A Scoping Study on the Macroeconomic View of Sustainability

Final report for the European Commission, DG Environment

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Executive Summary

Introduction

This scoping study, carried out by Cambridge Econometrics (CE) and the Sustainable Europe Research Institute (SERI), examines the links between macroeconomic perspectives and sustainable development. It considers how the links are represented in economic theory and asks if the macroeconomic modelling we use today is up to the task of evaluating policy from a sustainable development viewpoint. If not, then models risk missing out on the insights that sustainable development provides: the strong (two-way) linkages between the economy and the environment, the importance of the long term, the necessity of an integrated approach and the danger of thresholds. If these issues are missed by our models, then they risk giving us the wrong answers and leading us in the wrong direction.

The study has: examined the theoretical underpinning of macroeconomic analysis from different theoretical traditions; reviewed the wide range of models that operate within one or more of the sustainable development spheres; considered the appropriateness of the existing model toolkit to address policy questions; and identified gaps in the scope of existing models and their methods. We conclude with recommendations for improving the models on which policy makers can call.

The role of sustainability in macroeconomic theory

Macroeconomic analysis looks at the performance of the overall economy. How the macroeconomy and macroeconomic factors and their general conditions are examined varies in different schools of economic thought.

In the **neoclassical model** of the economy (which is the home of environmental economics) the environment and its natural resources have never found a strong footing.

- The ecosystem is treated as a subsystem of the economy whose main functions are the limitless extraction of resources and the free disposal of waste.
- The environment mainly features in microeconomics, where it is assumed that the internalisation of negative externalities through the price mechanism can solve our ecological problems.
- Mainstream macroeconomic theory is profoundly oriented towards the goal of continuous and exponential economic growth. It is assumed that economic growth can increase innovation and efficiency and lead to decoupling of economic growth from negative environmental impacts.
- The welfare of future generations is safe because there is full substitutability of natural capital so the depletion of natural resources can be compensated via investments in other forms of capital (a concept known as 'weak sustainability'). From a neoclassical economics perspective, there is no need for a new macroeconomic framework for sustainability.

An alternative macroeconomic framework is being developed by ecological economists by extending the neoclassical framework to explicitly include the environment and its services to the economy. In **ecological economics**:

- The economic system is not only embedded in the larger environmental system but is also completely dependent on it as both a source of inputs and as a sink for the matter or energy transformations required by economic activity.

- The assumption that capital can substitute for resources is rejected on the basis that certain functions that the environment performs cannot be duplicated by humans (known as 'strong sustainability').
- Environmental constraints imply limits on economic scale and thus limits to growth.
- Ecological economists are sceptical about the possibility to dramatically change technologies, investment and consumption patterns in a way that decouples economic growth from environmental impacts.

In effect, ecological economists argue for a serious rethinking of standard economic assumptions and theories (although a complete macroeconomic model in tune with ecological economists' thinking does not yet exist). This debate matters, as depending on whether a neoclassical or ecological economics perspective is taken, different conclusions can be drawn on how the macroeconomy and macroeconomic factors affect sustainable development and vice versa.

Many of the models reviewed in this study are derived from neoclassical economics and general equilibrium theory so they typically focus on economic relationships. Environmental factors, including resource consumption and greenhouse gas emissions, are typically considered as external to the economic system. The possibility of not being able to substitute between input factors, or of the depletion of stocks of resources, is largely ignored. Where external factors, such as environmental emissions or human health effects, are included in the modelling framework they are often assigned monetary values.

The macroeconomic models that we consider in this study (see below) could be used to test features of the two different schools of thought, for example estimating substitution elasticities or modelling scenarios without economic growth.

The existing situation

Policy domain of existing models

The study has focused on 60 of the most widely-used existing macroeconomic models (defined as quantitative computer-based tools), and mapped their scope against the ten policy themes from the Sustainable Development Indicators (SDI) framework, and their sub themes. Table 1 summarises the extent to which individual models cover more than one SDI theme by counting the number of linkages in the models that were reviewed. From this it is clear that:

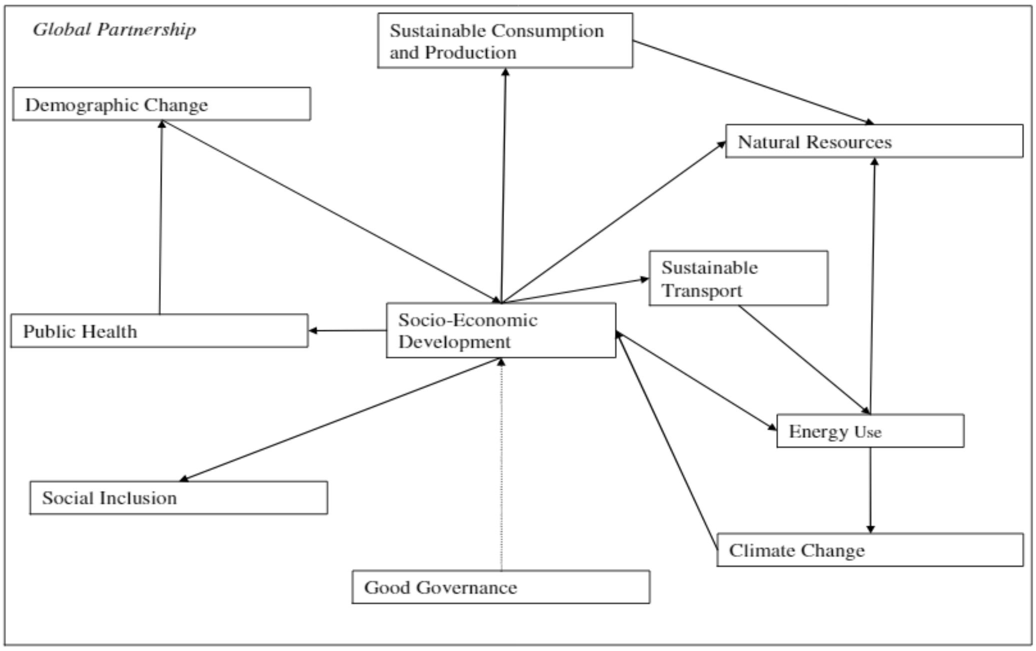
- The vast majority of existing models focus on the link between economic development and energy use.
- Other linkages that are well-represented are economic development and climate change; energy use and climate change; energy use and sustainable transport; and economic development and global partnerships.
- Perhaps the most notable omissions are links involving good governance or public health, suggesting that the interactions between these policy areas and other areas of sustainable development are not well covered.

Figure 1 illustrates the dominant direction of the main links between SD policy areas in existing models. There are some clear feedback loops between policy areas, for example environmental Integrated Assessment Models (IAMs) cover the themes in the bottom-right part of the diagram (economy to energy to climate change to economy), and integrated energy-transport models those in the mid-right section (economy to sustainable transport to energy use). Nevertheless, it is clear that the dominant direction of impact is *from* the economy, with few policy domains impacting back on to the economy. This is consistent with the neoclassical economic theory, which focuses on the economy as a system and treats other factors as external to this system. For example, while the models may give outputs for consumption of finite fossil fuels, they are less likely to include this as a driving factor of economic growth.

TABLE 1: HOW EXISTING MODELS LINK ASPECTS OF SUSTAINABILITY

Policy Theme		1	2	3	4	5	6a	6b	7	8a	8b	8c	9
Socio-economic devt	**1**												
Sustainable C & P	**2**	2											
Social inclusion	**3**	0	0										
Demographic change	**4**	2	0	2									
Public health	**5**	0	0	0	1								
Energy use	**6a**	23	2	0	1	0							
Climate change	**6b**	5	0	0	0	1	8						
Sust. transport	**7**	2	1	0	0	0	5	0					
Land use	**8a**	2	0	0	0	0	4	4	0				
Biodiversity	**8b**	1	0	0	0	0	1	1	0	1			
Oceans/ freshwater	**8c**	1	0	0	0	0	1	4	1	2	2		
Global partnership	**9**	6	0	0	0	0	3	0	0	2	0	0	
Good governance	**10**	0	0	0	0	0	0	0	0	0	0	0	0

Figure 1: Model Linkages



Overall, existing models appear only to provide limited coverage of SD policy areas (though greater coverage could in principle be achieved through linking models) and little role for developments in non-economic policy areas to influence economic outcomes.

Key gaps in existing analyses

The key gaps in the scope of existing models are:

- The good governance theme is not covered by any of the models, although some separate quantitative analysis has been carried out, for example the value of democracy in determining long-term growth rates.
- The direction of linkages within a particular model is often only one-way, especially in the case of models that include socio-economic development.
- The socio-economic development and energy themes are well connected to other themes. However, fewer direct linkages exist between the other aspects of sustainable development.
- Consumption of (non-energy) resources is not very well covered in existing models, but this is an area of potential development (see Box 1).
- Finally, there are a number of issues relating to the technical structure or functional form of existing models which could be improved upon, particularly the treatments of technology, uncertainty and non-linear relationships.

Do the current deficiencies matter?

In our view this leads to three major constraints in macroeconomic modelling analysis, which in certain circumstances are material for policy makers:

- The often one-way linkages from economy to environment can distort the results of analysis and therefore also policy recommendations. For example, environmental factors are usually only allowed to influence the economy through price-based measures, such as taxation. Other environmental impacts, such as loss of tourism due to degradation or loss of ecosystem services, are often excluded.
- Physical limits, such as stocks and maximum carrying capacities are not usually covered in the analysis (see Box 1). This means that models miss out on a wide range of factors, such as how the price of scarce material inputs changes, or non-linearities in impact.
- There is a loss of accuracy using conventional modelling approaches to consider the effects of large-scale change. This makes a proper assessment of 'extreme' scenarios, for example where fossil fuel stocks dwindle, or of large-scale change such as an 80% carbon reduction, difficult with existing tools.

Key areas for development

Scope for linking models or widening areas of coverage

It is not possible to have a single model that covers every aspect of sustainable development. While it is desirable to have a number of models in the tool kit, it is important to recognise boundaries and to ensure that the key relationships are determined endogenously. In some cases this may mean linking individual models to provide a more complete coverage, although it is often a resource-intensive exercise to set up two-way linkages between different models.

Our analysis identifies the following improvements as important to adding value to model-based analyses of sustainable development:

- The treatment of natural resources could be improved, using existing model structures (see Box 1).
- Migration: This is clearly important in all areas of sustainable development. It is usually treated as exogenous, but an endogenous treatment may be possible.

We also identified areas where exogenous factors should be identified more explicitly:

- Government actions: It is difficult to model this endogenously, but qualitative checks need to be carried out to make sure that model-based scenarios are politically feasible. For example, if a scenario predicted very high rates of unemployment, it is likely that the government would take action.
- Models should acknowledge explicitly impacts on stocks of natural resources, even if there is no feedback to behavioural patterns.
- Implicit assumptions, such as financial stability or availability of energy supplies, should be made much clearer so that they can be assessed in the context of any set of model simulations.

Box 1: Incorporating resource use into the explanation of economic development

This study finds that it would be possible to integrate demand equations for the physical consumption of materials (minerals and biomass) and water into existing macroeconomic frameworks (including feedback to economic sectors such as agriculture, mining and water supply). Eurostat provides relatively detailed data sets on which such an analysis could be based. However, this is only one step in setting up a system that is capable of carrying out a comprehensive analysis. A more complete list of steps is:

- Identify and define the most important groups of resources.
- Measure the available stocks (eg fossil fuels) or maximum carrying capacities (eg annual fresh water supply).
- Include the demands for these resources and, where possible, available stocks or carrying capacities in macroeconomic models.
- Allow supplies to influence behaviour, for example (but not limited to) in price formation in the model structures.

The last of these steps requires a much larger research input as the behavioural responses to extreme outcomes are unpredictable. However, the other steps are all possible with given model frameworks and supplementary analysis, and the modelling approach required is close to that already applied for energy use.

A possible extension to this exercise would be to incorporate a treatment of physical waste that is linked into the consumption of physical inputs.

Recommendation 1: The role of technology

All models need to recognise that technology, and its development, is an important factor; an endogenous treatment of technology should therefore be seen as a requirement. However, there is no agreed treatment at present and the focus of the modelling is usually on the development rather than the dissemination of technology.

The two most common treatments of technology are based on engineering principles, where individual technologies in a sector are explicitly defined (for example gas, renewables or CCS in the energy sector), and economic theory, where technology is implicitly linked to the capital stock. These two approaches affect efficiency, unit costs and product quality and each has its own advantages. However, when considering future scenarios, both approaches are limited by the fact that it is not possible to predict future trends in technological development. A good assessment of current technological options is therefore seen as a priority and a methodology that combines both approaches is possible.

Recommendation 2: Non-linear relationships, thresholds, limits

The standard modelling approach is based on linear (or log-linear) elasticities, for example an elasticity of -0.5 would mean a 10% increase in price leads to a 5% decrease in demand. Although there are cases where this assumption is relaxed, our view is that this type of relationship is often forced on model parameters. This potentially negates several important features and leads to the following issues and potential developments:

- Linear approximations of curved relationships may be reasonably accurate for small changes, but will become less accurate as the model moves further from base.
- Threshold effects and physical limits should be taken into account (see example in Box 1). However, problems arise in defining thresholds that have not previously been reached (eg mineral resources becoming scarce), or where thresholds vary over time (eg annual rainfall).
- A proper treatment of asymmetrical relationships could be a relatively easy improvement to make, with separate parameters for positive and negative relationships. For example, if high commodity prices lead to investment in new equipment, this equipment will still be used if prices fall again.
- The assumption that model elasticities do not change over time should be examined more closely.

Recommendation 3: Uncertainty

There are two separate issues related to uncertainty: the treatment of uncertainty within the model; and uncertainty resulting from the model itself and its various assumptions.

- Uncertainty clearly affects human behaviour, particularly in the case of investment decisions, and should therefore be included in a model of sustainability as an explanatory factor. An empirical exercise to identify the main sources of uncertainty would be helpful in this respect.
- Attempts to address the issue of uncertainty in model outputs are important for putting results in context. They should be carried out outside the structure of the model, for example by using different input assumptions. This is an area where research is already under way.

Other recommendations for model development

As well as better modelling of uncertainty, non-linear relationships and technology, there are a number of key priorities for model developments to better assess the role of sustainability in macroeconomic development. The report discusses longer-term aspirations, but we consider the following steps to be practical developments given the current state of the art.

1. Models should take biophysical data into account (for example the ecological footprint or physical consumption of resources) as it provides a link to problems that refer to the quality of the environment. This means moving away from only including monetary values to also providing physical outputs.

2. Models should be adapted to include issues of **resource use**. Modelling of the supply and demand for material inputs (biomass and minerals) and water could be integrated into existing frameworks relatively easily. This treatment could be extended to include waste, though other issues such as biodiversity are more difficult. The modelling would also need to be disaggregated as looking at (bio)physical data at macro level may not be very informative: materials used in the construction sector, for example, may be bulky but have little environmental impact. The models would need to provide outputs capturing the importance of the environmental impacts of the (non-renewable) resource use, and perhaps also the option loss for future unknown use.
3. Building on this point, models should take into account the **stocks of available resources**, at least given the available disaggregation. Even if no behavioural responses are included, this would give an indication of whether model results fit inside the limits imposed by bio-physical constraints.
4. The analysis identified **gaps in existing data**, specifically in data for incomes and spending for different household groups, and a definition of the eco-industries in standard classifications.
5. **Population movement** inevitably has an effect on sustainability, so the impact of migration should be included in the models. A more immediate exercise would be to use the models to quantify the effects of population changes.
6. For each set of model simulations, the model user should assess the accuracy of assuming that **exogenous factors** remaining unchanged.

Overall, these developments would move macroeconomic models towards a more systematic way of modelling the two-way linkages between the environment and the economy, and would allow for a more comprehensive assessment of how the economic, environmental and social aspects of our societies affect each other. Failure to do this could mean that the models used for policy assessment provide misleading results to decision makers.

1 Introduction

1.1 Background

This document presents the final report from *A Scoping Study on the Macroeconomic View of Sustainability*, a study that assesses the linkages between the macroeconomy and the goal of sustainable development, and how these links are represented in standard economic theory. The analysis focuses in particular on the role that macroeconomic modelling might play in evaluating policy and seeks to address the following key questions:

- What is the value-added of a macroeconomic perspective of sustainability?
- Can this perspective help to achieve sustainable development?
- What modelling tools exist for such macroeconomic analysis?
- To what extent do these tools address sustainability issues?
- Can these tools identify the most important policy levers and possible synergies?
- Ideally, what indicators should these tools take into account?
- How feasible is it for existing tools to meet this ideal?

The policy context underlying the analysis

This study was carried out in early 2010, as the world's major economies were mostly in the early stages of recovery from recession. Throughout the previous year, much of the world's attention was focused on macroeconomic matters, relating to the financial and economic crisis that started with the collapse of Lehman Brothers and the credit crunch in September 2008. The policy response to the crisis was fast and, in many countries, unprecedented in scale. The implications of this seemed to be clear; a return to economic growth is desirable, almost regardless of cost.

In many respects this was not an unreasonable approach for policy makers to take. Rapidly rising unemployment can lead to large losses of welfare and, particularly in the developing world, poverty rates had begun to increase. However, the narrow focus on a 'return to growth' largely ignored previous problems with the growth paradigm. At the same time, preparations were taking place for the Copenhagen summit that was held in December 2009. Again, previous research has found that there are many low or no-cost options available for decarbonisation and that the take-up of these would also benefit the investment industries that suffered the most in the recession (eg construction, engineering). However, the policy response was in many cases short-term in nature; to let the economic slowdown reduce emission levels, without making any structural change ahead of a return to growth. Even worse, there was evidence that low fossil-fuel prices and a lack of credit was leading to delays in investment in low-carbon technologies.

One interpretation of these outcomes is that the environment and sustainable development are luxury goods that we can afford to pay service to when times are good but are not priorities when incomes come under pressure. However, this rather simplistic conclusion ignores the fact that there are strong (two-way) linkages between the economy and the environment and that each component cannot be viewed in isolation. Typically, environmental analysis includes an aspect of economic cost (or benefit) but it is less common to assess the environmental effects of economic policy; as we shall show, the analytical tools available often reflect this position.

Objectives of this study

A more positive assessment is that the response to the economic crisis showed that it is possible for the world to take fast and coordinated action when required. This of course immediately raises the question of what would be needed to for the world to adopt a similar approach to global sustainability.

One possible reason for a lack of action so far is that the tools, in the form of computer-based models, that are available to researchers and to policy makers make it difficult for environmental impacts to be measured and, for this reason, they are excluded from policy assessments. This study is a preliminary step in addressing the issue, providing responses to the questions that are outlined above.

1.2 The EU's Sustainable Development Strategy

Sustainability is a global issue and the focus of our analysis is, where possible, on global assessment. In our analysis we use the EU's definition of sustainability to provide a basic framework for the main policy areas.

In the EU, sustainable development became a fundamental objective in 1997 when it was enshrined in the Amsterdam Treaty to underpin all EU activities and policies as an overarching principle. On this account it presents one of the core tasks of the Union. The renewed EU Sustainable Development Strategy (SDS, 2006[1]) is the core strategic document for a European vision of progress that links economic development, protection of the environment and social justice in an integrated and mutually reinforcing way. This aim is clearly highlighted in paragraph 10 of the SDS:

The EU SDS sets out an approach to better policy-making based on better regulation and on the principle that sustainable development is to be integrated into policy-making at all levels. This requires all levels of government to support, and to cooperate with, each other, taking into account the different institutional settings, cultures and specific circumstances in Member States.

The key challenges

The SDS sets out a number of key challenges:

- climate change and clean energy
- sustainable transport
- sustainable consumption and production
- conservation and management of natural resources
- public health
- social inclusion, demography and migration
- global poverty and sustainable development challenges

This approach is also reflected in the Impact Assessment (IA) guidelines[2]. However, many questions remain on how to reconcile the objective of sustainable development with the overall objectives of growth, employment, and competitiveness of the Lisbon strategy (and the new 2020 strategy[3]), and how to frame a coherent set of policies to achieve these objectives.

Nevertheless, as described in the following chapters, the SDS, and the Sustainable Development Indicators (SDIs) that quantify progress, form the basis for our analysis,

[1] European Council (2006).

[2] European Commission (2009).

[3] European Commission (2010).

in both the definitions of sustainability that we use and in the coverage of the macroeconomic models.

1.3 Structure of this report

Chapter 2 presents our review of the literature, starting with the main schools of economic theory and to what extent they consider the environment and sustainability. We then discuss the standard treatments of the linkages between the economy and the eco-system in more detail. In Chapter 3 we discuss how these theories are represented in macroeconomic models and present a view on what types of analysis can be carried out using the existing set of models, including a discussion of some of the common assumptions that these models employ. We split the policy areas into those defined in the SDS, and examine the linkages between each of the areas.

Chapter 4 builds on both these parts of the analysis by putting forwards suggestions of the features that, in an ideal world, a model should include in order to provide a complete assessment of sustainability; we address the issues of both what should be considered (in terms of policy areas) and how it should be considered (in terms of methodology). In Chapter 5 we then discuss whether in practical terms it is possible to meet these requirements, both with existing modelling tools, and with possible enhancements, given current capabilities.

Chapter 6 concludes with our recommendations for future research and possible developments to the existing modelling approaches.

2 Literature Review

2.1 Overview

Discussions and research about sustainable development have highlighted the need to understand the links between the economy, our society and the environment. The literature review contributes to this understanding by shedding light on the question of how the macroeconomy and its determinants affect sustainable development.

This review primarily explores the links between the macroeconomy and the environment and examines two of the most pressing issues of the social dimension of sustainable development: employment and equality. We subsequently identify those sustainability issues that can be represented in a modelling framework (discussed in Chapter 4).

