSMO calculates various criteria, including long term effects of climate change, reflecting the use of the coastal zone. Simulation of the CZM problems takes place in the fictional territory of Catopia, a developing region situated along the waters of Catfish Bay. In the first round, one can explore a number of predefined cases. In the second round, the user is allowed to specify new development scenarios and combinations of measures.	
Model dimensions	
Thematic focus	Coast and seas
Geographical scale	Coverage: abstract (territory of Catopia); Resolution: coast line (limited)
Analytical technique	Interactive model (i.e. DSS (Decision Support System) // Model with graphical user interface)
Key reference	www.netcoast.nl

Environment Explorer /BabyLOV	
The Environment Explorer (LOV) is a spatial, dynamic model, in which land use and the effects on social, economic and ecological indicators are modeled in an integrated way. Its primary goal is to explore future developments, combining autonomous developments with alternative policy options, in relation to the quality of the environment in which inhabitants of the Netherlands live, work and recreate. Various policy options from governmental departments are translated into a spatial, dynamic image of the Netherlands future with respect to issues such as: economic activity, employment, social well-being, transportation and accessibility, and the natural environment. The BabyLOV software is a simplified version of the Environment Explorer. It is a cellular-automaton based, dynamic land use simulation model of the Green Heart region of The Netherlands. The model permits a wide variety of 'what if' experiments to be performed, since land use demands, suitabilities, zoning, both the transport network itself as well as accessibility parameters, and even the CA transition rules themselves, can all be modified. In addition, a number of indicators are calculated and displayed as maps or tables in order to facilitate evaluation of the results.	
Model dimensions	
Thematic focus	Land use
Geographical scale	Coverage: The Netherlands ; Resolution: national, regional, 500m grid
Analytical technique	Interactive model (i.e. model with graphic user interface)
Key reference	http://www.lumos.info/environmentexplorer.htm

International Futures	
International Futures (IFs) is a computer simulation of global systems for classroom or research use. IFs can be used to teach or study demographics, economics, food, energy, the environment, and international politics. It is especially suitable for analysis of sustainable development and for examining the human dimensions of global change. IFs is a large-scale integrated global modelling system — heavily data-based and also deeply rooted in theory. It represents major agent-classes (households, governments, firms) interacting in a variety of global structures (demographic, economic, social, and environmental). The system draws upon standard approaches to modelling specific issue areas whenever possible, extending those as necessary and integrating them across issue areas.	
Model dimensions	
Thematic focus	Climate change, energy, agriculture, other (e.g. demography, economy, …)
Geographical scale	Coverage: global; Resolution: 182 regions/countries
Analytical technique	Interactive model (i.e. model with graphic user interface)
Key reference	www.ifs.du.edu

CLUE-S	
The CLUE model: a spatially explicit model for the analysis of land use change and its effects. The objective of CLUE is to make a spatially explicit, multi-scale, quantitative description of land use changes through dynamic modelling and the quantification of the most important (assumed) bio-geophysical and human drivers based on either knowledge of the land use system or empirical analysis of observed land use patterns. The dynamic simulation model allocates changes in land use of which the aggregate quantity is determined by trend analysis, scenario assumptions or macro-economic modelling. Besides tracking past or historical land use changes, the objective is to explore possible land use changes in the near future under different development scenarios, having a time horizon of about 10-40 years.	
Model dimensions	
Thematic focus	Land Use
Geographical scale	Coverage: depends on available date; Resolution: standard is 1 km grid
Analytical technique	Interactive model (i.e. model with graphic user interface)
Key reference	www.cluemodel.nl

iCity	
The iCity — Irregular City tool extends the traditional formalization of cellular automata (CA) to include an irregular spatial structure, asynchronous urban growth, and a high spatio-temporal resolution to aid in spatial decision making for urban planning. The iCity software tool was developed as an embedded model within a common desktop geographic information system (GIS) with a user-friendly interface to control modelling operations for urban land-use change. This approach allows the model developer to focus on implementing model logic rather than developing an entire stand-alone modelling application. It also provides the model user with a familiar environment in which to run the model to simulate urban growth. The iCity model is designed to allow planners, developers, and other stakeholders to simulate and visualize urban growth at the cadastral land-parcel scale given different neighbourhood designs and under various growth rates, density scenarios, and resident preferences.	
Model dimensions	
Thematic focus	Urban environment
Geographical scale	Coverage: municipalities; Resolution: land-parcels
Analytical technique	Interactive model (i.e. model with graphic user interface)
Key reference	D. Stevena, S. Dragicevic, K. Rothleyb (2007) iCity: A GIS–CA modelling tool for urban planning and decision making. Environmental Modelling & Software 22 (6): 761-773