Structure of the analysis

Section 2.2 provides broad definitions of the main terms in this investigation – macroeconomy, sustainable development, and environmental aspects of sustainable development (eg carrying capacity, resource availability) – as well as a brief overview of the main schools of economic thought, in order to be clear on the scope and context of analysis.

Section 2.3 picks up the fact that analyses of the environment and its impact on the economy differ substantially among different schools of thought. We focus on two schools of thought, mainstream neoclassical economics and ecological economics, and compare how the macroeconomy and its linkages to the environment are theorised and measured from both perspectives.

Section 2.4 investigates in more depth why these different schools of thought draw different conclusions on the interlinkages between the economy and the environment. This section focuses on how models used by neoclassical economics and ecological economics are applied to analyse the main links between macroeconomic factors and the environment.

Section 2.5 brings into focus the social dimension of sustainability. Employment and equality are chosen for an investigation of the links between the economy and social sustainability.

Section 2.6 reviews what the two chosen schools of economic thought (neoclassical economics and ecological economics) suggest on how to change the main macroeconomic factors in order to achieve sustainable development. Finally, we describe the first approaches for a macroeconomic framework for sustainability that already exist.

2.2 Basic definitions

Macroeconomy

Broadly speaking, the study of the macroeconomy (macroeconomics) looks at the performance of the overall economy. How the macroeconomy, macroeconomic factors and their general conditions are examined varies in different schools of economic thought. This literature review focuses mainly on the different interpretations of the macroeconomy and its functioning in two economic schools of thought, namely neoclassical economics and ecological economics. These two schools were chosen because neoclassical economics comes closest to representing the current mainstream view, and ecological economics is the only sub-discipline of economics that applies concepts and methods of both economics and ecology to the various challenges surrounding sustainable development.

Before going into depth in neoclassical and ecological economics, we provide a brief overview of different streams of economic thought in order to better understand why they often arrive at different, and sometimes contradictory, policy suggestions. The key to understanding these differences is in treatments of the links between macroeconomic factors and sustainable development.

Neoclassical economics

Classical economics is recognised as the first modern school of economic thought. The theories of the classical school that mainly originated from England and France during the late 18th century concentrated on analysing and promoting economic growth and economic freedom, stressing the role of markets and free competition, often from a laissez-faire perspective. The classical economists were quite concerned with the biophysical aspects of production. Physiocrats, in the 18th century, such as François Quesnay, had claimed that the ultimate source of wealth was derived from the use of solar radiation by biotic organisms and the value of land by capturing this energy through agricultural production. Thomas Malthus (1766-1834) was one of the key classical economists thinking about sustainability. He became widely known for his thesis that population growth is necessarily restricted by the limitations of the natural environment. Other classical economists such as Adam Smith (1776) and David Ricardo (1817) encompassed both the physical origin and the distribution of wealth. One of the most important aspects of economic activity at that time was to preserve means of livelihood.

Neoclassical economics evolved from about 1870 as an attempt to establish a positive, mathematical and scientifically grounded field above normative politics. It is a basket of approaches to economics that focuses on determining prices, outputs and income distribution in markets through supply and demand in accordance with an individual's rationality and one's ability to maximize utility or profit. It strongly differs from classical economics, especially in terms of its conceptualisation of the environment. According to Hall et al, the primary reason for the displacement of classical economics was the 'superior mathematical rigor of neoclassical economics and the development of the marginal utility theory' (2001: 664).

However, the underlying biophysical perspective of the physiocrats was not incorporated into the new mathematical models. Classical economics was still based on the view that the environment sets limits to the expansion of economic activity and concerned with problems of scarcity (especially of available land). For neoclassical economists, by contrast, the natural environment and its management were no major sources for concern.

While the neoclassical analytical framework was initially only used for partial equilibrium analyses, ie the analysis of particular markets, (groups of) firms and consumers, Walras and Pareto also started employing it to the entire economy, namely as a set of different, linked markets connecting many firms and customers. The work of Walras was the starting point for 'general equilibrium theory', a branch of neoclassical economics which tries to explain the behaviour of supply, demand and prices in a whole economy with several or many markets, by seeking to prove that equilibrium prices for goods exist and that all prices are at equilibrium, hence general equilibrium, in contrast to partial equilibrium. Walras' seminal work is also the basis for Computable General Equilibrium (CGE) models. These are widely used economic models based on neoclassical fundamentals that combine the abstract general equilibrium structure with actual economic data to estimate 'economy-wide' impacts of changes in policy, technology or other external factors.

Keynesian economics

Keynesianism developed after the two world wars as a reaction against what has been described as governmental abstention from macroeconomic affairs, advocating interventionist fiscal policy to stimulate economic demand and growth. The emergence of macroeconomics as a truly separate discipline is usually ascribed to John Maynard Keynes and his seminal work The General Theory of Employment, Interest and Money (Keynes, 1936). Keynes and his followers were mainly concerned with questions about business cycles, unemployment and inflation. Today, building on Keynes' framework (but not necessarily his ideas), a wide range of schools have emerged which look at other broad macroeconomic issues, such as how central banks manage money and interest rates, what causes international financial crises, and the reasons for economic growth and stagnation.

The natural environment did not figure in the first generations of (macroeconomic) growth theories developed in the 1950s and 1960s in the context of the 'neoclassical synthesis'. This term describes the analytical merging of Keynesian (typically for demand-led short-term analysis) and older, neoclassical macroeconomic theories that dominate microeconomics (for supply-based longer-term outcomes). The 'neoclassical synthesis' dominates mainstream economics today. This also implies that a lot of modern macroeconomic theory has been built on microeconomics that is based on assumptions about micro-level behaviour.

Environmental economics

Since the 1970s two major sub-disciplines have developed within the neoclassical school that look more closely at the natural environment. They are environmental economics (Hanley et al, 2007) and natural resource economics, a subfield of environmental economics that focuses on issues related to the spectrum of natural resource and environmental management (Conrad and Clark, 1987; Tietenberg, 2009). Many (later) Nobel Prize winners, experts in growth and general equilibrium theorists, were doing research in this field in the 1970s (Heal, 2007).

Environmental economics is essentially an extension of neoclassical economics and follows the same logic (Söderbaum, 2008). The approach incorporates the environment and environmental problems into existing economic concepts, preserving as much of conventional economic thinking as possible (Kennet and Heinemann, 2006). In essence, environmental economics is concerned with the efficient use of (non-renewable) resources (resource economics) and the negative external effects arising from economic activities. Environmental economists offer two main approaches to overcome these externalities. One solution is seen by introducing a so-called Pigouvian-tax (Pigou, 1920) to capture the social cost of a market activity that is not covered by the private cost of the activity. The second solution, related to Nobel Laureate Ronald Coase, is to distribute property rights that theoretically lead to an optimal use of the environment. The basic idea in both cases is to set a price for the environment (see Section 2.3).

Ecological economics

Ecological economics goes further than environmental economics. Söderbaum (2008: 53) describes it as 'economics for sustainable development' or 'sustainability economics' because there is a commitment to work for sustainable development and, more precisely, for the more radical interpretation of sustainable development.

Baumgärtner et al (2008) describe two central characteristics of ecological economics. First, ecological economics aims to study the relationships between ecosystems and economic systems, and second, how to manage these relationships. In other words, ecological economics understands itself as "the science and management of sustainability" (Costanza, 1991).

This area of interdisciplinary and transdisciplinary study was established in the late 1980s out of the concern that the analytical apparatus of (environmental) economics had not sufficiently addressed issues of human-nature relationships and of sustainability. Ecological economics follows a pluralistic and open-minded attitude to different theories of science and disciplines. The idea is not to defend one particular theory, science or discipline but rather to borrow useful elements from different disciplines. Investigations focus on how ecosystems and economic activity interrelate (Common and Stagl, 2005: 5; Proops, 1989: 60) and go beyond neoclassical economics and conventional ecology in terms of the breadth of perception of the problem and in the importance attached to the environment-economy interactions. According to its proponents, ecological economics takes a 'wider and longer view in terms of space, time and the parts of the system to be studied' (Costanza, 1991: 3). Ecological economics is oriented toward the normative vision of sustainability, its science and management (Costanza, 1991). In the literature of ecological economics institutions and politics are recognised as important to our understanding of resource and environmental problems (Martinez-Alier, 2002; Söderbaum, 1999).

Box 2.1: Approaches and Applications of Ecological Economics (EE)

This box provides a concise overview of the main principles and approaches in ecological economics and their application in practice.

- **Interdisciplinarity and Transdisciplinarity**

EE aims to analyse the complex relationships between ecosystems and the economic system in a holistic way, which encompasses several dimensions, including physical, economic, political, social, ethical and cultural aspects. This requires an interdisciplinary approach, ie the cooperation and coordination of many disciplines. For example, an interdisciplinary analysis of greenhouse gas emissions could involve a discussion process among scientists of various fields about the different disciplinary concepts, methods and theories that may be adequate to examine the problem, how they relate to each other, and how they need to be adjusted (Baumgärtner et al, 2008).

As the science and management of sustainability, EE aims to develop sustainable solutions in concrete contexts and to feed back results into practical actions. This interrelationship between science and society is called transdisciplinarity (Hirsch Hadorn, 2006). For example, investigating the relationship between lifestyles and climate change with the aim to reduce emissions can be done through focus groups and interviews with residents about their lifestyles and perceptions of climate change. A close cooperation with citizens allows a profound examination of the subject.

- **Allocation, distribution and scale**

EE deals with allocation, distribution and scale issues related to economic activities in equal terms (Daly, 1992). This emphasis is a major difference to neoclassical economics, which strongly focuses on allocation, while distributional issues are secondary and scale is subsumed under allocation, arguing that if we get the prices right there is no scale problem. EE maintains that every policy goal must have an independent policy instrument, or as Daly (1992) famously puts it "You can't kill two birds with one stone".

The process of identifying policy instruments to achieve the goal of fair and sustainable resource use is a good example of the interdependence of allocation, distribution, and scale in ecological economics. The first question from an ecological point of view is "What are the ecological limits of sustainable scale?" Given these limits, defining caps on resource use may ensure that economic throughput stays within these limits. One option to achieve a fair and just redistribution of resources and to capture scarcity rents, would be the auctioning of quotas. Trade can be used as a market-based mechanism to allocate resources efficiently. Such Cap-Auction-Trade Systems are conceivable for all basic resources that are scarce or overused. They have already proven manageable for CO_2 emissions (Daly, 2010).

- **Decision-making and valuation**

As a policy-oriented and problem-driven science, EE is concerned with improving decision-making processes. EE argues that standard economic valuation methods are inappropriate for contemporary environmental issues, which are global in scale, long-term in their impact and require urgent decisions based on uncertain knowledge. EE prefers approaches that focus on processes as they bring together various forms and sources of information and viewpoints. The focus is on the quality of the decision-making process rather than solely on results. Participation and public discourse are seen as a learning process for all involved that improve the results and their acceptance. Multi-criteria analysis as a decision-making tool for complex problems that highlights conflicts and derives compromises in a transparent process has become prominent. As a reaction against traditional monetary valuation, a wide range of alternative indicators such as physical indicators and sustainability indices have been developed in order to conceptualize human impacts on the environment. Prominent examples include the Ecological Footprint, materials flow analysis (MFA), and rucksack concepts.

New economics

New economics is an approach which believes that traditional, neoclassical economics is dependent on false assumptions of human behaviour and physical systems. The approach acknowledges the findings from other disciplines, particularly those from ethics, political science, history and engineering, as well as complexity and evolutionary theory (Barker, 2009). There are also similarities with climate science, which addresses the likelihood and risks of extreme events and the approach incorporates findings from behavioural economics (eg risk aversion and non utility maximisation). There are four particular issues that distinguish New Economics from neoclassical economics:

- The economy is a complex and non-linear system, in which technological change is inherent in economic growth.
- Many economic policy issues are ethical-economics in nature, and should therefore take moral philosophy into account rather than just economics in isolation. Utilitarianism approaches and the use of discount rates ignore the concept of justice and are therefore inappropriate in policy decision-making.
- Production processes involving the supply and demand of materials, energy and skills can be informed by the engineering discipline. Similarly, economic history is important in understanding the relationship between economics and technological change.

- The politics of sustainable development implies unstable alliances and trade-offs between governments and political parties.

Sustainable development and its environmental dimension

By far the most commonly used and well-known definition of sustainable development originates from the Brundtland Commission's report Our Common Future (WCED, 1987). Therein, sustainable development is defined as a development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs.

Reflecting increasing concern with environmental problems in developing countries, and the failure to relate these problems to development issues, Our Common Future describes a vision of a sustainable future with a strong focus on human needs. The UN definition is not universally accepted and has undergone various interpretations (Kates et al, 2005). What sustainability is, what its goals should be and how they are to be achieved is all open to interpretation (Holling, 2000). There are understandings of sustainable development with different foci and priorities, and many interpretations place heavy emphasis on economic growth.

Forum for the Future, an organisation focused on sustainable development, takes an ecological perspective and defines sustainable development as 'a dynamic process which enables all people to realize their potential and to improve their quality of life in ways that simultaneously protect and enhance the planet's life-support systems' (Forum for the Future, 2000). In contrast to the Brundtland definition, this characterisation explicitly conveys the idea that there are biophysical limits within which society must operate. According to Porritt (2005), sustainable development is not simply about managing the environment more effectively while people pursue their business as usual. It is a social and economic project as much as an environmental project, with the objective of optimizing human well-being.

It is often noted that sustainable development requires the reconciliation of environmental, social and economic demands – the 'three pillars' of sustainability. This view has been expressed as an illustration using three overlapping ellipses, indicating that the three pillars of sustainability are not mutually exclusive and can be mutually reinforcing. The link between the EU SDS and the Lisbon strategy is formulated in this way.

For some environmentalists the idea of sustainable development is an oxymoron as development seems to entail environmental degradation (Redclift, 2005). The ecological economist Herman Daly asked 'what use is a sawmill without a forest?' (Daly and Cobb, 1989). From this perspective, the economy is a subsystem of human society, which is itself a subsystem of the biosphere (Porritt, 2005)

A universally-accepted definition of sustainability is elusive because it would need to achieve conflicting objectives. On the one hand it must be factual and scientific. The definition 'sustainability is improving the quality of human life while living within the carrying capacity of supporting eco-systems' (IUCN et al, 1991), though vague, conveys the idea of sustainability having quantifiable limits. On the other hand, sustainability has also been interpreted as a call for action, a task in progress or a 'journey' (Milne et al, 2006) and therefore a political process. Thus, some definitions set out common goals and values. The Earth Charter Initiative (Earth Council, 2000) calls for 'a sustainable global society founded on respect for nature, universal human rights, economic justice, and a culture of peace.'

Moreover, the word sustainability is applied not only to human sustainability on Earth but also to many situations and contexts over different scales of space and time, from small local ones to the global balance of production and consumption (Costanza and Patten, 1995). For all these reasons sustainability is perceived, at one extreme, as nothing more than a feel-good buzzword with little meaning or substance (Marshall and Toffel, 2005) but, at the other, as an important but unfocused concept like 'liberty' or 'justice' (Blewitt, 2008). It has also been described as a 'dialogue of values that defies consensual definition' (Ratner, 2004).

Apart from the academic discourse, attempts have also been made in politics to define and address the environmental aspects of sustainable development. In the European Union, the renewed SDS has environmental protection as one of its key objectives (European Commission, 2005: 3). It identifies the following actions to achieve this objective:

- to safeguard the earth's capacity to support life in all its diversity
- to respect the limits of the planet's natural resources and ensure a high level of protection and improvement of the quality of the environment
- to prevent and reduce environmental pollution
- to promote sustainable consumption and production to break the link between economic growth and environmental degradation

In the context of this literature review (and the following chapters) we understand sustainable development as a concept that allows for radical change to achieve economic development that is socially just and ecologically sound.

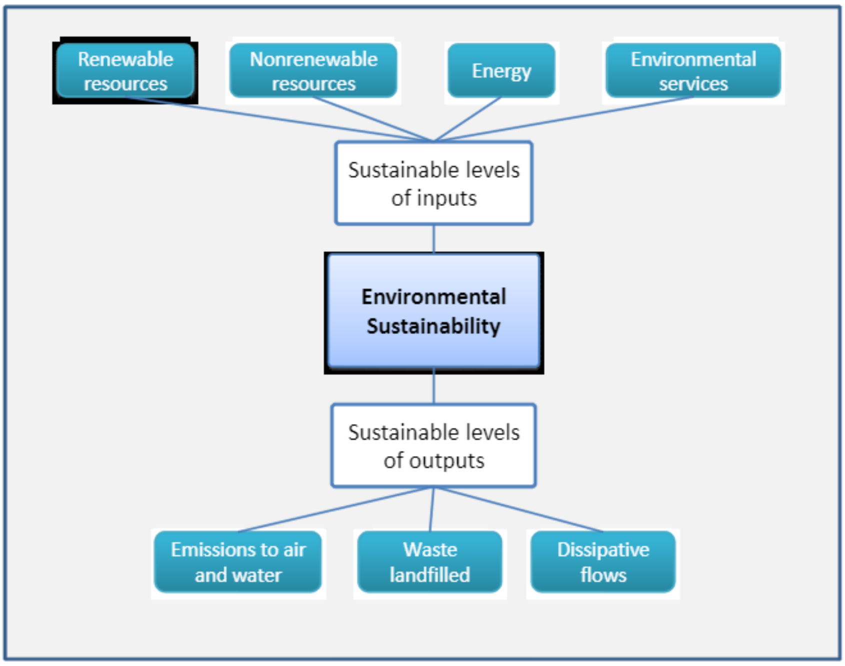
Extent of the literature review

A large amount of literature looks at the environmental dimensions of sustainable development. We focus on two schools of thought, a mainstream neoclassical economics and ecological economics, and compare how the macro economy and its linkages to the environment are theorised and measured from both perspectives. The main question guiding this review is 'How does the macroeconomy and macroeconomic factors affect sustainable development?'

2.3 A broad understanding of the macroeconomy and its links to the environment

This section provides the background to the following sections by explaining the macroeconomy (hereafter referred to as the economy) and its linkages to the environment. The environmental dimension of sustainable development is largely influenced by two factors which are linked to economic activities: the amount of inputs taken from the environment (including consequences such as resource depletion and biodiversity loss) and the amount of outputs released into the environment as a result of production and consumption (see Figure 2.1), as well as their consequences (such as climate change and freshwater water scarcity).

Figure 2.1: Some Determinants of Environmental Sustainability

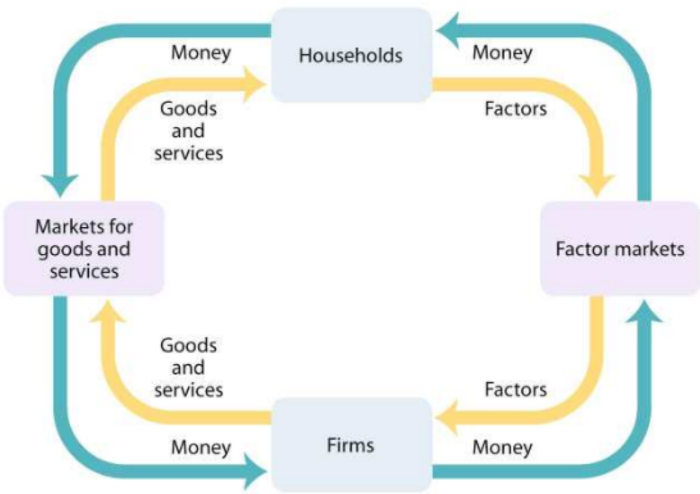


In the following sections, we will briefly outline the standard depictions and models of the economy used by neoclassical (environmental) and ecological economists, including their assumptions and metrics. This is essential in order to understand Section 2.4, which analyses why these different schools of thought draw different conclusions from the interlinkages between the economy and the environment.

The neoclassical macroeconomic model and its links to the environment

The most basic model in macroeconomics is the circular flow in the economy (see Figure 2.2). It describes how households and firms are linked by incomes and expenditures, and how the various sectors of the economy (households, firms, government and financial markets) are linked.

Figure 2.2: The Circular Flow of Income in the Economy



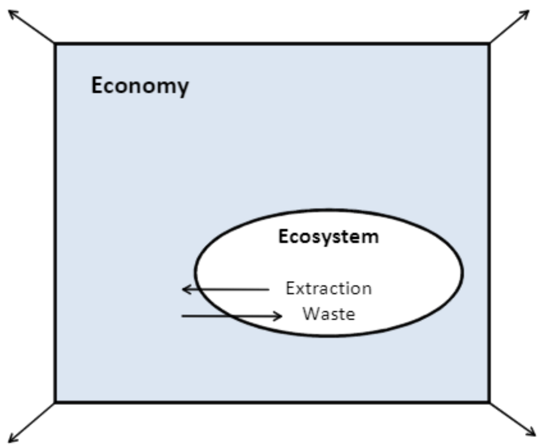
In this model of exchange, the economy consists of two main categories of actors, households and firms, and their market relationships. Households supply labour, which firms reimburse with wages. Firms supply goods and services for which households pay money. The coming together of buyers and sellers is referred to as a market. In the market for factors of production (factor markets) households provide labour, land and capital. Firms make use of these factors of production in return for wages, rent, dividends and interest.

Sometimes, this model is extended to include additional actors and markets, as well as the national government in its role in regulating of markets, administering taxation and making decisions about how tax income should be used.

Role of the environment

The environment and its natural resources have never found a strong footing in the neoclassical model of the economy (Daly, 1996: 46). The ecosystem is theorised as a subsystem of the economy (see Figure 2.3) whose main functions are extraction (the environment as a source of natural resources) and waste disposal (as a sink for waste products). Herfindahl and Kneese (1974) add that the environment may also provide amenity services and general life support. However, it is important to note that they treat natural resources as (a specific type of) capital, or, rather a production factor, and, as a consequence, assume a high degree of substitution with manufactured capital goods[4].

Figure 2.3: The Ecosystem as a Subsystem of the Economy



Source: (Daly and Farley, 2004).

The arrows at the sides of the economy box in Figure 2.3 symbolise an important concern for economists understanding economic growth and its underlying factors. Economic growth is the increase in an economy's production (and consumption) of goods and services over time. A difference can be made between actual and potential (also called structural or trend) growth. In the short run, actual growth may arise from a fuller use of resources (using machinery more efficiently or reducing unemployment). However, for actual growth to sustain in the long run there would have to be an increase in potential output.

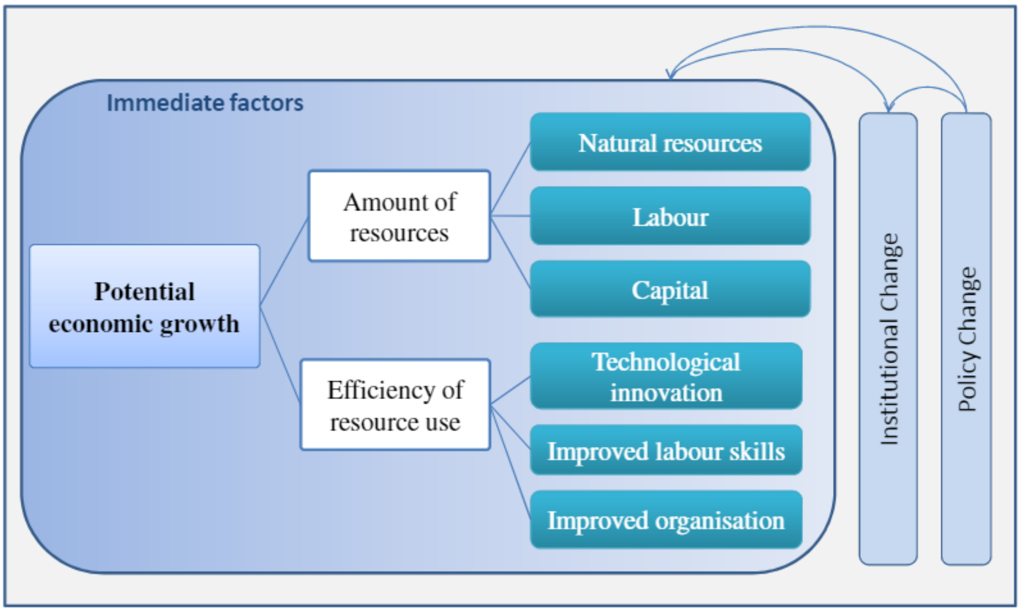
Factors of growth

The suggested underlying factors of growth shed light on the role they assign to the economy and its natural resources. The original neoclassical growth model (Solow,

[4] The fundamental assumption of substitutability is treated in more detail in Section 2.4.

1956) worked with a stylised macroeconomic 'production function' linking GDP with production input factors. It assumed that the only endogenous driving variables were labour and capital (in abstract and accumulated form) and the exogenous driver variously called 'technological progress' or 'total factor productivity'. Natural resources and the environment were left out of this model, as it intended to answer the question of which parts of growth could be attributed to the accumulation of capital, the growth of the labour force, the substitution of labour by capital and other sources. In more recent models the exogenous driver has become endogenous as 'knowledge' or 'human capital' (this is discussed further in Chapters 3 and 4). Recent textbooks (see for example Sloman, 2000) distinguish between two major factors contributing to potential economic growth: an increase in resources (natural resources, labour or capital) and an increase in the efficiency with which these resources are used (through technological innovation, improved labour skills or improved organisation) (see Figure 2.4). The model allows for fixed amounts of production factor, such as land or a natural resource; this does not necessarily stifle growth as the increase of the price of the limited factor leads in such models to substitution to more widely available production factors. The debate between technology optimists and pessimists is then narrowed down to the empirical question of how large is the substitution elasticity between the factors of production.

Figure 2.4: Main Factors Contributing to Economic Growth



The main factors underlying the quantity and growth of real GDP also depend on the volume of supply and demand. The aggregate supply is the total quantity that firms produce during a given period, which in turn depends on:

- the quantity of the labour employed
- the quantity of physical and human capital
- the state of technology

Aggregate supply and demand

Aggregate supply represents the productive capacity available in the economy to produce goods and services either in the short term or in the long term. In the short run, producers respond to higher demand (thus prices) by using more inputs in the production process and increasing the utilization of their existing inputs. In the long run, the productive capacity of an economy is based on the state of production technology and the availability and quality of factor inputs.

Aggregate demand (AD) is the total amount of final goods and services produced in the economy that people, businesses, governments and overseas agents buy. It can be expressed by the following identity:

AD= C + I + G + (X – M), where
C is consumers' expenditure on goods and services,
I is investment,
G is government spending,
X is exports, and
M is imports.

While in the short run fluctuations in demand determine the level of GDP, over the long run, it is the ability to supply output that supports the growth of read GDP. However, the demand component investment provides an important link to long-term economic growth. Unlike other expenditures (eg on private consumption) investments augment the capital stock and capital is one of the factors of production that directly determine the economy's productive capacity or aggregate supply.

Despite their differences, exogenous and endogenous growth theories agree on the crucial role of investment and capital accumulation to economic growth. Investment (either as machinery and equipment investment or as investment in human capital through education and worker training and research and development) is the main driver of technological change; virtually all new technology is embodied in new capital equipment. Thus, investment induces new capital inputs for future use and offers opportunities for economic growth.

With regard to the analysis of economic growth, neoclassical economists stand in sharp contrast to their classical predecessors since Ricardo who still thought that the economy would naturally end up in the stationary state, with wages at a subsistence level and the surplus all going to landlords as rent, with nothing left over for the capitalist's profit, and therefore no motive for further growth. While most of the classical economists dreaded the stationary state as the end of progress, Mill welcomed it, recognizing that 'a stationary condition of capital and population implies no stationary state of human improvement' and that in fact it would be more likely to improve 'the art of living […] when minds ceased to be engrossed by the art of getting on'. In the language of today, Mill was arguing for sustainable development - development without growth - that is, qualitative improvement without quantitative increase. Daly (1996) argues that Mill's writing on the stationary state has been forgotten, and most economics graduates since the 1970s have never heard of this concept.

Metrics used in neoclassical economics

While classical economists still considered demographic and ecological limits as important to the viability of the economy, the standard neoclassical economic theory begins with non-physical parameters (Daly, 1996). In their models, the non-physical, qualitative conditions are given and the physical, quantitative magnitudes must adjust. This 'adjustment' almost always involves growth.

Capital plays a major role in the growth model. In the neoclassical understanding, capital consists of durable produced goods that are used to make other goods, for example factories, houses, and various types of equipment. These capital goods are valued in monetary terms (eg constant dollar value).

Main assumptions of the neoclassical theory

The most important environment-related, behavioural and actor-related assumptions underlying neoclassical economic theory and the conventional growth model have been extensively assessed and criticised in theoretical, conceptual and practical analyses in the literature (Ayres and Warr, 2009; Daly, 1996; Samuelson and Nordhaus, 2001; Söderbaum, 2008; Solow, 1974b). They can be summarised in three categories:

Assumptions of many works in neoclassical economics with regard to the environment, its resources and capacities are:

- the environment provides an unlimited flow of natural resources
- capital can substitute for resources, ie any input (capital) can substitute, albeit with diminishing returns, for another (land or a scarce material) and maintain the same level of output

The main neoclassical assumptions on the behaviour and constraints of economic actors are:

- assumed self-interest is the starting point in the model for the consumers' calculations of optimal behaviours, in other words, consumers try to maximise their utility subject to a budget constraint.
- preferences of actors are given
- decision-making is carried out by systematically comparing alternatives, observing the 'opportunity cost principle'
- reasoning in marginal terms is common: what will be the benefits and costs of producing (purchasing) one extra unit of a specific commodity?
- the distribution of income is traditionally seen as given, although nowadays mainstream economists deal with many aspects of the distribution of income and wealth

Traditional assumptions on other macroeconomic factors and the limits to economic growth include:

- technology is given (although this is now often relaxed)
- labour growth is given in principle
- the economy as a whole can grow indefinitely (the marginal costs of further growth never become greater than the marginal benefits)

The ecological macroeconomic model and its links to the environment

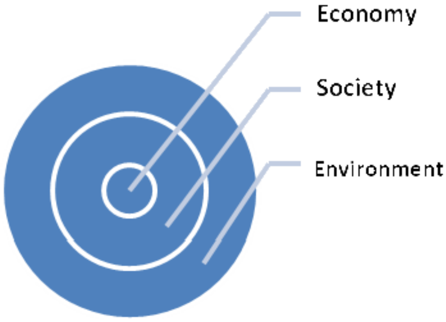
An alternative macroeconomic framework is provided by ecological economists. In its most basic form, it extends the neoclassical framework by explicitly including the environment and its services to the economy, for instance as production factors, as factors determining utility and in other forms[5]:

[5] Sometimes these services are also called ecosystem services. Usually, they are not only seen in relation to the economy but also to other systems, both within and outside the human sphere. Two comprehensive assessments of ecosystem services are: *World Resources 2000-2001: People and Ecosystems* and the Millennium Ecosystem Assessment, *Ecosystems and human well-being*. The former distinguishes eight types of ecosystem services: food/fibre production, water quality, water quantity, biodiversity, carbon storage, recreation, shoreline protection and wood fuel production.

- the provision of resources, which are extracted from the environment and used in production
- the service as a sink for waste from production and consumption activities
- amenity services for humans
- basic life support services

Ecological economists emphasise that the economy is, in the first instance, a subsystem of human society which is itself, in the second instance, a subsystem of the environment (see Figure 2.5). No subsystem can expand beyond the capacity of the total system of which it is a part (Porritt, 2005). The economic system is not only embedded in the larger environmental system but also completely dependent on it as both a source of inputs and as a sink for the matter or energy transformations required by economic activity and constrained by the law of entropy.

Figure 2.5: The Economy as a Subsystem of the Environment

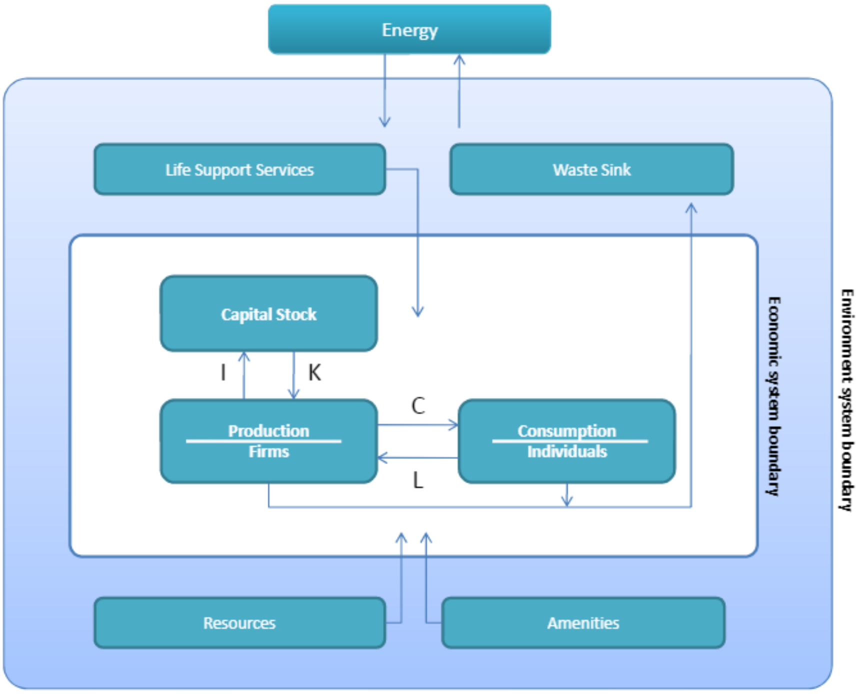


In one of the standard textbooks in this field, *Ecological Economics: An Introduction*, Common and Stagl (2005) illustrate this interdependence between the economy and the environment in a simple diagram (see Figure 2.6).

There are also more complex depictions of this interdependence. Hall et al (2001), for example, illustrate various processes and their boundaries (see Figure 2.7). Here, the global economy operates within the wider global ecosystem. Natural energies drive geological, biological, and chemical cycles that produce natural resources and public service functions and maintain the milieu that is essential for all other economic steps. Extractive industries use energy to exploit natural resources and convert them to raw materials which are then used by manufacturing and other intermediate sectors to produce final goods and services. These final goods and services are distributed by the commercial sector to satisfy final demand. Eventually, non-recycled materials and waste heat return to the environment as waste products.

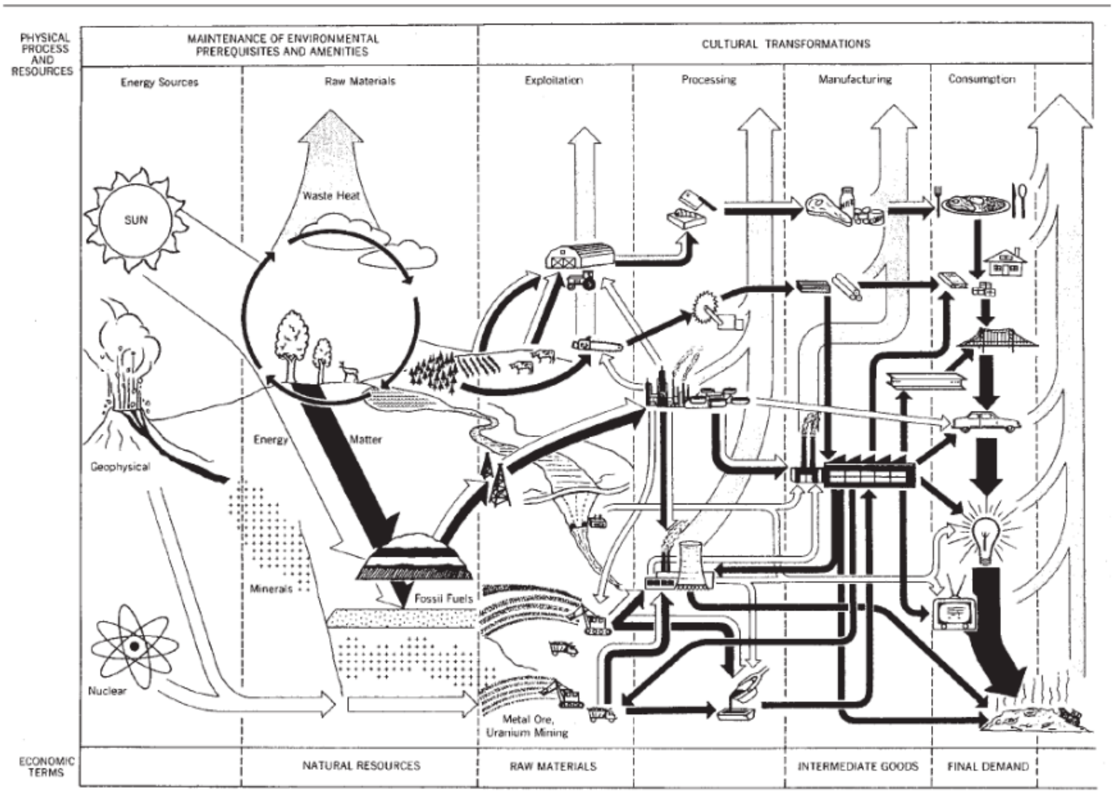
In these models the environment, in which the economy is embedded, is a thermodynamically closed system which exchanges energy, but not matter, with the rest of the universe. Energy is provided by the sun and the incoming flow of solar radiation, which is the basis for all life on earth. The outgoing energy flow is thermal radiation emitted by the earth.

Figure 2.6: Economy-Environment Interdependence



Note: C = commodities (goods and services); I = investment; L = labour; K = capital
Source: Common and Stagl (2005: 87)

Figure 2.7: A Comprehensive Model of How the Economy Works



Source: Hall et al (2001: 665)

Ecological economics does not yet comprise a comprehensive theory of macroeconomics with all its interlinked dimensions such as the financial market, theories of interest rates, etc. There are gaps which make it difficult to construct extensive models for scenario simulations and other analyses. For example, while neoclassical economic models measure success by a set of indicators of which GDP is most important[6], it is still unclear how success can best be measured in ecological macroeconomics.

Regarding growth theories, ecological economists have long criticised neoclassical theory for failing to take into account the limits of natural resources and eco-systems. In contrast to the neoclassical theory, they believe that growth cannot be sustained in the long term by continuously exploiting finite material and energy supplies, and degrading the functioning of ecosystems. However, a comprehensive model which accounts for these relationships and thresholds in the economy is still missing in the ecological economics school of thought. At the time of writing, many ecological economists are busy trying to fill this important gap in the literature. For example, an important debate was launched regarding the role of the monetary system in making economies dependent upon continued growth; in what ways could it change to facilitate the transition to a sustainable economy[7]?

Even without a comprehensive model of economic growth, however, a common idea shared by ecological economists (first introduced by Nicolas Georgescu-Roegen, 1971) is that increases in economic growth must be linked with increases in entropy. Therefore, the laws of thermodynamics are fundamental to an understanding of the growth dilemma (Porritt, 2005: 58).

Main assumptions of the ecological macroeconomic theory

Ecological economics is a very heterodox discipline which does not have a large set of commonly shared assumptions. It embraces a variety of perspectives and models. Some of the most prevalent assumptions are that (i) the limited carrying capacity of the Earth sets limits to economic expansion, (ii) there is limited human scale related to the biosphere, and (iii) the economic process is a social, not individualistic, phenomenon taking place within a finite biophysical universe.

Klaassen and Opschoor (1991) point out that ecological economists replace the 'fixed context' premise of neoclassical economics (ie the assumption that a range of parameters are static or given) by one of 'circular interdependence' including the 'major processes in the environment and taking into account essential biophysical laws'. Moreover, they reject methodological individualism, which is a basic assumption underlying neoclassical theory. In contrast, they state that the values prevalent in a society may differ from (aggregated) individual values. For example, given its much longer life expectancy, society as whole may value environmental quality more than individuals do. According to Klaassen and Opschoor (ibid.) ecological economics presumes a value hierarchy in which societal and human behaviours are driven by welfare, wants and values. 'Sustainability' and 'environmental compatibility' are proposed as ultimate values. Such values imply the protection of biodiversity and of ecologically viable patterns of resource use.

[6] The drawbacks of GDP as a progress indicator are today a general issue. Economic output and its growth, as measured in GDP, do no longer necessarily mean an improvement in our quality of life for the majority of people and overemphasizing GDP growth as a policy objective may jeopardize our socio-economic and sustainable development. Some other indicators are discussed in Chapter 3.

[7] An overview of the first approaches towards a new macroeconomics is given in Section 2.6.

Metrics used in ecological economics

Ecological economics begins with physical parameters: a finite world, complex ecological interrelations, and the laws of thermodynamics (a good illustration is provided by Daly's paradigm of the steady state, see Daly, 1973). The physical quantitative magnitudes are given, and the non-physical qualitative patterns of life are treated as variables.

Some ecological economists argue that monetary and biophysical values bear little relationship to each other (as is often argued in environmental economics in the framework of imperfect or missing markets, or the absence of property rights). Assigning a value to nature cannot be reduced to a single metric such as a price. Ecological economists have developed valuation methods such as multi-criteria analyses that do not put a higher preference on consumer valuations than on biophysical and ecological relationships, but put weights on different criteria or assets according to stakeholders' preferences. An important characteristic of such evaluations is the use of qualitative and diverse quantitative indicators.

A short ecological critique of the neoclassical model

Natural scientists and ecological economists have long criticised the neoclassical models and assumptions for their lack of an ecological dimension. Three fundamental arguments stand out.

First, the boundaries of analysis in the neoclassical model exclude the processes of the biosphere that provide the material and energy inputs, waste sinks, and the necessary conditions for economic processes to happen. Treating the macroeconomy as an isolated system prevents thorough analysis of its relationship with the environment. Daly (1996: 48) points out that the macroeconomy should not be pictured as an isolated circular flow of abstract exchange value, unconstrained by mass balance, entropy and finitude. The circular flow of exchange value is a useful abstraction for the macroeconomic sphere; therefore it underlies almost all economic models. But it hides all physical relationships between the macroeconomy and the environment. At a time of overconsumption of natural resources, these relationships become ever more important and can only be analysed when the macroeconomy is seen as an open subsystem of the finite natural ecosystem (environment).

Secondly, the structure of the neoclassical model is said to be unsuitable for questions on the relation between the economy and the environment because it is detached from the laws governing the biophysical world, especially the laws of thermodynamics (the study of energy conversion between heat and mechanical work) (Daly, 1973; Georgescu-Roegen, 1971). It would be necessary to include the basic energy and material inputs and outputs that are essential if the economic processes within the firm are to take place. In his seminal book, *Wealth, Virtual Wealth and Debt: The Solution of the Economic Paradox*, the chemist Frederick Soddy (1926) criticised the neoclassical economists' focus on monetary flows. He argued that 'real' wealth was created by using energy to transform materials into physical goods and services. In the field of ecological economics, the omission of the material contributions of natural resources has also been pointed out repeatedly (see for example Daly, 1973; Georgescu-Roegen, 1971; Martínez Alier and Schlüpmann, 1987). Daly argues that mainstream economics is unable to seriously analyse economy-environment relations because of its focus on self-reproducing circular flows in which production and consumption are only illustrated as 'exchange value abstracted from the physical dimensions of goods and factors that are exchanged' (Daly, 1977) and from the laws and principles of physics, chemistry and biology that all these processes must obey.