RAINS-Europe (GAINS)	
The regional air pollution information and simulation (RAINS) model provides a tool for analysis of reduction strategies for air pollutants. The model combines information on economic and energy development, emission control potentials and costs, atmospheric dispersion characteristics and environmental sensitivities towards air pollution. The model addresses threats to human health posed by fine particulates and ground-level ozone as well as risk of ecosystems damage from acidification, excess nitrogen deposition (eutrophication) and exposure to elevated ambient levels of ozone. The RAINS model framework makes it possible to estimate, for a given energy and agricultural scenario, the costs and environmental effects of user-specified emission control policies. With this on-line implementation of the RAINS model you can review all data used for the computations, explore costs and environmental impacts of alternative emission control scenarios, and develop your own emission control scenario, which can then be evaluated along its costs and environmental implications.	
Model dimensions	
Thematic focus	Air
Geographical scale	Coverage: Europe ; Resolution: country
Analytical technique	Interactive model (i.e. model with graphic user interface) (note: has limited input options only)
Key reference	www.iiasa.ac.at/web-apps/apd/RainsWeb/

MAGICC /SCENGEN	
MAGICC and SCENGEN are coupled, user-friendly interactive software suites that allow users to investigate future climate change and its uncertainties at both the global-mean and regional levels. MAGICC (Model for the assessment of greenhouse-gas induced climate change) consists of a suite of coupled gas-cycle, climate and ice-melt models integrated into a single software package. This software allows the user to determine changes in greenhouse-gas concentrations, global-mean surface air temperature and sea-level resulting from anthropogenic emissions of GHG. SCENGEN uses these results, together with results from a set of coupled GCMs and a detailed baseline climatology, to produce spatially-detailed information regarding future changes in temperature, precipitation and other climate parameters.	
Model dimensions	
Thematic focus	Climate change
Geographical scale	Coverage: global; Resolution: countries/world-regions
Analytical technique	Interactive model (i.e. model with graphic user interface)
Key reference	www.cgd.ucar.edu/cas/wigley/magicc/index.html

JCM 5	
This interactive model lets you explore the system and how we can change it. The core calculation methods are similar to those used in the Intergovernmental Panel on Climate Change Third Assessment Report, implemented efficiently in the java language to make this tool accessible to everybody via the internet. The Java Climate Model enables anybody on the web to experiment with climate models and policy options. Parameters are adjusted simply by dragging graphical controls with a mouse in a web browser, causing an instant response in several linked plots (including regional and per-capita emissions, carbon cycle, radiative forcing, global temperature, sea-level, regional climate maps, etc.) This is not another "data visualiser" but a complete model, yet fast and compact (downloadable in a few seconds, then also working offline).	
Model dimensions	
Thematic focus	Climate change
Geographical scale	Coverage: global; Resolution: countries/world regions
Analytical technique	Interactive model (i.e. model with graphic user interface)
Key reference	http://jcm.chooseclimate.org/

ScFAIR	
The FAIR model: a tool to analyse environmental and costs implications of climate regimes. The policy decision-support-tool FAIR aims to assess the environmental and abatement costs implications of climate regimes for differentiation of future commitments. The model links long-term climate targets and global reduction objectives with regional emissions allowances and abatement costs, accounting for the used Kyoto Mechanisms: 1. A climate model for the evaluation of the climate impacts of a global emission profiles and the calculation of the regional contributions to climate change. 2. An emissions-allocation model to explore and evaluate the emission allowances for different climate regimes for the differentiation of future commitments. 3. A mitigation costs and emission trading model to distribute the emission reduction objective over the different regions, gases and sources following a least-cost approach, to calculate the international permit price and determine the buyers and sellers on the international trading market and to calculate the regional mitigation costs.	
Model dimensions	
Thematic focus	Climate change (GHG emissions)
Geographical scale	Coverage: global ; Resolution: large country/world-regions
Analytical technique	Interactive model (i.e. model with graphical user interface)
Key reference	www.mnp.nl/fair/introduction

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