A third argument on the weakness of the neoclassical model is that its basic assumptions have not been put forward as testable hypotheses but rather as givens. Moreover, the mathematical theory underlying neoclassical economics, and the high level of abstraction, may be inadequate to investigate phenomena that require a more interdisciplinary approach. Söderbaum (2008) points out that neoclassical economics relies heavily on positivism as a theory of science, and emphasises mathematics as the language of presentation (more recent advances in the theory of science are connected with the humanities and social sciences; these theories, such as social constructivism and hermeneutics, are largely neglected).

Some authors have also warned about the implications of using neoclassical economic assumptions. As Hall et al (2001) point out, the failure of neoclassical economics to incorporate and be consistent with the basic laws of nature 'leads to the failure of those economic policies that run counter to these laws and endanger sustainable development'(Hall et al, 2001: 664). Assuming that scarcity is solvable through the price mechanism, for example, leads to its neglect as a fundamental problem to sustainability. The market does not necessarily lead to a selection of (in a neoclassical sense) optimal technologies, production activities, and use of space, even when prices are 'correct'. Therefore, ecological economics considers systems, including markets, as adaptive and coincidental rather than optimal (Van den Bergh, 2001).

The assumption of easy substitution of manufactured capital for depleting resources or a degraded environment may lessen the concern about 'the capacity of the environment to sustain development' (Victor, 1991: 193-194). These policy implications will be covered in more detail in the next section.

Relation to New Economics

The first two of these criticisms could also be applied to models based on the principles of New Economics. Although these models do tend to place a greater emphasis on the links between the economy and the physical resources it consumes than is present in environmental economics (and do not reduce all outcomes to monetary values), the approach does not go as far as that of Ecological Economics in placing the economy fully within the environmental system. It should be noted, however, that this is partly due to the empirical modelling approach adopted in New Economics, which counters the third argument above but limits the coverage of the models to the areas of sustainable development with available published data.

A short critique of ecological economics

There is no comprehensive and substantial critique on the ecological economics approach. This is not because it is flawless and beyond the need for improvement but because ecological economics operates at the margin of the economics profession and has not received significant attention from the large majority of mainstream economics. In this regard, Daly wrote in 1997: 'Serious criticism and serious replies are both essential parts of science. When a fundamental critique from a very prominent economist [Georgescu Roegen] goes for 20 years without a reply, we should worry about the health of our discipline! […] It is appropriate to […] put an end to 'conjuring tricks' – to mathematical fun and games with infinity in the Garden of Eden – and to devote their impressive analytical powers to helping develop serious ecological economics for the real world' (Daly, 1997: 265).

Compared with neoclassical economics, ecological economics generally only has a marginal influence on decision-making. Although the role of ecological economics has become more prominent in recent years, neoclassical economics largely dominates the public policy discourse. Ecological economics has therefore been criticised for its lack of political influence on questions of sustainability.

Ecological economics also receives scant attention from the mainstream neoclassical school because its focus on the environment and the explicit inclusion of natural resources in the production function is not generally accepted, given its contradiction to the neoclassical assumption that reproducible capital is a near perfect substitute for land and other exhaustible resources (see eg Nordhaus and Tobin, 1972; Solow, 1974b).

Another serious shortcoming is the lack of a workable applied macroeconomic model incorporating the key aspects of the ecological economics approach.

Ecological economics may also be criticised because it is not regarded as a homogeneous school of thought with consistent theories. This may be due to the fact that ecological economics combines a variety of disciplines with different concepts, definitions and approaches. Moreover, many neoclassical economists argue that all the issues which are of concern to ecological economics have already been addressed in environmental economics or elsewhere and that the field thus offers limited added value (Shi, 2004).

2.4 Analysis of interlinkages between macroeconomic factors on the environment in different schools of economic thought

The ways in which the environment and its relationship to the economy are theorised and measured have direct implications for modelling and for policy. This section analyses how the models used by neoclassical economics (mainly CGE models) and ecological economics have been used to analyse the main interlinkages between macroeconomic factors and the environment. As the previous section has shown, analyses of the environment differ substantially among different schools of thought, depending on their assumptions, metrics and models. Therefore, they arrive at different, and sometimes contradictory, conclusions on the extent to which environmental factors could constrain or foster economic growth. We review the literature that applies the models to the analysis of environmental issues in order to examine the implications of applying different models to the analysis of environmental issues.

The main questions guiding this second part of the literature review are ‘What are the implications of a conventional growth scenario and the factors underlying it for the environmental aspects of sustainable development?’ and ‘Under what assumptions do these linkages work?’

Neoclassical economic analyses of sustainable environmental development

Neoclassical (environmental and resource) economics offers important insights into the analysis and governance of sustainable development. At the analytical level, it builds on the notion of opportunity cost and is consequently concerned with valuing natural assets based on their various contributions to human welfare. Environmental economics applies the neoclassical theory of economic growth and its various models to understanding sustainable development. At the policy level, a number of policy instruments, including taxation and tradable permit systems, that are based on the efficient functioning of markets have been suggested.

Cost-benefit analyses

The monetary metrics used in neoclassical economics to evaluate nature enable cost-benefit analyses (CBA). These are routinely used to determine, for example, efficiency at the national level or the costs of climate change.

However, CBA conclusions can be very sensitive to assumptions on discount rates. According to the standard orthodox theory, the social discount rate should be equal to the time preference of society, the opportunity cost of investment. In standard CBA of climate change, a discount rate is used approximately equal to the opportunity cost of a risk-free investment, ie to market interest rates for government bonds ('descriptive' approach to discounting). A higher rate would channel scarce resources away from investments that provide the future with a higher real rate of return towards consumption and short-term investments. There is a strong debate about this approach. Critics (Martinez-Alier 1998 and 1999; Munda, 1996 and 1998) have long been pointing out that the practice of discounting economic costs and benefits of policies and projects where costs and benefits occur at points of time strongly favours projects with short-term benefits and long-term costs, often (though not always) with highly negative environmental effects. From an ethical perspective it is questionable whether individual discounting models should be translated to the intergenerational context. Such an approach does not appear to be compatible with a sustainable model of the macroeconomy.

CBA as a methodology is discussed further in Section 3.3.

Contingent valuation

Where monetary values are difficult to assign, neoclassical economics uses the survey-based method of contingent valuation (Adamowicz et al, 1998; Boxall et al, 1996; Carson, 2000). Environmental preservation of the impact of contamination, for example, does give people utility, but a complete monetary value cannot easily be determined because certain aspects (eg the view of a beautiful scenery) are outside the market. To measure the value of these aspects which are based outside the market, neoclassical economists use contingent valuation, a stated preference model, in contrast to a price-based revealed preference model. A contingent valuation survey typically asks people how much money they would be willing to pay (or willing to accept) to maintain the existence of (or be compensated for the loss of) an environmental feature, such as biodiversity, or an environmental resource (for further details see Mitchell and Carson, 1989).

In the neoclassical framework, scarcity of resources is not regarded as a fatal bottleneck for growth or even for a sustained level of prosperity. In his theory of growth, Solow (1974; 1956) assumes that there are no limits on the availability of resources. Dasgupta and Heal (1979), whose book *Economic Theory and Exhaustible Resources* is the standard neoclassical text on natural resources, similarly conclude that non-renewable resources do not pose a fundamental problem, even in the absence of technological progress. Consequently, production can be modelled as a function of capital and labour only. Natural resources are not included separately but as a form of capital.

This resource optimism is strongly linked to the basic assumptions of neoclassical economics (Neumayer, 2000). First, higher use of a non-renewable or fixed stock of resources would make such a production factor scarcer. This scarcity should lead to a rise in the price of a resource and consequently to a substitution of this resource with another, more abundant, resource and to a substitution of products that are intensive in this resource. This implies that there is a high degree of substitution between resources and capital and that constant annual output can be obtained indefinitely even with very few resources (Herfindahl and Kneese, 1974).

Second, a rise in the price of a resource leads to increased recycling of the resource and to the exploration and extraction of lower quality grades (eg ores). Third, man-made capital can substitute for natural resources. Fourth, technological progress can increase the efficiency of resource use and makes extraction of lower quality resources economical. The extension of the neoclassical growth theory of endogenous technical progress has reinforced this optimist view, as the theory reasons that R&D efforts will be focussed on alleviating the bottlenecks posed by the scarcest resources.

Weak sustainability

This resource optimism is reflected in a paradigm of sustainable development, called 'weak sustainability' (Hartwick, 1977; Solow, 1974a, 1993). It is assumed that the welfare of future generations can be secured because there is full substitutability of natural capital and that the depletion of natural resources can be compensated via investments in other forms of capital.

Decoupling

Within this neoclassical system of the economy-environment relationship, relative decoupling of economic growth from pollution is possible with increased efficiency (Jackson, 2009). Economic growth can help reduce pollution if it accelerates resource productivity at a faster rate than both resource consumption and population growth. In his well-known book, *In Defence of Economic Growth*, Beckerman (1974, cited in Porritt, 2005: 59), argues that 'in the longer run, the surest way to improve your environment is to become rich'. In a free market society, producers will try to minimise their costs by improving resource efficiency. The more efficient use of resources will lead to relative decoupling (a decrease in environmental intensity per unit of economic output). A thorough analysis of ways to achieve absolute decoupling, however, is much more difficult, if not impossible, to find in the neoclassical economics literature. For a detailed discussion of the decoupling concept see Section 4.2.

Effect of macroeconomic factors on sustainable development

The neoclassical theory thus concludes that, due to substitution and technical progress, consumption can be sustainable even if production is dependent on natural capital that is being depleted. Consumption can be sustained forever, at a certain level, when production depends on a renewable resource. Sustainable economic development is possible if potential resource growth is higher than the sum of the discount rate minus the rate of exogenous technical progress and if resource productivity is sufficiently high. The possibilities for sustainable economic development are also influenced by the initial levels of environmental quality and man-made capital. Finally, neoclassical economists do recognise that optimal consumption and extraction are lowered if the resource stock itself affects utility, or if irreversibilities occur. Irreversible transformations of the environment may restrict resource utilisation and economic development. The expected net benefits of an irreversible decision must be adjusted to reflect the loss of choices which results.

Coase theorem and Pigouvian policies

Every standard environmental economics text advocates two approaches to environmental policy: the Coasian assignment of property rights and the Pigouvian application of taxes and subsidies. Both approaches are based on the standard assumptions of neoclassical economics and arise from the attempt to place monetary values on the surpluses forgone when markets are missing (environmental valuation). As described in Section 2.2, both Coase and Pigou designed allocation systems capable of realising these foregone surpluses. The same logic led to the rules on optimal depletion of renewable and non-renewable resources.

Pigou (1920) thoroughly analysed the externality problems and devised a solution known as Pigouvian tax. In theory, the tax, which is paid by the polluter, should be equal to the marginal external cost born by those who suffer from the pollution. The polluter is thus informed about the full social (regional and global) cost of his operations.

Coase (1960), by contrast, suggests that the efficient solution to the misallocation problem is independent of the initial assignment of property rights to use the common environment. According to the Coase theorem the optimal allocation of resources among individuals, who can freely bargain at no cost, should be independent of the initial assignment of property rights. If the parties behave rationally, abatement will be undertaken as long as its costs are justified in terms of benefits. Thus, there are 'optimal levels of pollution'. The optimal level of a pollution emission occurs when the marginal damage created by the emissions is equal to the marginal cost of reducing the emissions.

Ecological economic analyses of sustainable environmental development

In its analyses of the environment, ecological economics builds on some of the concepts of neoclassical theory, while attempting to overcome some of its main limitations. The thrust of ecological economics is the idea of limited substitutability of natural capital. As a result of their metrics and assumptions, ecological economics models may give more value to the maintenance and enhancement of stocks of natural capital, economies based on restoration, regeneration, and adding value to natural resources. In modelling the relationship between the economy and the environment, ecological economics emphasises the 'evolutionary nature of the system' and generally takes a sceptical view on general equilibrium models. Instead of letting prices determine what will be produced and how much, ecological economists have long been suggesting a focus on 'ecologically right quantities', letting prices adjust accordingly.

Limits to economic growth

The scale and growth of total throughput are the major causes of environmental degradation (Daly, 1996). If economic growth is not decoupled from growth in physical production in an absolute sense, it is not solving environmental problems but may in fact be worsening them – 'the myth of sustainable growth' (Porritt, 2005). As Ekins (2000) points out, 'growth in physical production and throughput that is not based on solar energy must increase entropy and make environmental problems worse'. This implies an eventual limit to such growth. The Gross National Product can free itself from these limits only to the extent that it 'decouples' itself from growing physical production.

This issue was first and most prominently described by Meadows et al (1972) in their Report to the Club of Rome *Limits to Growth*. The authors used the World3 model to simulate the consequences of finite resource supplies and a growing world population. The report attracted controversy from the beginning. Many mainstream economists were critical on the report's approach and conclusions. Robert M. Solow, for instance, complained about the weak data base on which predictions were made (Newsweek, March 13, 1972. 103). Advocates of the report point out that even though the role of the price mechanism was probably underestimated, critics have overestimated it (eg Victor, 2008) and that the prediction that the world will run out of oil and other natural resources was extrapolated out of context by critics. An updated and expanded version was published under the name *Limits to Growth: The 30-Year Update* in 2004.

Ecological economists maintain that indefinite growth is unrealistic for several reasons. For instance, rising demand for natural resources, and related resource scarcities and the consequences of anthropogenic interventions such as climate change, could restrict growth in the medium term. Even if technical solutions were found to counteract environmental change, there are other factors that put limits on ongoing economic growth. Many authors name social factors as restrictive to future growth. As far back as 1977, Hirsch suggested that high consumption could decline after having reached a certain point. Economic growth also has certain limits that are inherent to the system. Empirical studies show that, not exponential but, linear growth is the normal case in developed economies (eg Bourcarde and Herzmann, 2006).

Analysing the overall impact of economic productivity increases on the environment with physical metrics has revealed the importance of rebound effects. Ecological economists have found that any additional environmental space created by increased resource efficiency is immediately offset by additional consumption (for examples see Barker et al, 2009, Stocker et al, 2007). Some therefore conclude that the economy should be adjusted by qualitative development, not quantitative growth. As natural resources may act as inputs into the production process, a steady state may be seen as specific type of sustainable development in which the availability of natural resources determines the physical size of the economy (Daly, 1973) (described in more detail in Section 2.6).

Strong sustainability

Ecological economists reject the assumption that capital can substitute for resources because there are certain functions that the environment performs that cannot be duplicated by humans (this concept is called 'strong sustainability'). The ozone layer, for example, cannot have a monetary value as it provides an ecosystem service that is difficult for humans to duplicate. Strong sustainability has two main schools of thought. One requires the preservation of the value of natural capital. The other one requires that the subset of total natural capital, which consists of assets that are irreplaceable and cannot be substituted by anything else, should be preserved in physical terms so that its core functions remain intact. Examples of such 'critical natural capital' include biological diversity, the ozone layer, and the carbon cycle. In both interpretations of strong sustainability, the size of the economy relative to the ecosystem is important. Thus, scale is a major concern in ecological economics.

Daly suggests three broad criteria for ecological sustainability, two for the inputs side and one for the output side (Daly 1989):

- renewable resources should provide a sustainable yield (the rate of harvest should not exceed the rate of regeneration)
- to the same extent as non-renewables deplete, there should be equivalent development of renewable substitutes
- waste generation should not exceed the assimilative capacity of the environment

Decoupling economic growth and environmental impact

Ecological economists argue that environmental constraints imply limits on economic scale and thus limits to growth (see Section 2.6). They are sceptical about the possibility to dramatically change technologies, investment and consumption patterns in a way that decouples economic growth from environmental impact (Jackson, 2009; Pirgmaier 2008). Victor (2008) argues that changes in the composition of GDP (such as a shift from goods to services) and technological progress are not likely to solve the problems of the overuse of natural resources, sinks and services. For example, the probability of achieving carbon emission reduction targets is very much increased by a slower increase in the scale of the global economy.

A detailed discussion of the decoupling concept is presented in Section 4.2.

A short critique of the Coasian and Pigouvian approaches

Both the Coasian and the Pigouvian approaches to environmental policy have been strongly criticised and shown to have limits in actual application. Evidence from experimental economics suggests that the Coase theorem of optimal allocation is misleading in separating distribution and allocation issues (Kahneman et al, 2004). When making choices, individuals tend to place a higher value on things already in possession ('the endowment effect') (Thaler, 1980). This is also reflected in the common phenomenon of 'loss aversion', where people are more averse to taking a loss than to enjoying an equal gain (Kahneman and Tversky, 1979). These results confirm the ecological economists' position that allocation and distribution cannot be separated from each other.

Empirical evidence also fails to support the behavioural assumptions of Pigouvian models. The success of the resulting polices depends on rational and well-informed actors who are able to respond to price incentives in consistent and predictable ways. The effect of monetary incentives on behaviour, however, is sometimes mixed and perverse. For example, paying people to do an act that is done voluntarily due to social norms has been shown to result in a decline of the amount of the social good provided. Awards (or penalties) may actually have an opposing (or reinforcing) influence on intrinsic motivation.

This calls into question the relative importance of 'getting the prices right' in environmental policy over potentially more effective non-price adjustments. For example, rather than assume exogenous preferences that respond in predictable ways to price signals, some economists have begun to stress the pervasiveness of endogenous preferences and the importance of an individual's personal history, interaction with others, and the social context of the individual choice.

Last, but not least, the notion and calculation of 'optimal levels of pollution' has been strongly criticised. Farmer et al (2001) argue that the definition of benefits from pollution is too narrowly defined in the neoclassical theory. They suggest including at least three other sources of benefits. First, they develop a game-theoretic model in which firms may under-invest in cost-saving 'green technologies'. Second, they demonstrate that consideration of future damages and abatement costs leads to a lower current optimal pollution level than that obtained in conventional models. Finally, they show that ecological complexity creates indirect pathways by which greater pollution increases the likelihood of generating irreversible environmental damage. This broader definition of the benefits of pollution abatement yields an optimal level of pollution that may be lower than the level at which conventionally-measured marginal damages are equal to marginal abatement costs. They therefore conclude that environmental policy should be stricter.

2.5 Links between the economy and social sustainability

The scope of this literature review does not permit an extensive review of the literature on the social aspects of sustainability but it is acknowledged that there are important interactions. This section will focus on two important dimensions, employment and equality, in an attempt to answer the question: To what extent does economic growth impact on employment and equality, and vice versa?

Equality and redistribution

Equality is hardly ever seen as a central issue in macroeconomic theories, and theories of redistribution are marked by their absence – with considerable effects on policies. For example, Coasian policy approaches tend to abstract from equity issues, as they are based on the idea that efficiency gains can be obtained independent of the allocation of property rights, and that equity should be addressed not by environmental policy but by income policy. From this perspective, the aggregate gains and losses by different economic agents are more important than their distribution in society. Yet, as the levels of equality influence the level of well-being and growth, it may be useful to accord more importance to this issue.

The most commonly used approach in economics to refer to equality is income (in)equality. This concept describes the extent to which income, expressed between households, individuals or all individuals, is distributed in an (un)even manner. The two widely used measures for income inequality are the Lorenz curve and the Gini coefficient. The Lorenz curve describes the proportion of national income earned by any given percentage of the population; if income were distributed totally equally, the Lorenz curve would be a straight 45° line. The Gini coefficient is a way of measuring the position of the Lorenz curve. It is a ratio between zero and one, where total income equality is zero and total inequality is one (Sloman, 1997).

A widespread theory to describe the relationship between income inequality and economic development over time was developed by Simon Kuznets in 1957. The inverted U Kuznets curve illustrates that economic inequality increases throughout the early stages of a country's development before it begins to decrease after a certain average income is attained. The Kuznets hypothesis has caused both agreement and critique. Fields (2007) highlights that about 10% of country cases are consistent with Kuznets' inverted-U, another 10% support an ordinary U, and the remaining 80% exhibit no statistically significant tendency at all. He concludes that what matters for inequality is not the rate of economic growth of the level of national income but the type of economic growth (Fields, 2007).

Links between inequality and economic growth

Despite extensive literature on the effects of inequality on growth, this remains a topic of considerable controversy. While there are theories in which economic inequality has a positive effect on economic growth, there are also plenty of others in which the effect is negative (Fields, 2007). The international empirical evidence shows an equally ambiguous picture. Different cross-country empirical studies arrive at different conclusions on this issue, even when using relatively similar data sets. For instance, Sukiassyan (2007) highlights that Alesina and Perotti (1996), Perotti (1996), and Persson and Tabellini (1994) come to significant negative effects of income inequality on subsequent economic growth and that Forbes (2000), and Li and Zou (1998) find a positive relationship. Barro (1999) shows little overall relation between income inequality and rates of growth by evidence from a broad panel of countries. However, there is an indication that inequality retards growth in poor countries but encourages growth in well-developed countries. Cornia et al (2001), Sukiassyan (2007) and Fields (2007) come to analogous conclusions. The results suggest that the relationship between inequality and growth is likely to vary across samples.

Even though economic theory is ambiguous, many economists argue that redistribution measures weaken growth by undermining incentives. This approach rests on a separation between income growth and income distribution. It is assumed that growth and redistribution happen independently from each other, which implies that growth can be pursued by certain policies, while distribution is adjusted by a different set of redistributive policies. As a consequence, how distribution changes critically depends on the policies that are used to achieve growth. According to the new economics foundation, an ecological economists' think tank, the key question therefore is not whether growth affects distribution or vice versa but how distributional effects could be integrated into the design of economic policies as a whole (nef, 2006).

Recent OECD data provide evidence of a moderate but significant increase in income inequality over the past two decades across the OECD, although the intensity and causes vary between countries. A key message is that what matters is not just income but also factors such as access to public services, including health and education. In other words, equality of opportunities matter more than equality of outcomes (including income) and achieving greater equality of opportunity goes hand-in-hand with more equitable outcomes in practice (OECD, 2008).

Inequality and social development

In a groundbreaking book, Wilkinson and Pickett (2009) comment on thirty years of research using reputable sources such as the United Nations, the World Bank, the World Health Organisation and the US Census. They found that more unequal societies have negative effects for almost everyone within them, including the well-off as well as the poor. Almost all of the identified social issues, and several environmental ones, (including community life, social relations, mental health, life expectancy, obesity, education, teenage births, violence, social mobility and consumerism) were found to be more likely to occur in a less equal society. Gradients show a strong correlation between income inequality and these social outcomes (Wilkinson and Pickett, 2009).

Whether the current level of distribution is desirable or not is ultimately a normative question, dependent on different government policies.

Employment

Besides earning income, employment means participation in society, community, contacts, respect, self-esteem and recognition (Ax, 2009). It therefore importantly contributes to people's well-being. Consequently, un- and underemployment have many negative effects, such as contributing to the prevalence of family breakdown, substance abuse, alienation, discrimination, psychological disorders, suicide and criminal activity (Lawn, 2009). Unemployment also causes a rise in anxiety and depression, a loss of confidence and a reduction in self-esteem and the level of general happiness.

Links between employment and economic growth

Economic growth plays a central role in delivering employment. Conversely, the absence of economic growth causes high rates of unemployment. A look into the relationship between growth and employment is therefore crucial in order to better understand the real-world links between the macroeconomy and social sustainability.

The co-movement of output and unemployment was put into a numerical relationship for the first time by Arthur Okun. The relationship became known as Okun's Law, saying that for every two percent that actual GDP falls relative to potential GDP, the unemployment rate rises about one percent (Samuelson/Nordhaus, 2001). This means that actual output has to grow faster than potential output (ie faster than productivity growth) in order to decrease unemployment. Recent literature has focused on possible asymmetries in Okun's Law (Holmes/Silverstone, 2006). Empirical data for 1961-

2000 show that the average correlation between GDP growth and unemployment is weaker than supposed by Okun's Law and changes both from country to country and over time (Khemraj et al, 2006).

These economic factors might cast faster economic growth as a problem solver for unemployment into doubt. 'Green jobs' are increasingly seen as win-win opportunity for both increasing employment and decreasing environmental impacts. The environmental sector could foster economic growth as it is often more labour-intensive than other sectors (GHK, 2009). But there are two reasons for scepticism: first, the capability of 'green jobs' to compensate or even overcompensate the loss of jobs in environmentally destructive industries is questioned (Lawn, 2009). Second, economic growth based on the creation of 'green jobs' might still be ecologically unsustainable.

Therefore, other ways to reduce unemployment are also considered, such as increasing the number of jobs through a reduction in working hours (Spangenberg et al, 2002). Besides the 'classical ways' like reducing the standard weekly hours or increasing the amount of leave days, the discussion about the introduction of a basic income must be mentioned (Jackson, 2009), which would take off some working pressure from the employees and in that way could reduce working hours in a voluntary way. Additionally, a shift to more labour-intensive industries creates employment, eg from production to maintenance and repair, or a strengthening of other labour-intensive sectors, such as education and care, through measures like reducing the number of students per class or of care patients per care giver.

Quality of jobs

Besides quantitative aspects, the question about the relationship between economic growth and the quality and type of work is raised. Within the last decades types of work differing from the standard employment relationship have increased, including temporary employment, part-time and low-paid employment. This can lead to the phenomenon of the so-called 'working poor' and can make the mental well-being suffer (Buczko et al, 2010). There are several approaches for a holistic description of quality of work, for example the EU in 2007 has put up a list of five factors: fair wages, protection against health risks at work, workers' rights to assert their interests and to participate, family-friendly working arrangements and enough jobs (EC, 2008). The investigation of job quality in European countries showed that high job quality has a positive influence on the unemployment rate and on productivity (EC, 2008).

2.6 Towards a macroeconomic picture of sustainability

In this section we consider which first approaches for a macroeconomic framework for sustainability already exist. We then review what the different schools of economic thought suggest on how to change the main macroeconomic factors in order to achieve sustainable development.

The current debate on how to overcome the ecological crisis and economic recession can broadly be categorized into two strands: those who think that we must very rapidly stimulate economic growth (that they call 'green') and those who consider that we must take advantage of the crisis to put an end to the cult of growth and propose another vision of progress and prosperity, with an orientation of moderate consumption levels and greater equity.

Mainstream macroeconomic theory

Mainstream economists follow the first route as macroeconomic theory is profoundly oriented towards an assumption of continuous, exponential, GDP growth. Disruptions in economic activity, such as expansions and recessions, are perceived as deviations from the standard conception of a long-term stable macroeconomic growth path. Neoclassical economics has, as we have already discussed, generally rejected the concept of limits to growth. Areas in which ecological capacities are evidently being overused, such as declining fish stocks or biodiversity loss, have been accepted as significant problems, but are usually not seen as serious threats to the continuation of global economic growth. What has to be achieved is to 'get the prices right' in order to fully internalise external costs and to decouple economic growth from negative environmental impacts. Economic growth is seen as a prerequisite for achieving rapid changes in energy technology and industrial patterns, leading to a development in which economic performance and environmental impact is no longer interlinked. Following this logic, a new approach for a macroeconomic framework for sustainability is not needed, as adapting the existing approach is enough to achieve sustainable development.

First approaches for a new macroeconomic framework

On the other hand, ecological economists argue that environmental constraints imply limits on economic scale and thus limits to growth (see Section 2.3). They are sceptical about the possibility to dramatically change technologies, investment and consumption patterns as a way to decouple economic growth from environmental impact. Consequently, new approaches for a different macroeconomic framework have to be elaborated. In the following paragraphs we present three examples for working towards this goal.

A steady state economy (SSE)

The notion of the 'stationary state' economy dates back to John Stuart Mill's *Principles of Political Economy* (chapter VI of Book IV) in 1888. Therein, Mill describes the impossibility of ultimately avoiding the stationary State. This is, however, not an unpleasing and discouraging prospect, but 'a very considerable improvement on our present condition' as a stationary condition of capital and population does not imply a stationary state of human improvement and social progress:

'If the earth must lose that great portion of its pleasantness which it owes to things that the unlimited increase of wealth and population would extirpate from it, for the mere purpose of enabling it to support a larger, but not a better or a happier population, I sincerely hope, for the sake of posterity, that they will be content to be stationary, long before necessity compel them to it.' (Mill, 1888: 2.).

Herman Daly, former Senior Economist at the World Bank has done more than anyone to advocate 'steady state' economics. He defines a SSE as 'an economy that maintains a constant metabolic flow of resources from depletion to pollution: a throughput that is within the assimilative and regenerative capacities of the ecosystem' (Daly, 2010). It is a system that permits qualitative development but not aggregate quantitative growth. 'Growth is more of the same stuff; development is the same amount of better stuff (or at least different stuff)' (Daly, 2008: 1).

For Daly, economic growth already has become uneconomic as the quantitative expansion of the economic system increases social and environmental costs faster than production benefits, making people poorer rather than richer. Ecological economists have offered empirical evidence for uneconomic growth in high consumption countries (some examples are Ecological Footprint, ISEW, GPI, Happy Planet Index, see Section 3.4 for further details).

Daly's main point of critique refers to the absence of any notion of optimal scale in macroeconomics. Scale has become important because the economic system has grown to a point where its physical demands on the ecosystem are far from trivial. Macroeconomic theory has disregarded scale in two ways: first, by assuming that environmental sources and sinks are infinite relative to the scale of the economy. Second, by assuming that scale is total rather than infinitesimal, ie that nature is just one more sector in the economy and that all micro-allocative decisions for each resource includes the in natura use among the set of alternative uses. Given these assumptions, there is no separate macro issue of scale, and no policy instrument needed to manage scale (Daly, 1992).

Alongside optimal scale (sustainability), Daly concludes that, for any model to work, allocation (efficiency) and distribution (justice) are equally important. These three parts shape the fundamental economic problem.

Just like Mill, Daly believes that society would benefit from establishing a SSE before it is inevitable. He puts forward ten specific policy proposals for moving to a SSE (Daly, 2010):

1 Cap-Auction-Trade Systems for Basic Resources

2 Ecological Tax Reform

3 Limit the Range of Inequality in Income Distribution

4 Free Up the Length of the Working Day, Week, and Year

5 Re-Regulate International Commerce

6 Downgrade the IMF/WB/WTO

7 Move Away from Fractional Reserve Banking Toward a System of 100% Reserve Requirements

8 Stop Treating the Scarce As If It Were Non-Scarce, but Also Stop Treating the Non-Scarce As If It Were Scarce

9 Stabilize Population

10 Reform National Accounts

Daly explains that, while these policies might appear radical, it is worth remembering that they are amenable to gradual application. Also, they are based on the conservative institutions of private property and decentralized market allocation.

LowGrow – a macroeconomic model for the Canadian economy

The Canadian economist Peter Victor designed the interactive systems model 'LowGrow' of the Canadian economy to specifically answer the question: can we have full employment, no poverty, fiscal balance, and reduced greenhouse gas emissions without relying on economic growth? Figure 2.8 shows the simplified structure of LowGrow.

The model is based on standard economic theory and practice. Aggregate demand (GDP, shown as Y) is determined in the normal way as the sum of consumption expenditure (C), investment expenditure (I), government expenditure (G), and the difference between exports (X) and imports (M). The model includes separate equations for each of these components that are estimated with Canadian data from 1981 to 2005. Macro Supply, shown at the bottom of Figure 2.8, is estimated by a Cobb-Douglas production function, in which output (GDP) is a function of employed labour (L), employed capital (K) and a time variable (t) that represents changes in productivity. Population is an exogenous variable based on a selection of one of three projections from Statistics Canada. It is also one of the variables that determines consumption expenditures. The labour force is estimated as a function of GDP and population. The model keeps track of the overall fiscal position by calculating total revenues and expenditures, and estimating debt repayment based on historical data. Fiscal policies that can be simulated include a balanced budget and counter-cyclical expenditures. While LowGrow lacks some features (eg for simplicity there is no monetary sector in the model), it includes others that are extremely useful in exploring low or no-growth scenarios such as carbon dioxide and other greenhouse gas emissions, a carbon tax, a forestry sub-model, provision for redistributing incomes and the UN's Human Poverty Index etc.

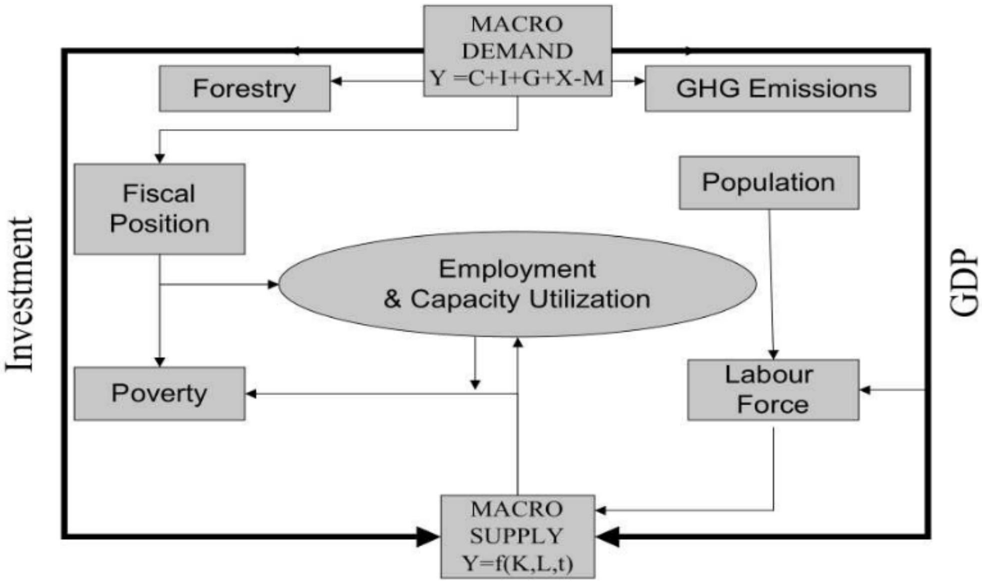
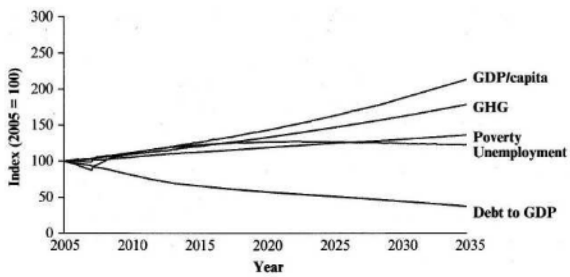


Figure 2.8 High Level Structure of LowGrow

Source(s): Victor (2008: 171).

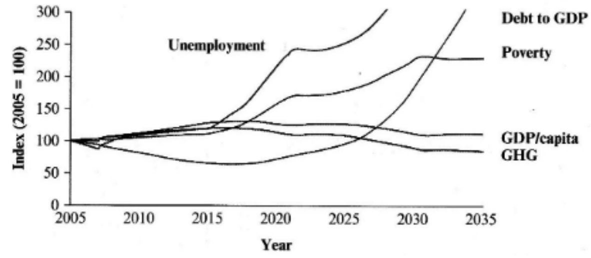
In the LowGrow model, economic growth is determined by six variables: growth in population, growth in the labour force, growth in the trade balance, growth in government expenditures, net investment which adds to productive assets, and increases in productivity. By reducing the rates of increase in various combinations of these factors, low and no-growth scenarios can be described. Peter Victor explores six such scenarios until 2035 in his book *Managing Without Growth*:

- Scenario 1 – Business as Usual (BAU) is a projection of the Canadian economy. It assumes that the economy will perform on average from 2005-2035 in much

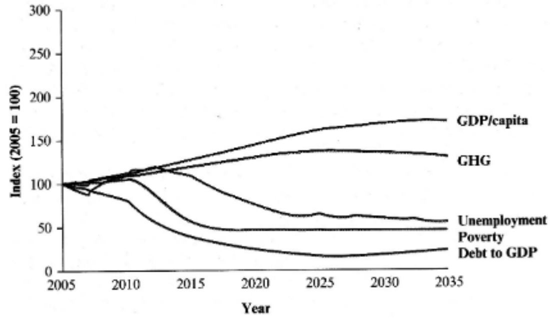


the same way as it did in the last 25 years.

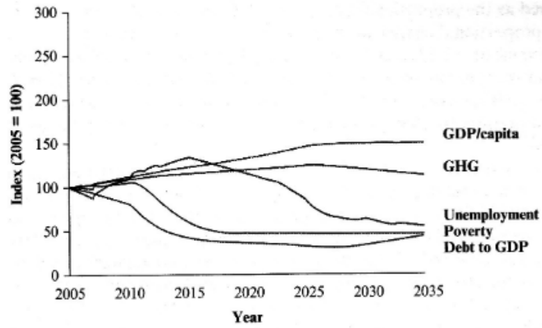
- Scenario 2 – A No-Growth Disaster shows that by reducing all growth variables to zero, unemployment, poverty and the government's debt/equity ratio rise sharply to unbearable levels.



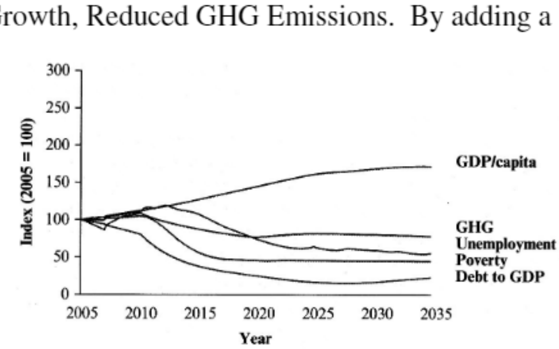
- Scenario 3 – Low Then No Growth with High Investment maintains a fairly high level of investment expenditures. Investment is reduced in comparison to the BAU scenario but not to zero (as in scenario 2). A decline in the average working week reduces unemployment and poverty. Scenario 3 is far more attractive than the previous no-growth scenario. GDP per capita rises more slowly than in the BAU scenario until 2030 and then levels off.



- Scenario 4 – Low Then No Growth with a Higher Trade Balance: here investment is reduced more than in scenario 3 and the trade balance is reduced less compared to the BAU scenario. The difference to scenario 3 is that GDP per capita levels off several years sooner and GHG emissions end up 14% greater in 2035 than in 2005. The outcomes for employment, poverty reduction and leisure are nearly the same in both no-growth scenarios.



- Scenarios 5 and 6 – Low Then No Growth, Reduced GHG Emissions. By adding a carbon tax on energy-related greenhouse gas (GHG) emissions of $200 per tonne GHG (CO2 equivalent) all benefits of scenarios 3 and 4 can be obtained plus a reduction of GHG emissions from all sources of 22% for scenario 3 and of 31% for scenario 4 (not shown) by 2035 compared with 2005.



The numerical results of all six scenarios are summarised in Table 2.1.

Table 2.1: Summary of scenario results for 2035

Variable	Units	Base Year 2005	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
GDP/Capita	Index	100	213	111	169	148	169	148
Unemployment	Index	100	122	358	56	56	56	56
Deb/GDP	Index	100	36	331	48	48	48	48
HPI	Index	100	136	230	46	46	46	46
GHG	Index	100	177	86	130	114	78	69
GDP/Capita	million 97$	35053	74493	39000	59132	51873	59132	51873
Unemployment	per cent	7.2	8.8	25.7	4.0	4.0	4.0	4.0
Deb/GDP	per cent	62.1	22.1	205.7	29.8	30.0	29.8	30.0
HPI	per cent	10.7	14.6	24.6	4.9	4.9	4.9	4.9
GHG	mtonnes CO_2 eq	747	1323	645	974	854	584	512
Consumption	per cent	57.0	58.6	59.2	58.1	58.0	58.1	58.0
Investment	per cent	19.6	19.2	13.1	18.7	12.2	18.7	12.21
Government	per cent	21.7	20.3	27.7	22.9	24.4	22.9	24.4
Trade Balance	per cent	1.8	1.9	0.0	0.3	5.4	0.3	5.4

Notes:
Scenario 1 Business as usual
Scenario 2 No growth 'disaster'
Scenario 3 Low then no growth, high investment, low trade
Scenario 4 Low then no growth, low investment, high trade
Scenario 5 As 3, with GHG tax
Scenario 6 As 4, with GHG tax
Values are for the start of the year

By simulating a variety of scenarios for the Canadian economy (see above), Victor (2007, 2008, 2008a) tried to close a gap in the growth-sceptical literature, which had not worked with such a model before. He shows that 'no growth' can be catastrophic if not implemented carefully, leading to disastrous results, including exploding unemployment and debt, strongly increased poverty and only a slight positive effect of reduced GHG emissions. But he also demonstrates that slower growth (leading to stability around 2030) can be consistent with attractive economic, social and environmental outcomes: full employment, fiscal balance, considerable reduction in greenhouse-gas emissions, near elimination of poverty, and more leisure. The difference between the scenarios is striking and the question emerges as to what makes the difference. The answer is that the better no or low-growth scenario(s) result from a wide range of policy measures. In summary these policy measures include (Victor 2008):

- **Investment:** reduced net investment, a shift from investment in private to public goods through changes in taxation and expenditures.
- **Labour force:** stabilization through changing age structure of the population and population stabilization.
- **Population:** stabilization through changes to immigration policy.
- **Poverty:** trickle down replaced with focused anti-poverty programmes that address the social determinants of illness and provide more direct income support.
- **Technological change:** slower, more discriminating, preventative rather than end of pipe, through technology assessment and changes in the education of scientists and engineers.
- **Government expenditures:** a declining rate of increase.
- **Trade:** a stable, positive net trade balance (and diversification of markets).
- **Work week:** shorter, more leisure through changes in compensation, work organization and standard working hours, and active labour market policies.
- **Greenhouse gases:** a revenue neutral carbon tax.

To complement these policies:

- **Consumption:** more public goods and fewer positional (status) goods through changes in taxation and marketing.
- **Environment and resources:** limits on throughput and use of space through better land use planning and habitat protection and ecological fiscal reform.
- **Localization:** fiscal and trade policies to strengthen local economies.

Victor explores the macroeconomic aspects of managing without growth in a rich country. His scenarios show the possibility of achieving positive results for the main social, economic and ecological policy goals without ongoing economic growth in a macroeconomic model. They therefore foster the challenging of economic growth as a self-contained policy goal. Victor is currently working on further elaborating the LowGrow model.

Prosperity without Growth

The UK Sustainable Development Commission launched the project 'Redefining Prosperity' to look into the connections and conflicts between sustainability, growth, and well-being. After a two year work programme including commissioned thinkpieces, organised seminars, and invited feedback, the results were compiled in the report *Prosperity without Growth?: the transition to a sustainable economy* by SDC's Economics Commissioner Tim Jackson. One of the most important messages from his analysis is the call for a robust macroeconomics for sustainability. Jackson highlights that a different kind of macroeconomics that does not rely on ever-increasing consumption growth and that remains within ecological scale is urgently needed but that virtually no attempts have been made to develop an economic model that does not rely on growth. He refers to Daly's pioneering work to develop the ecological conditions for a SSE, but criticises the missing ability to establish economic stability under these conditions. As the most notable exception he mentions the work being done by Peter Victor who shows that even in a rather conventional macroeconomic framework, a new macroeconomics for sustainability is not only meaningful but also possible.

Jackson concludes by proposing twelve steps towards a sustainable economy that fall into the three broad categories: 'building a sustainable macroeconomy', 'protecting capabilities for flourishing' and 'respecting ecological limits' (see Box 2.2).

Recent developments

Ecological economists have been pointing towards the unsustainability of the current growth paradigm given the limits imposed by ecological boundaries. However, since Herman Daly first called for an environmental macroeconomics, there has been little progress on this issue. Ecological economists have focused on developing alternative macroeconomic indicators and have only more recently started addressing macroeconomic relationships and developing an alternative macroeconomic framework. However, the issue of combining ecological and macroeconomic thinking is strongly gaining momentum among ecological economists. The Vienna University of Economics and Business, for instance, launched a scientific workshop series on the topic of ecological macroeconomics. The first workshop took place on 11 December 2009, including a presentation from Peter Victor (see above) and the second one was held on 25/26 May, including a presentation by Tim Jackson (see above)[8].

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[8] For more information, please visit http://www.wu.ac.at/ruw/allgemeines/EcologicalMacroeconomics

Box 2.2: Steps to a Sustainable Economy

Building on a sustainable macro-economy

Debt-driven materialistic consumption is deeply unsatisfactory as the basis for our macro-economy. The time is now ripe to develop a new macro-economics for sustainability that does not rely for its stability on relentless growth and expanding material throughput. Four specific policy areas are identified to achieve this:

- developing macro-economic capability
- investing in public assets and infrastructures
- increasing financial and fiscal prudence
- reforming macro-economic accounting

Protecting capabilities for flourishing

The social logic that locks people into materialistic consumerism is extremely powerful, but detrimental ecologically and psychologically. A lasting prosperity can only be achieved by freeing people from this damaging dynamic and providing creative opportunities for people to flourish – within the ecological limits of the planet. Five policy areas address this challenge:

- sharing the available work and improving the work-life balance
- tackling systemic inequality
- measuring capabilities and flourishing
- strengthening human and social capital
- reversing the culture of consumerism

Respecting ecological limits

The material profligacy of consumer society is depleting natural resources and placing unsustainable burdens on the planet's ecosystems. There is an urgent need to establish clear resource and environmental limits on economic activity and develop policies to achieve them. Three policy suggestions contribute to that task:

- imposing clearly defined resource/emissions caps
- implementing fiscal reform for sustainability
- promoting technology transfer and international ecosystem protection

Source(s): Jackson (2009: 13).

The first workshops explored the following questions:

- How dependent are current societies on economic growth for their well-being and social cohesion? How are productivity improvements, economic growth, and energy use interconnected?
- Under what conditions is sustainable development compatible with full employment? What kind of distribution of income is necessary on a global and national scale? How can this be achieved? What role does a reduction of working hours play?
- What role does the monetary system play in making economies dependent upon continued growth? In what ways could it change to facilitate the transition to a sustainable economy?

- What role does energy play in driving productivity improvements and economic growth? How can this better be reflected in macroeconomic models?
- Macroeconomic models measure success by a set of indicators of which GDP is most important. How would success be measured in ecological macroeconomics? How can ecological limits be included in macroeconomic models?

Thus, steps are being made in building an ecological macroeconomics.

2.7 Summary

Macroeconomics looks at the performance of the overall economy. How the macroeconomy and macroeconomic factors and their general conditions are examined varies in different schools of economic thought. This literature review has provided an overview of how economic theory in the traditions of neoclassical economics and ecological economics value the environment and the services it provides. These two schools were chosen because neoclassical economics comes closest to representing the current mainstream view, and ecological economics is the only sub-discipline of economics that applies concepts and methods of both economics and ecology to the various challenges surrounding sustainable development.

The neoclassical school of thought

Many of the existing models reviewed in this study (in Chapter 3) are derived from neoclassical or environmental economics and general equilibrium theory. This means that they typically have a focus on economic relationships, with environmental factors considered as external to the economic system. Where external factors are included in the modelling framework they are often assigned monetary values.

The ecosystem is theorised as a subsystem of the economy whose main functions are extraction and waste disposal. The environment's role is mainly limited to microeconomics, based on the assumption that the internalisation of negative externalities through the price mechanism solves our ecological problems. Environmental problems are therefore not being dealt with on the macro level.

The depletion of stocks of resources and the existence of danger zones and thresholds in some environmental categories are largely ignored because it is assumed that there is high degree of substitution of natural resources with manufactured capital goods. This resource optimism is reflected in a paradigm of sustainable development, called 'weak sustainability'. It is assumed that the welfare of future generations can be secured because there is full substitutability of natural capital and that the depletion of natural resources can be compensated via investments in other forms of capital.

Mainstream macroeconomic theory is profoundly oriented towards the goal of continuous and exponential economic growth. The concept of limits to growth is rejected. Economic growth is seen as a prerequisite for achieving rapid changes in energy technology and industrial patterns. Neoclassical economists are thus highly optimistic about technological change and suggest that economic growth increases innovation and efficiency and thus helps to tackle environmental pressures. What has to be achieved is to 'get the prices right' in order to fully internalise external costs and to decouple economic growth from negative environmental impacts and steer the economy towards a sustainable pattern of growth.

From a neoclassical economics perspective, there is no need for a new macroeconomic framework for sustainability.

The ecological economics school of thought

Ecological economists emphasise that the economy is, in the first instance, a subsystem of human society which is itself, in the second instance, a subsystem of the environment. The economic system is not only embedded in the larger environmental system but also completely dependent on it as both a source of inputs and as a sink for the matter or energy transformations required by economic activity and constrained by the law of entropy.

Ecological economists reject the assumption that capital can substitute for resources because there are certain functions that the environment performs that cannot be duplicated by humans ('strong sustainability'). Treating the environment as an economic input factor which can be indefinitely substituted is perceived to result in a lose-lose situation for the economy and for the environment.

Scale matters in ecological economics. The main assumptions are that there is limited human scale related to the biosphere, that the economic processes are taking place within a finite biophysical universe and that the limited carrying capacity of the Earth sets limits to economic expansion.

Ecological economists argue that environmental constraints imply limits on economic scale and thus limits to growth. They are sceptical about the possibility to dramatically change technologies, investment and consumption patterns in a way that decouples economic growth from environmental impact. Ecological economists argue that changes in the composition of GDP (such as a shift from goods to services) and technological progress are not likely to solve the problems of the overuse of natural resources, sinks and services. Although resource intensities are steadily declining with economic growth in industrial economies (relative decoupling), it is much harder to find empirical evidence for overall reductions in resource throughput (absolute decoupling). Improvements in resource efficiency are often offset by increases in the overall scale of economic activity (rebound effects).

Ecological economists have long criticised the neoclassical theory for failing to take into account the limits of natural resources and eco-systems. They argue for a serious rethinking of standard economic assumptions and theories and for the creation of an alternative macroeconomic framework that explicitly includes the environment and its services to the economy. However, a comprehensive model which accounts for these relationships in the economy is still missing in the ecological economics school of thought. A standard macroeconomic theory for sustainability is marked by its absence. At the time of writing, many ecological economists are busy trying to fill this important gap in the literature.

Conclusions

Depending on whether a neoclassical or an ecological economics perspective is taken, different conclusions can be drawn on how the macroeconomy and macroeconomic factors affect sustainable development and vice versa. Ultimately, this choice is a question of conviction.

The investigation of assumptions of different economic theories, valuation methods and metrics used offer valuable insights for building models that simulate the relationships between the economy and the environment. In the following chapter, existing macroeconomic models dealing with economy-environment relationships using different assumptions and valuations are presented and discussed. Following on from that we pose the question of whether models account for the issues identified in the literature review and how we could account for them.

3 Identification of Existing Models

3.1 Introduction

Overview

In Section 2.1 macroeconomics is described as the study of performance, structure and behaviour of the economy as a whole. This principally concerns the generation of wealth and the allocation of wealth in society. Monetary units are typically used as a proxy for wealth and welfare, either in terms of GDP, household income or a similar measure. This chapter summarises the existing models (mainly defined as quantitative simulation tools, see below) that are used for economic or sustainability analysis in the EU.

The role of macroeconomic models

Unlike other scientific disciplines it is not usually possible to carry out real-world macroeconomic experiments. Macroeconomic models are therefore used as a proxy in policy assessment. Like all representative models, these are based on an underlying set of assumptions and exogenous inputs to provide a simplified version of reality that may be represented on a desktop computer. This usually implies that non-economic inputs are fixed, for example demographics and political factors but also the supply of environmental inputs and natural resources. Thus, as we shall show, the usual linkages are that economic activity is allowed to affect the environment but not vice versa.

Throughout most of this chapter our primary focus is on established and quantitative computer-based models, although we do also briefly consider the benefits offered by other types of model in Section 3.3. The analysis in this chapter draws heavily on the most recent version of the model inventory in the IA Tools database[9], which summarises the available models in terms of scope and coverage. We expand on this list to cover several additional (mainly non-European) models.

Following the approach used in IA Tools we divide the policy areas according to the EU's Sustainable Development Indicators (SDIs), as defined on the Eurostat website. The first of these is socio-economic development, but we find that many of the models in other policy areas also have economic components. Throughout this report we consider all of these models from a macroeconomic perspective looking at behavioural change, with a particular focus on linkages between the different policy areas.

Structure of this chapter

Section 3.2 provides a summary of the models that are formally defined in IA Tools and elsewhere. In Section 3.3 we discuss the underlying approaches and assumptions behind these models and how they link into the different economic schools of thought that were outlined in Chapter 2. We also consider the less formal modelling techniques that are often applied, including input-output analysis.

Section 3.4 addresses one of the most important aspects of this study, the links between the different aspects of sustainable development, as they are represented in existing model frameworks. This includes a summary of the links in existing models, but also the use of composite indicators to provide a single sustainability index.

Section 3.5 focuses on how the models are applied for sustainability analysis and our findings are summarised in Section 3.6.

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[9] http://iatools.jrc.ec.europa.eu/

3.2 Scope of the existing models

This section provides a summary of the main macroeconomic[10] models used for modelling the world economy, including a discussion of the links in these models to the EU's SDIs, which we use as the basis for defining our policy areas.

The Sustainable Development Indicators

The SDIs were set up to monitor the EU Sustainable Development Strategy, which was adopted by the European Council in 2001 and renewed in 2006 (Council of the European Union, 2006). The following paragraph is taken from Eurostat's web pages and summarises the indicator framework:

The SDI framework is based on ten themes, reflecting the seven key challenges of the strategy, as well as the key objective of economic prosperity, and guiding principles related to good governance. The themes follow a general gradient from the economic, to the social, and then to the environmental and institutional dimensions. They are further divided into sub-themes to organise the set in a way that reflects the operational objectives and actions of the sustainable development strategy.[11]

These themes provide a broad overview and are used as the basis of our analysis. Where there are important sub-themes that are represented by different modelling approaches, these are also considered separately. The full list, including the ten themes and the main sub-themes, is shown in Table 3.1.

For further details about the SDIs and linkages between the different themes, and treatments in environment-economy models, the reader is referred to Giljum and Polzin (2009) and the website of the INDI-LINK project[12].

TABLE 3.1: POLICY AREAS BY THEME

Theme	Sub-Theme
Theme 1: Socio-economic development	Economic development
	Innovation, competitiveness and eco-efficiency
	Employment
Theme 2: Sustainable consumption and production	Resource use and waste
	Consumption patterns
	Production patterns
Theme 3: Social inclusion	Monetary poverty and living conditions
	Access to labour market
	Education
Theme 4: Demographic changes	Demography
	Old-age income adequacy
	General government consolidated gross debt
Theme 5: Public health	Health and health inequalities
	Determinants of health
Theme 6: Climate change and energy	Theme 6a: Energy

[10] By macroeconomic we mean models that work at the macro level that cover and apply economic principals; the scope is by no means limited to pure macroeconomic analysis.

[11] http://epp.eurostat.ec.europa.eu/portal/page/portal/sdi/introduction

[12] http://www.indi-link.net

TABLE 3.1: POLICY AREAS BY THEME

Theme	Sub-Theme
	Theme 6b: Climate change
Theme 7: Sustainable transport	Transport growth
	Transport prices
	Social and environmental impact of transport
Theme 8: Natural resources	Theme 8a: Land use
	Theme 8b: Biodiversity
	Theme 8c: Oceans/ freshwater resources
Theme 9: Global partnership	Globalisation of trade
	Financing for sustainable development
	Global resource management
Theme 10: Good governance	Policy coherence and effectiveness
	Openness and participation
	Economic instruments

Coverage of policy areas

We define 13 different policy areas, based on the SDIs. Policy theme 6, climate change and energy, has been separated into two separate policy areas, as these are distinct strands of research. Theme 6a therefore corresponds to energy, while 6b relates to climate change. Policy theme 8, natural resources, has similarly been split into three policy themes, land use (now theme 8a, which includes agriculture and forestry), biodiversity (theme 8b) and freshwater resources (theme 8c).

Table 3.2 provides a summary of the policy coverage from a set of commonly used models, many of which have global focus. The main data source is the EC's IA Tools model inventory, supplemented by a UN database with global coverage. However, many other model inventories exist; examples include the JRC collection, the models included in the European Environment Agency's model inventory report (European Environment Agency 2008)[13] and a model inventory held by COMMEND, the Community for Sustainable Energy Analysis[14].

The models summarised in Table 3.2 (and described in more detail in Appendix A) cover a good range of the various policy themes, with a large majority specialising in socio-economic, climate change or energy analysis. The notation 'A' in Table 3.2 represents a main policy area, broadly defined as one which the model was designed to cover, while 'B' represents a secondary policy area or one that was defined at a later stage.

It should be noted that the coverage of an individual model is to a certain extent subjective[15] as inevitably some models fit parts of categories. We have tried to include only endogenous treatments in the list (for example almost all of the models use demographics as an exogenous input but this is not included). For Theme 6b we

[13] http://www.eea.europa.eu/publications/technical_report_2008_11

[14] http://www.energycommunity.org/default.asp?action=67

[15] In this report it is based on the judgment of the authors.

have only included models that consider the climate system, rather than just produce estimates of greenhouse gas emissions.

TABLE 3.2: COVERAGE OF POLICY AREAS

Model	Policy Theme											
	1	2	3	4	5	6a	6b	7	8a	8b	8c	9	10
Ecomod	**A**					**B**							
E3ME	**A**	**B**				**A**		**B**					
E3MG	**A**					**A**						**B**	
GEM-CCGT	**A**					**B**						**A**	
GEM-E3	**A**					**A**							
GINFORS	**A**	**B**				**A**							
GTAP	**A**					**A**						**A**	
MIRAGE	**A**											**A**	
NEMESIS	**A**					**A**							
PACE	**A**					**A**							
QUEST	**A**			**B**		**B**							
WorldScan	**A**					**A**						**A**	
EUROMOD			**A**	**A**									
IIASA Population Project			**A**	**A**									
PHEONIX				**A**	**A**								
CETAX	**B**			**A**									
ETA				**A**									
EcoSense					**A**				**A**				
MIASMA					**A**								
GAINS					**A**		**A**						
FAMOUS							**A**						
GENIE							**A**						
MAGICC							**A**						
MARKAL/TIMES/TIAM						**A**							
POLES						**A**							
PRIMES						**A**							
ASTRA	**B**					**B**		**A**					
T-REMOVE						**B**		**A**					
TRANS-TOOLS						**B**		**A**					
NEAC								**A**					
VACLAV								**A**					
GLOBIO										**A**	**B**		
WaterGAP											**A**		
CAPRI									**A**			**B**	
CLUE									**A**				
IMAGE							**A**		**A**	**B**			
WATSIM									**A**			**A**	
EFISCEN									**A**				
EU-FASOM									**A**				
AIM						**A**	**A**						
ASF						**A**	**A**		**A**				
ENTICE-BR	**B**					**A**							

TABLE 3.2: COVERAGE OF POLICY AREAS

Model	Policy Theme												
	1	2	3	4	5	6a	6b	7	8a	8b	8c	9	10
FAIR	A					A							
FUND	A						A						
G-CUBED	A											A	
GTEM	A					A			B		B		
ICLIPS	A					A	A						
IGSM	A					A	A						
IMACLIM						A							
MERGE	A					A	A						
GCAM						A	A		A				
OECD-GREEN	A					A							
Second Generation Model	A					A	A						
MESSAGE	A					A							
NIEIR Multi-purpose model						A							
VLEEM						A							
World Energy Model (WEM)						A							
LEITAP	A					A			A				
EU-Clue Scanner									A				
PAGE	B						A						

Notes: A = main policy area, B = secondary policy area. The policy themes are detailed in Table 3.1.

Policy areas not well covered

Policy areas that are not particularly well covered by the range of models described in Table 3.2 include sustainable consumption and production (Theme 2), social inclusion (Theme 3) and good governance (Theme 10). In the case of social inclusion, only one model has been identified, used in the IIASA Population Project. The model used in the project specifically focuses on analysis of the population and educational mix, so does not cover some of the other areas identified as part of the general social inclusion theme, for example monetary poverty and living conditions.

There are few models that can be used for the analysis of the sustainable consumption and production policy theme. Furthermore, for those models that can be applied, the theme is not their primary focus. For example, the E3ME and GINFORS models are both economy-energy-environment models, so their main policy areas of concern are socio-economic and energy policies. However, both do include a module for material consumption so can be used for analysis of some sustainable consumption and production issues.

Socio-economic development

There is a wide and diverse range of models that cover socio-economic policies, and in general the range of models includes analysis of the policy sub-themes; economic development, innovation, competitiveness and eco-efficiency and employment. Many of the models also cover secondary policy areas too. For instance, there are a large number of E3, energy-environment-economy, models which consider the interlinkages between these three areas of concern. The E3ME and GEM-E3 models look at these issues on a European level, while E3MG, GINFORS and PACE considers the interlinkages on a global scale. Other socio-economic models also focus on the analysis of global partnership policies, such as WorldScan, which looks at long-term issues in the world economy and links and spillovers between countries, while GEM-CCGT, G-CUBED and GTAP specifically focus on international trade policies.

Demographic changes

Population development is usually an exogenous input to other types of models, but the projections (for example those published by Eurostat[16]) are formed using modelling approaches. There are several models which analyse issues surrounding demographic changes. The PHOENIX model has been developed to provide analysis of long-term population development and can be used for comparing different demographic scenarios, fertility and mortality patterns.

The Euromod model is more focused in its analysis on estimating the distributional impact of changes in tax policy and evaluation of efficiency-equity trade offs in different types of welfare reform, amongst other things. It does this by calculating disposable income for each household in its dataset. The CETAX model is similar, in that it focuses on tax policies, but analyses the effects of policies on labour markets. ETA also considers tax policies by calculating and comparing tax burdens of different partnerships and corporations.

Public health

As well as demographic development, the PHOENIX model can be used in the analysis of general public health matters. The other models presented in the table that deal with public health issues are more focused on this area, and tend to consider the impacts of pollution or global atmospheric changes on human health. The EcoSense and MIASMA models are devoted to this type of analysis, whereas the GAINS model is focused on environmental emissions more generally, but has the capability to analyse the impacts of air pollution on human health.

Climate change & energy

There is a relatively large number of models concerned with climate change and energy policy, with many of them tying into other themes such as socio-economic development or public health policy. As already mentioned, there are several models which can be classified as E3 models as they consider the interlinkages between the economy, the environment and energy.

Many of the models focus explicitly on the climate change sub-theme and cover many different aspects of the issue. For example FAMOUS is a global model which can be used to create long-term climate change solutions. Meanwhile, the GENIE model is focused on long-term paleo-climate change and the future long-term response of the Earth to human activities. The MAGICC model is more focused in its investigation of future climate change, being mainly used to compare temperatures and sea levels. These are by no means the only climate change models in existence[17].

Some of the models consider climate change in a wider context; these are often referred to as Integrated Assessment Models. The AIM model is an example; it comprises three main models, the greenhouse gas emission model, the global climate change model and the climate change impact model, making it a very useful research tool for the analysis of climate change.

Other models focus specifically on energy markets. The PRIMES model simulates energy markets in the EU and calculates equilibrium prices for each energy source. The model is mainly used for the analysis of energy policy and energy-efficiency issues, as well as the analysis of environmental issues. Similarly, the POLES model

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[16] http://epp.eurostat.ec.europa.eu/cache/ITY_SDDS/en/proj_08c_esms.htm

[17] See Appendix A for further examples.

replicates the world energy system up to 2030 and is used to run world energy scenarios and the impact on emission levels. The MARKAL family of models carry out a similar analysis.

Yet another category of models, that includes PACE and E3ME, combines a bottom-up representation of the energy sector and its most important technologies (and also sometimes a more detailed disaggregation of energy-intensive industries) with the merits of a fully-specified economic framework. This disaggregation enables the user to distinguish energy goods by CO_2 intensity and the degree of substitutability. The model then features important CO_2 or energy-intensive industries which are potentially most affected by carbon abatement policies, for example mining, chemicals, air transport, other transport, non-metallic minerals, iron and steel, non-ferrous metals and paper-pulp-printing.

Sustainable transport

The policy theme of sustainable transport is well covered by the models. Some of the transport models focus on providing analysis of the impacts of transport policies either on an economic or emissions basis, such as the ASTRA model or T-REMOVE. The VACLAV model and NEAC are slightly different in that they forecast transport flows and demand. The TRANS-TOOLS has been developed more recently under European funding and is a large network model.

Natural resources

There is quite a wide range of models covering natural resource issues such as biodiversity and land use (including agriculture), partly reflecting the broad nature of this category. Some examples of the models within this policy theme include the EcoSense model, which analyses the impacts resulting from emissions of pollutants into the atmosphere, part of which includes looking at the impacts on materials and crops. The GLOBIO model is used to specifically look at the impact of environmental change on biodiversity, while WaterGAP is concerned with modelling water availability.

The large climate models include an ocean component, often analysing the impacts of climate change on sea levels, temperatures or ecosystems. The ocean component of the GLOBIO model focuses specifically on marine ecosystems. Models of fish stocks also exist but they tend to focus on a particular area or species; linkages to economic development are less well explored despite the obvious impacts on coastal communities.

Some of the models focus specifically on land use, for example, the CLUE model was built to provide detailed analysis of land-use changes. The LEITAP model is an extension of the GTAP model, developed by LEI to cover land use as well as the other policy areas. The IMAGE system of models perhaps has the broadest scope out of all the natural resources models given in Table 1.2. It has been designed to simulate the global society-biosphere-atmosphere system and is mainly used for assessing linkages between these three dimensions, as well as the consequences of global policies.

Agriculture and forestry is another area where models are well represented, especially in the EU. There are several different types of agricultural model, including for example issues such as optimal allocations for crops and commodity trading. The GTAP model and its database have a very disaggregated treatment of agricultural products.

Material inputs are included in Theme 2 (Sustainable consumption and production) and discussed briefly above.

Global partnership

As mentioned above, there are a number of models that focus on both socio-economic issues and international trade. There are, however, a couple of models that focus more specifically on trade as the main policy theme. The MIRAGE model was developed specifically for the analysis of trade policies and includes among its usages the explicit modelling of foreign direct investment and detailed modelling of the agricultural sectors. WATSIM is a world trade model for agricultural commodities and can be used for analysis of trade policy changes and analysing trends in agricultural markets.

While the sub-theme of trade is broadly covered by both socio-economic models and pure trade models, other sub-themes within global partnership are neglected, such as financing for sustainable development and global resource management.

Good governance

We are not aware of any formally-defined models that explicitly include good governance; a continuation of existing trends is generally regarded as one of the implicit underlying assumptions (see Section 3.3). It should also be noted that data on governance are unlikely to be available in countries where it is most relevant as an issue. However, with the exception of the policy coherence sub-theme, there are international indicators available which have been used in partial analyses.

We give some examples of indicators and research in Appendix A. One of the best known is the World Bank's *World Governance Indicators* (WGI). However, several NGO's also publish indicators, including Freedom House[18] and Transparency International[19].

The published quantitative research has tended to focus on these indicators as causes of economic growth rather than vice versa and there is not much (yet) linking governance to environmental pressures. Examples include:

- Studies such as Halperin et al (2005) find that GDP growth on average tends to be higher in democracies than in autocracies.
- Credit ratings agencies (eg Fitch, Standard and Poors, Moodys) give indicators of the likelihood of national debt defaults. Reinhart and Rogoff (2009) expand on this by providing a wider range of financial indicators.

Other model dimensions

The models included in Table 3.2 cover many geographical areas. While some are restricted to the EU member states, others consider the OECD countries, many countries worldwide, or split the world up into regions. As sustainability is a global issue, our focus is on global coverage, unless the regional or national models offer a policy coverage that is beyond that of the global models[20]. Care must be taken when interpreting the results from a model without global coverage; for example, issues such as carbon leakage suggest that it is not always clear whether results show a global net change in resource use or just a shift in geographical location of consumption.

The time horizons used by the models also vary considerably. Some only cover relatively short time spans, for instance the next 10 or 20 years. Normally in these cases annual solutions are given. Other models forecast up to 2050 or even 2100 and beyond. In some cases these forecasts are annual, whereas other models forecast in five or ten-year periods.

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[18] http://www.freedomhouse.org/template.cfm?page=1

[19] http://www.transparency.org/

[20] See Appendix A for further details of the geographical coverage of the models.

Most of these models disaggregate their datasets further. Some examples are given below:

- economic sector
- emission type
- energy type
- age/gender group
- transport mode
- agricultural product

When these dimensions are crossed, for example by a variable that covers geographical region, time period and one or more of the above examples, the data sets can become very large.

3.3 Different modelling approaches

Introduction If the previous section considered *what* could be modelled we now move on to the question of *how* the modelling can be carried out. This section discusses some of the most common modelling approaches and how their key assumptions may be related to issues of sustainability. The IA Tools model inventory also provides some discussion of most of these approaches.

The second part of this section discusses more general modelling techniques, such as input-output analysis, and important factors that are common to most modelling approaches.

Economic modelling approaches In the paragraphs below we provide a brief summary of the different economic modelling approaches and how their respective features relate to modelling sustainability issues, both in the short and long terms. These concepts are also relevant to the non-economic models that are based on economic principles, for example energy and transport modelling.

CGE models Computable General Equilibrium (CGE) models draw heavily on neoclassical economic theory and provide a consistent long-run macroeconomic framework for economic analysis that may be extended into other areas. This approach integrates microeconomic mechanisms and institutional features with clear feedback mechanisms between equations and between sectors. All behavioural equations (demand and supply) are derived from microeconomic principles (for example utility-maximising individuals, profit-maximising enterprises). They assume that these principles hold (described in Section 2.2).

Macroeconometric models Econometric models are based on empirical relationships and are developed using large-scale (usually time-series) data sets. The parameters of the equations are estimated with formal econometric methods which are integrated into a framework based on the national accounts and also often extended into other areas. Depending on the econometric specification, econometric models are also suitable for short-term analysis. The main assumption is that the historical behavioural relationships remain valid in forward-looking projections.

Input-output modelling Input-output (IO) tables form the basis of most CGE and macroeconometric models that disaggregate the economy into sectors. However, they may be applied outside a formal modelling framework; although this means many of the feedback mechanisms in a full model are missing, it allows a much greater degree of flexibility. The simplest IO analysis is based on economic multipliers but recent developments have extended the approach to environmental and trade-based analysis.

Agent-based modelling

Agent-based modelling is a relatively new approach and, so far, there is no fully-specified agent-based representation of the macroeconomy. However, the agent-based approach potentially offers an assessment of large-scale transitions, which the more established approaches (eg when validated on historical trends) are less well equipped to study. As an area of ongoing development that has been applied in partial analyses (see below) it is therefore important to consider this methodology which, along with some of the other new approaches being developed, is described in Section 5.3.

Partial models

A partial[21], as opposed to general, model is one that focuses on a particular sector rather than a whole economy. This term derives from economic modelling; it could also be argued that even a fully-specified economic model (one that includes all the main components of demand) is also a partial model if it does not include an endogenous treatment of demographic or environmental inputs.

The main advantage of partial models is that they are able to make use of detailed, specialised data that are only available for a particular field. Common examples include the agricultural, energy and transport sectors.

The main disadvantage is that all external factors are treated as exogenous so the feedback is limited. For example, if new transport infrastructure is built, one of the outcomes could be an increase in average incomes and therefore transport demand; however, the partial model would not include the economic interactions so would miss this effect. There are now many examples in Europe where different partial models have been linked to avoid this trade-off (see Section 3.4), some of which have been successful although the process is highly resource-intensive.

Models based on ecological economics

In Chapter 2 we note that there is not (yet) a fully-specified macroeconomic model based on the theories provided by ecological economics, although some examples of ongoing work were given in Section 2.6. A complete model would explicitly include environmental stocks as an input to economic production and the limited substitutability of capital for environmental inputs. In most existing frameworks there is very limited treatment of environmental stocks and, while it would be possible to limit substitution between factors of production, the environmental inputs are not normally defined.

Some of the other common assumptions, such as economic processes being described as social rather than individualistic activities, are incorporated into some (in this case usually macro-econometric) approaches. This is very much an area of ongoing development, which we return to in Chapter 5.

Conceptual models

The main focus of this study is on quantitative modelling tools, but we should not exclude conceptual and scenario-building tools completely. For example, they could provide indications of linkages that clearly exist but cannot be used in quantitative analysis due to data issues; this potentially allows analysis of linkages from the environment to the economy that are usually missing from the quantitative models.

[21] These models are also described as 'partial equilibrium' or 'sectoral'; we have used the term partial as our examples include non-equilibrium models and so that there is not confusion with general models that have sectoral detail.

We first consider cost benefit analysis (CBA), defined in Section 2.3, which provides a general non-modelling conceptual framework for quantitative analysis and is commonly applied for analysis. We then briefly look at the area more generally.

Environmental cost benefit analysis

At present no single method of environmental cost benefit analysis (CBA) is universally accepted, nor is any single methodology applicable to all situations. This is because, despite CBA having been developed over a long period of time, the use of CBA as a practical tool for analysing environmental impacts is a more recent development.

DG Regional Policy, European Commission, published guidance on CBA in the reports *Guide to Cost-Benefit Analysis of Investment Projects* (2002)[22] and the more recent version *Guide to Cost Benefit Analysis of Investment Projects* (2008)[23]. The document includes *Annex E (Annex F* in 2008 version*)* which provides a guideline on how to carry out monetary evaluation of environmental services. The guideline provides qualitative descriptions, but not practical examples, of how to carry out environmental CBA.

There are five key steps suggested in the guideline on how to carry out monetary evaluation of environmental impacts. They are as follows:

1 Gather information of the project. The aim of this step is to get the general understanding of the projects and to gather necessary information on the technical description of the projects.

2 Environmental impact analysis. This step involves assessing the environmental impact of a project in terms of its physical or biological effects on the environment. This could include impacts on air quality, human health and landscapes, for example.

3 Describe the external effects and economic agents. In order to estimate the total monetary value of the environmental impact we also need to know how many economic agents (households, firms, consumers, individuals, and industries) will be affected, either directly or indirectly (or both) by the environmental impacts.

4 Establish the methodology of evaluation and validation of monetary value. The choice of methodology will depend on the type of project, on the type of environmental goods and services involved, and on the general socio-economic and political context. The aim of the evaluation is to assess total economic value[24], considering both explicit uses (current or future physical consumptions and/or benefits) and implicit non-use values (altruistic, values of their existence, and value for future generations). Not all environmental goods and services have functioning markets. When there is no market, prices need to be derived via non-market evaluation procedures, such as revealed preference methods.

5 Establish the discount rate and carry out the estimation. Once the preferred method of estimating CBA is established, the next step is to choose an appropriate discount

[22] European Commission, Directorate General for Regional Policy (2002) 'Guide to Cost-Benefit Analysis of Investment Projects', Documentation Centre.

[23] European Commission, Directorate General for Regional Policy (2008) 'Guide to Cost-Benefit Analysis of Investment Projects', Documentation Centre, 2008.

[24] Total economic value is a monetary measure of a change in an individual's well being due to a change in environmental quantity.

rate to apply for the future costs or benefits. Once the discount rate has been chosen, the estimation of the environmental net benefit (loss) of the project can be carried out.

The issue of the discount rate, described in Chapter 2, can be highly contentious and is often cited as a determining factor in the results. Nevertheless it should be noted that CBA is able to offer a flexible means of carrying out quantitative analysis without using a fixed modelling structure.

More general conceptual approaches

More generally we define conceptual models as similar in scope to the quantitative models without explicit parameterisation. This provides a fixed structure to explore ideas on future scenarios, while at the same time offering a greater degree of flexibility as it is not reliant on the collection and processing of quantitative data. Conceptual models can therefore be applied to all the aspects of sustainability. There are clear roles in:

- providing a starting point for analysis before carrying out a formal modelling exercise
- validating the results from quantitative modelling and assessing whether they meet prior expectations
- considering impacts that are excluded in the quantitative models, either due to missing linkages or unavailable data

In summary conceptual models can operate in parallel with the more formal quantitative models that we are focusing on, can inform them and be used to provide a comparison of results. We will draw on our own conceptual models in later tasks when considering the ideal scope of a model of sustainability.

Which factors are fixed and which are variable?

A generalisation of the discussion of partial and general approaches is the question of how the model provides a simplification of reality, in terms of which factors are represented in the model as fixed, which are allowed to vary and which are ignored altogether.

This is often referred to as the treatment of exogenous and endogenous variables (see below) and is a key characteristic of any model (either quantitative or conceptual). However, we go beyond the standard definition of exogeneity to cover several distinct areas:

- the scope of an individual model
- structure in terms of identity relationships
- structure in terms of behavioural relationships and causality
- parameterisation

These are discussed in turn below.

Model scope

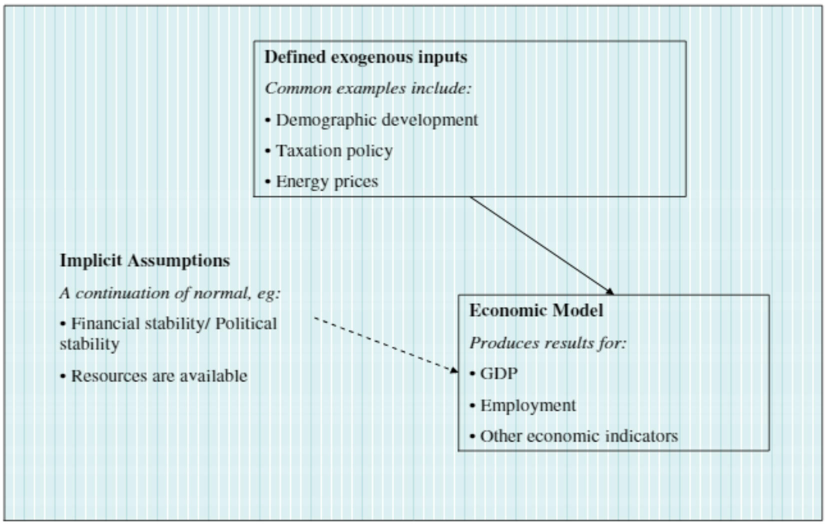
It is sometimes asked if it would be possible to have a ‘model of everything’ that covers all the aspects of sustainability that anyone could conceivably think of. Perhaps one day this will be possible at the macro level (or by linking different models, see Section 3.4) but at present there are both theoretical and practical reasons why this is not the case.

The main theoretical reason is that such a model would be unnecessarily complex for most of the problems it would be used to address. For example it may not be necessary or helpful to include XX in assessing YY if, in reality, XX and YY are not closely related.

However, the practical obstacles are even greater. The model operator would be required to understand all the parts of the model and their various interlinkages on a daily basis and, despite interdisciplinary research now being more common, much of it will lie outside their area of expertise. Computing capabilities, both in terms of absolute size and solution time, also remain a limiting factor.

Therefore, the endogenous scope of a single model tends to be limited to a small number of research areas. Model variables are split into those that are exogenously set by the model user and those that are endogenously determined by the model. In addition we can consider two sets of exogenous variables; those that directly affect the model results and are therefore defined explicitly, and those that are defined only implicitly. Figure 3.1 provides a standard economic model as an example.

Figure 3.1: Exogenous and Endogenous Model Inputs



Practical issues often also play an important role in defining the choice of exogenous variables used in the model. If it is not possible to measure a particular factor then it clearly will not appear in a quantitative model; this is also the case if the necessary data are not available. A good example of this in economic models is the treatment of R&D, which is usually given as exogenous despite the widely-accepted view that it is a key driver of growth.

Another common reason for treating a model variable as exogenous is if it cannot be explained within the scope of the model. International energy prices is perhaps the best known example; while an energy model may include detailed treatments of both energy demand and supply, it is unlikely to cover other potentially important factors in determining prices, such as the geo-political situation or the role of financial speculation.

More generally, it is important to note the trade-off between a model that is designed for a specific purpose, which it can represent in detail, and one that presents a more general framework. The main advantages and disadvantages in each case are outlined in Table 3.3.

TABLE 3.3: MAIN ADVANTAGES OF GENERAL AND SPECIFIC APPROACHES

Specific Approach	General Approach
Allows for a higher degree of specialisation in modelling approach, to capture specific effects	Consistency between different applications allows comparisons to be made
Can make use of more detailed classifications and data sets	Previous validation means errors are less likely
	Usually less resource-intensive to use existing model
	Linkages to other areas of sustainability more likely (although also more general)

Finally it is important to consider the way in which the model is applied. Leaving aside forecasting, the most common use for macro-level models is in policy assessment and is of interest to policy makers who wish to choose between two or more proposed options. It is therefore not surprising that policy inputs are generally entered into the model as (scenario) assumptions rather than being determined endogenously by the model.

Identity relationships

Another aspect of models that is treated as fixed is the set of identity relationships that is used. This is usually referred to as part of the model structure rather than an exogenous input, but is clearly important in the way in which the model reflects the real-life situation.

Identity relationships are usually intuitive and are not generally questioned. Some simple examples are:

- total population = children + adults
- GDP = the sum of its components
- unemployment = labour force - employment

Even in the most extreme scenario analyses these relationships are not expected to change.

Macroeconomic models benefit from having the structure of the National Accounts to provide many of the identity relationships required. This is by no means the case in other areas of research though; even the most advanced climate models admit that there are relationships, both identity and behavioural (see below), which are not yet understood.

Behavioural relationships

The difference between behavioural and identity relationships is that behavioural relationships are unobserved. It is therefore up to the model operator to define these links; a very simple example for energy consumption is given below:

$$Energy\,Consumption = a + b_1 * Income + b_2 * Energy\,Price$$

where a and b are the parameters that are assigned numerical values (see below). If this was an identity relationship, a and b would be set to one, zero, or some other logically pre-defined value.

Even so, it is clear that there is a degree of exogeneity in the model's behavioural relationships. First there is the structure of the equation, and the choice of factors on the right-hand side; in the example above all other possible influences on energy consumption have been assumed to have a value of b=0[25]. It is assumed that the income and price effects can be added. Second there is the nature of the parameter values that are used, in that once they are determined they are rarely changed. This is discussed in more detail below.

Parameterisation of the models

The means with which model parameters for behavioural relationships are determined is extensively discussed in modelling documentation and in other academic literature. This topic forms a project in its own right so we will only cover the key issues here.

In a CGE[26] model, most of the parameters are typically calibrated so that the theory that underpins the model is consistent with the data available for the base year. This reduces the resource requirements for the model but means the model is heavily dependent on the relationships in this year holding for other time periods.

Macroeconometric models also derive their parameters from historical data sets, although usually from much larger time-series databases. While this makes them less reliant on a single year of data, the same issue arises that historical relationships are assumed to hold in future years.

Alternative methods of forming model parameters include using results from published literature (for example using econometric estimates in a CGE model) or, where data problems are severe, using an intuitive judgement.

Key characteristics

The parameters in a standard modelling framework have the following key characteristics:

- once they are determined they are exogenous in the modelling framework
- they are usually invariant over time, or follow an exogenous path of change
- they are applied in a linear fashion

The issue of non-linearity is an important one when considering sustainability issues. Some specialised or partial models can take non-linearities into account, but general models tend to rely on linear (eg if X increases by 10 then Y increases by 10) or, more commonly, log-linear (if X increases by 10% then Y increases by 10%) relationships but there are many instances when in reality this assumption does not hold. Some examples are given below:

- The role of threshold effects – eg humans can absorb so much of a pollutant without negative health effects, but beyond a certain concentration effects can be severe. Or the commonly asked question of how much does a product's price have to increase before people stop buying it?
- Scenarios where the changes are so large that the behavioural relationships themselves would be expected to change, for example large-scale decarbonisation or dematerialisation.

The second point can be illustrated for a standard price/volume relationship. Figure 3.2 shows how the model's linear elasticities are represented as a constant slope while

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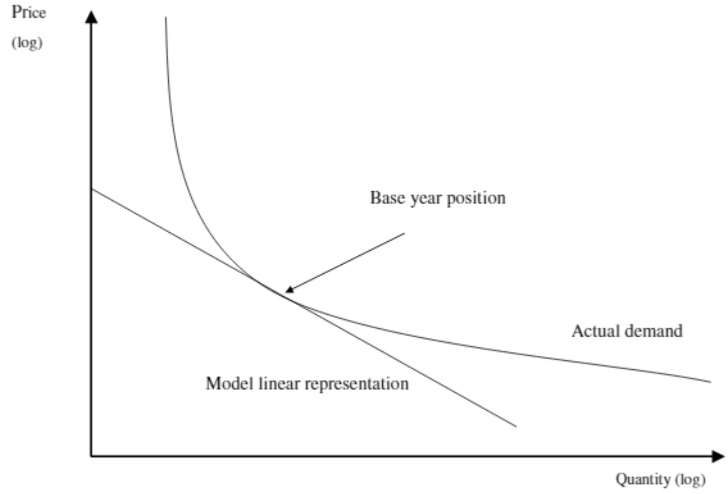
25 VAR models allow all factors in the model to influence all other factors but the resource requirements for this are so extreme that in the macroeconomic context they have only really been applied to a small number of key indicators.

26 See the start of Section 3.3 for a brief description of the most common modelling approaches.

Figure 3.2: Linear Model Representation of a Non-Linear Demand Relationship



the actual non-linear relationship differs the further we move away from the base point.

Parameterisation is a key issue that we discuss further in Chapters 4 and 5.

Treatment of technology

The treatment of technology is also a factor in economic models that rightly often draws attention. Technology itself is an unobservable factor but, in a traditional production function, it makes up the difference between the input factors and the outputs. The traditional approach in modelling was that, while a range of technologies and types of capital may be defined, technology increases exogenously over time due to factors lying outside the model.

More recently, endogenous technical change (ETC) has become a more common feature in modelling approaches. Including endogenous technical change in a model can have a profound impact on policy analysis, if the assessed policy is expected to impact on the rate of technological progress itself. It is still reasonable to say, however, that there is no agreed representation of technology in models and a definition that explicitly includes the various stages of development and diffusion is still some way off.

Bosetti and Galeotti (2009) provide a summary of how technology is represented in some of Europe's most well-known economy-environment models. The two most common representations of technology are described below.

Learning by doing

The inclusion of learning by doing and scale economies is particularly common in 'bottom-up[27]' models. The concept is especially relevant to new industries, for example wind and solar power in the energy sector, where average costs are expected

[27] In this context we mean models that typically start from a detailed sectoral supply-side engineering-type perspective. In contrast, top-down models make more use of macro and macro-sectoral economic data with a stronger focus on demand.

to reduce over time as more efficient production methods are discovered. Following the literature on technological development and diffusion the change in costs is often fixed to follow a logarithmic S-shaped path. An assumption must be made about the slope of this curve (ie the rate of learning), usually based on historical values.

The reduction in relative costs is used in a demand function to show the long-run adoption and growth of a particular technology, although this approach can also be applied to more aggregate sectors.

Technology as a stock

The top-down modelling approach incorporates a measure of technology through the accumulation of capital and/or R&D. This approach tends to be more implicit than the one described above, and does not usually define particular technologies. This has benefits (it is not trying to predict specific technologies) and disadvantages (the development it is predicting may turn out not to exist).

Other issues related to technology

The descriptions above relate to the more traditional definition of technology and do not touch upon what is defined by Beinhocker (2006) as ‘social technologies’, including business models and other social practices. It is difficult to see how these could be explicitly included in a macroeconomic model (so instead they form part of the implicit assumptions) but it is also not difficult to imagine how such factors could play a crucial role in achieving long-term structural change.

Finally it is important to note an area that is still under research is how broad the geographical representation of technology should be. The continuing rise of globalisation and multinational firms means that, in particular sectors, new technologies can be rolled out regionally or globally relatively quickly, leading to ‘spill-over’ effects (development in one country influencing outcomes in another). However, as rates of spill-over vary by sector and country there is currently no generally accepted methodology.

All of these issues are described further in the following chapters.

3.4 Links between the different parts of sustainable development

Table 3.4 outlines the number of models that cross over each policy theme, according to the definitions provided in Table 3.2 (and subject to the same assumptions). The table shows that there is a relatively wide range of models that link socio-economic development to the other SDIs. Even when the socio-economic theme is not explicitly covered, there are usually underlying economic assumptions about rates of development (which is similar to the way economic models include assumptions about population growth).

Of the other SDIs, energy modelling is perhaps the only other theme to be well connected to the other policy areas in the models. However, there are fewer models with direct linkages between it and the other aspects of sustainable development than have such links to and from the socio-economic theme. This is also underlined by the results of the INDI-LINK project which showed that interlinkages between economic growth and social welfare, as well as between social welfare and the environment, are rather limited.

Energy-economy linkages

By far the most common linkage is between socio-economic development and energy use. This is partly because economic and energy models are more common in their own right and also partly due to the availability of international data sources and the

TABLE 3.4: HOW THE MODELS LINK ASPECTS OF SUSTAINABILITY

		Policy Theme											
Policy Theme		**1**	**2**	**3**	**4**	**5**	**6a**	**6b**	**7**	**8a**	**8b**	**8c**	**9**
Socio-economic devt	**1**												
Sustainable C & P	**2**	2											
Social inclusion	**3**	0	0										
Demographic change	**4**	2	0	2									
Public health	**5**	0	0	0	1								
Energy use	**6a**	23	2	0	1	0							
Climate change	**6b**	5	0	0	0	1	8						
Sust. Transport	**7**	2	1	0	0	0	5	0					
Land use	**8a**	2	0	0	0	0	4	4	0				
Biodiversity	**8b**	1	0	0	0	0	1	1	0	1			
Oceans/ freshwater	**8c**	1	0	0	0	0	1	4	1	2	2		
Global partnership	**9**	6	0	0	0	0	3	0	0	2	0	0	
Good governance	**10**	0	0	0	0	0	0	0	0	0	0	0	0

focus of much previous policy development. However, another key factor is the ease with which energy demand can be integrated into the economic system.

Essentially a sectoral energy model and an input-output table represent the same purchases, with one in physical units and one in economic units. If it is assumed that the relationship between physical energy content and economic value, after correcting for price changes, remains constant (which is reasonable) then it is not a large step to combine the approaches. Hence a natural extension of the pure economic model is to include equations for energy demand.

Could this approach be applied elsewhere?

Chapters 4 and 5 discuss ways in which existing modelling practices could be applied in different settings. However, there are other linkages where a similar methodology has been applied in a small number of the models reviewed; these are between socio-economic development and sustainable production and consumption, and between socio-economic development and sustainable transport.

In the case of sustainable production and consumption, the similarity arises from the fact that purchases of raw materials are also represented in the standard input-output structure and therefore the same principles could be applied. The main reason this linkage is less common (other than the fact that energy has long been regarded as a more important issue) in formal modelling approaches is that obtaining data on material consumption, and indeed defining the point of consumption, has been much more problematic.

Nevertheless, it should be noted that input-output linkages have been exploited in Material Flows Analysis, for example in the construction of Physical Input-Output Tables. The ongoing Exiopol[28] project is continuing this work.

A similar approach can be applied with transport modelling, with passenger and freight km being used as a proxy for economic production in the transport sectors.

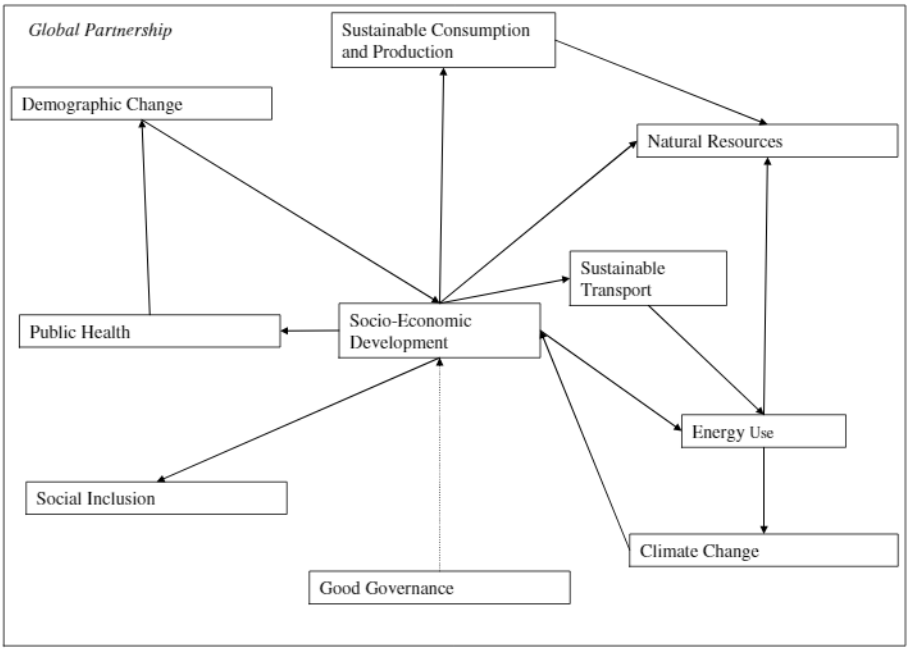
[28] See http://www.feem-project.net/exiopol/

This is quite important when considering the impacts of changes in fuel duties, where changes in intermediate demands (ie by industries, represented as points on the IO table going from the energy sectors to these industries) will be one of the primary impacts.

Linking different models

Figure 3.3 attempts to add direction to the linkages between policy areas within existing models, based on Table 3.4 although also taking into account exogenous inputs. We have only included the main modelling linkages here although there are many other linkages (for example energy-economy models can have a feedback from energy use to economic development through the economic performance of the energy sector).

Figure 3.3: Model Linkages



There are some obvious loops, for example environmental Integrated Assessment Models (IAMs) cover the bottom-right part of the chart, and integrated energy-transport models the mid-right section. The link from good governance is shown by a dashed line to indicate that previous analysis has been carried out outside a formal modelling framework. All the areas have analysis with global scope, so the global partnership indicator is implicitly included in all indicators.

The missing linkages within individual modelling frameworks raise the question of whether it is possible to link different models. The attractions of this approach are quite obvious; it allows for a degree of specialisation in expertise, data and modelling approach, while still capturing the feedbacks between areas. Some recent examples include:

- SENSOR[29] – agriculture, forestry and transport infrastructure
- SEAMLESS[30] – agriculture and environmental policy
- iTREN[31] – transport, energy and economy

[29] http://www.sensor-ip.org/

[30] http://www.seamless-ip.org/

- the IMAGE[32] system – land use, energy and climate
- the PRIMES[33] system – energy, economy and emissions

It should also be noted that economic or economy-environment models have recently incorporated more detailed treatments of the energy sector based on bottom-up engineering principles. The PACE and E3ME models are examples of successful model linkages (see Section 3.2).

Model linkages are usually defined in terms of either 'hard' or 'soft' links. Hard linkages include an integration of model software and source code, while soft linkages usually entail a transfer of data. It should be noted that, due to restrictions on intellectual property rights, soft linkages are more common.

It is also important to make the distinction between one-way and two-way linkages One-way linkages are relatively straight-forward, involving the outputs of one model being passed as the inputs to another, but obviously lack full feedbacks. This process essentially involves carrying out two separate modelling exercises and, if the feedbacks can be ignored reasonably, this may be a suitable approach for some purposes.

Two-way linkages require an iterative process of passing information between, and solving, both models, which can be extremely resource-intensive. In the case of hard linkages, the cost is up front in a development phase to link sections of computer code; in the case of soft linkages every time the model is run a human effort is required to carry out the data transfer and this must be repeated with each model run. For this reason, two-way linkages between models are quite uncommon outside academic research.

Other potential issues include:

- Differences in model classifications – For example, in disaggregation of economic sectors or modes of transport; usually this is not an insurmountable problem but it requires additional resources for processing.
- Differences in other dimensions – Issues such as time period can be much more problematic, for example if one model solves annually and another in ten-year snapshots. The approach to this tends to be to set the whole system to use the most limited specification (ie ten-year gaps in the example).
- Overlaps in scope – for example if the two models produce different results for the same indicators then a careful interpretation is required. This is quite important for presentation of results, with preference usually given to the model that provides the most detailed treatment for a single indicator.
- Differences in underlying assumptions – for example if one model assumes optimisation and one does not then it is not clear how to interpret the results from the system as a whole. This is perhaps the most problematic of all the issues with linking models. Unless the two model operators have a complete understanding of both models (which is unlikely) this is always a risk with working with linked models.

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[31] http://isi.fraunhofer.de/isi-de/projects/itren-2030/index.php

[32] http://www.pbl.nl/en/themasites/image/index.html

[33] http://www.e3mlab.ntua.gr/manuals/PRIMREFM.pdf

Could a linked set of models cover all sustainability aspects?

The ultimate aim of linking models would be to design a system that could cover all of the areas defined by the SDIs, with two-way linkages between the different areas. Other than the missing arrows in Figure 3.3, this theoretically could be achieved by developing existing tools, with the socio-economic development theme central to the linked system.

This would require a substantial research effort, however, and careful planning for how one model could incorporate feedbacks from several others simultaneously. Perhaps a more realistic approach is to exclude some of the linkages that are not well covered and focus on those that are most important. It is not difficult to imagine a system of one-way linkages, with an economic forecast being used as the basis for model runs in the other areas and, in our view, this is both technically and practically feasible[34].

Composite indicators

The issue of linking the various areas of sustainable development and different macroeconomic models inevitably leads to the question of how the results should be presented. Much research has been put into developing composite indicators for economic, environmental and social sustainability, including indicators that link all three pillars. Even within economics it is widely accepted that GDP is not necessarily the most appropriate measure of welfare, as it is only concerned with the economic side of development, and does not take into account environmental sustainability or social factors. In fact, the economist behind the creation of GDP, Simon Kuznets, warned that the welfare of a nation cannot be determined from a measure of national income such as GDP (Kuznets, 1934)[35].

Many institutions are currently developing a method of 'green accounting' whereby an indicator that measures progress on more than just one of the three pillars of sustainability is established. For example, the European Commission's 'Beyond GDP' process aims to improve the measures of progress, wealth and well-being, due to the recognition that GDP was never meant to be a comprehensive measure of these things[36]. The European Environment Agency (EEA) is developing techniques in line with national accounting methods to record the contribution of ecosystems to society's welfare[37]. Other initiatives include United Nations Environment Programme's (UNEP) 'Green Economy Initiative'[38]. In Bhutan, the Gross National Happiness Index (GNHI) is considered more important as a measure of progress than GDP. The GNHI is broken down to nine dimensions covering health, education, living standards and environmental diversity, among other things. These dimensions are considered to be components of happiness and well-being in Bhutan[39].

The EEA's green accounting approach makes use of a variety of 'indicators of ecological potential' in order to measure the level of investment needed to ensure that ecosystems remain sustainable and continue to provide the same level of resources. Making use of composite indicators is one way in which a broad indicator can be developed to measure sustainability on an economic, environmental and social scale.

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[34] Indeed, on an informal level, this is what happens anyway as the results from the PRIMES model, published by DG Energy, are used to provide the baseline for other studies.

[35] There is a long debate about alternative economic indicators, but this is outside the scope of this study.

[36] http://www.beyond-gdp.eu/

[37] http://www.eea.europa.eu/articles/the-time-is-ripe-for-green-accounting

[38] http://www.unep.org/greeneconomy/

[39] http://www.grossnationalhappiness.com/

The Stiglitz Commission, launched by Nicolas Sarkozy[40], advises against the use of a single composite indicator, but suggests that a small selection of physical indicators should be used, with a particular focus on proximity to thresholds and tipping points (see Section 2.2 of Chapter 3 of the report for further details).

Genuine Progress Indicator

One of the first alternatives to GDP accepted by the scientific community was the Genuine Progress Indicator (GPI) (Talberth et al, 2006) which is used regularly by governments and NGOs[41]. It further developed the Index of Sustainable Economic Welfare (ISEW), and uses several indicators to form a measure of sustainability. While the GPI uses the same personal consumption data as GDP, it makes deductions for negative characteristics of an economy, such as income inequality, environmental degradation and the costs of crime. The GPI has been calculated for many countries in order to provide a more accurate picture of progress. In many cases it shows much lower long-term growth rates.

Socio-economic indicators

There is a wider range of indicators that combine economic and social, but not environmental, factors. The most well-known is the Human Development Index (HDI). The HDI attempts to measure the well-being of a country by considering three basic aspects of human development: health, knowledge and living standards. The indicator was produced by the United Nations Development Programme (UNDP) and combines GDP (as a measure of living standards) with life expectancy at birth (a measure of health) and the adult literacy rate and enrolment ratios (measures of knowledge) to produce a more well-rounded indicator of development. The Index of Human Progress (Emes and Hahn, 2001) was developed as an improvement to the HDI by using six more indicators, including additional measures of health and also measures of technological progress. Other variations of the HDI include a pollution sensitive HDI, which uses the same indicators for health, knowledge and living standards as the UNDP measure, but also includes CO_2 emissions from industrial processes per capita as an environmental factor (Lasso de la Vega and Urrutia, 2001). Other indicators that measure progress on both an economic and social platform include the Well-being Index (Prescott-Allen, 2001), the Social Progress Index and the Physical Quality of Life Index[42].

Environmental indicators

There is a wide range of composite indicators designed to measure the overall state of the environment, the impact certain activities have on the environment, or the environmental performance of a country's policies. Composite indicators like these have the potential to be combined with measures of income, such as GDP, to give a measure of progress from both an economic and an environmental perspective.

One of the most recognised indicators of the environmental impact of economic activities is the ecological footprint. While the methods of calculating ecological footprints vary, standards of calculation are being developed so that the results are more consistent and comparable. In essence, the ecological footprint compares the demand that populations and economic activities put on the environment and ecosystems in a given year, with the current supply the environment can produce in that year. The Environmentally Sustainable National Income (eSNI) is a similar measure; it is defined as the maximum production level at which environmental resources will remain available forever, based on current technology. The impact of

[40] http://www.stiglitz-sen-fitoussi.fr

[41] http://www.rprogress.org/sustainability_indicators/genuine_progress_indicator.htm

[42] http://www.brown.edu/Administration/News_Bureau/Op-Eds/Morris.html

economic activities can also be calculated using the carbon footprint measure, defined by the UK's Carbon Trust as a measure of the total greenhouse gas emissions caused directly and indirectly by an individual, firm, event or product. The measure takes into consideration the six greenhouse gases and compares each of them on a like-for-like basis relative to one unit of CO_2. The carbon footprint of a good or a service is similar to its Life Cycle Assessment (LCA), which measures the environmental impact of the product during its lifetime.

The Environmental Performance Index (EPI)[43] takes a slightly different approach by quantifying and benchmarking the environmental performance of a country's policies. The composite indicator consists of 25 single indices that cover two broad topics; environmental health and ecosystem vitality. The Environmental Sustainability Index (ESI)[44] was designed to benchmark the ability of nations to protect the environment. A total of 21 indicators of environmental sustainability are included in this index, including measures for air quality, environmental health and environmental governance. The 21 indicators are further broken down into more specific indicators. The Index of Environmental Indicators (Brown et al, 2004) measures progress or deterioration in five broad environmental categories; quality of air, quality of water, use of natural resources, management of solid wastes and land. These categories are further broken down into a number of individual variables. Other similar composite indicators include the Natural Capital Index[45], the Index of Environmental Friendliness (Puolamaa et al, 1996) and Eco-Indicator 99[46].

Several environmental composite indicators consider more specific areas of the environment or ecosystem. For example, the Living Planet Index (LPI)[47] tracks populations of over 1,000 vertebrate species worldwide in order to measure trends in biological diversity. Other very specific environmental composite indicators include the Air Quality Index (part of the EPI) and the National Biodiversity Index[48].

Linking composite indicators to macroeconomic models

There is no obvious practical or theoretical reason why a macroeconomic model should not be able to provide results for a composite indicator, as long as its framework includes all the components of that indicator. This would allow forward-looking composite indicators to be formed in ex-ante analysis.

The question is whether this is a preferable means of presenting results to showing the individual components, as it could imply a degree of substitutability between components. To a certain extent, this is a matter of judgment on the composite indicator involved.

3.5 Application of the models

Presentation of results is part of a more general issue of how the models are applied. By using an inappropriate tool it is quite easy to achieve results which are biased in one direction.

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[43] http://epi.yale.edu/Methodology

[44] http://www.yale.edu/esi/

[45] http://www.mnp.nl/mnc/i-en-1119.html

[46] http://www.pre.nl/eco-indicator99/default.htm

[47] http://www.panda.org/about_our_earth/all_publications/living_planet_report/living_planet_index/

[48] http://www.unep-wcmc.org/collaborations/BINU/

The two main applications of modelling are through forecasting (comparisons between time periods) and through scenario analysis (comparisons between different inputs[49]). Both are important but our focus is on scenario analysis which, as described below, can contain an element of forecasting through the baseline.

A baseline and scenarios

The standard modelling approach is to set up a baseline case and a series of 'what-if?' scenarios to compare it to. The scenarios are defined by a small[50] change in inputs and results from the scenarios are compared to the baseline, giving a quantification of cause and effect.

Although in many ways the baseline often does not have a direct impact on the results, a lot of resources are put into forming acceptable baseline cases. This is partly for presentational reasons but there are also theoretical grounds for ensuring that the baseline is coherent. A commonly-cited example is how international energy prices affect the impacts of energy taxes:

If a scenario assumes an energy tax of $50/pb in 2020 against an international price of $100/pb, this represents a 50% increase. However, if the international price is assumed to be $200/pb, the increase is only 25%. In a standard model with logarithmic parameters (eg a 10% increase in price leads to a 5% reduction in demand) this means that all the impacts under the higher starting price will be half those under the lower starting price.

This issue becomes even more prevalent if we start to consider non-linear relationships such as threshold effects (see Section 4.3).

Clearly there are cases where the assumptions on the baseline represent a major uncertainty (see below) in the analysis. However, as a tool for isolating the effects of single input variables, scenario analysis is invaluable, and there is no obvious alternative approach.

Defining scenarios

Another important issue is the definitions of the scenarios that are modelled. Substantial resources are put into this. The most important aspects to scenario building include ensuring that they are neutral in design (including both the positive and negative aspects of a particular policy) and that they are not overly reliant on particular modelling assumptions (ie the assumptions should not automatically determine the results).

One important issue when considering the macroeconomic approach to sustainable development is the means of revenue recycling. Revenues are accrued when a market-based instrument, such as a tax on consumption of a particular product, is applied in the scenario. This instrument has economic impacts itself, but these can be reduced or even outweighed by the use of the revenues for other purposes. How the revenues are used is therefore highly important, but historically has often been neglected. This issue has become more prevalent as the use of market-based instruments as a means of economically efficiently meeting policy goals has grown.

Table 3.5 provides some examples of recycling methods and their main impacts, by theme in the SDIs.

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[49] In this report we generally define a scenario as a model run with any change in inputs that differs from the baseline, including testing of sensitivities or variants of key assumptions.

[50] Chapters 4 and, in particular 5, discuss issues with dealing with larger changes.

TABLE 3.5: EXAMPLES OF REVENUE RECYCLING METHODS

Method	Primary Impact
Directly back to companies affected	Theme 1: Profitability of firms
Increase benefits / lump-sum payments	Theme 3: Reduce inequality
Reduce income taxes or VAT	Theme 1: Increase GDP
Reduce labour taxes	Theme 1/3: Increase employment
Energy-saving investments	Theme 6: Reduce energy demand
Increase government expenditure	Theme 3/5: Education or health benefits (eg)

Ex-ante and ex-post modelling

Typically scenario analysis is carried out *ex-ante*, which asks the question of what will happen to future developments if an input is changed today or at some time in the future. However, *ex-post* analysis is also possible although rare (Andersen and Ekins, 2009, provides an example, CBA has also been applied in this way). This involves an assessment of previous policy using a counterfactual (what would have happened if we had done or not done this?) approach. Although by nature this type of analysis may often be of less use to forward-looking policy makers it does have some advantages which reduce the amount of uncertainty (see below) around the results:

- the baseline is provided by historical data
- model parameters are determined in the time period that they are used

Both approaches clearly have their merits.

Treatment of uncertainty

The term 'uncertainty' is used to describe a wide range of issues, which can be grouped into two broad categories:

- how real-world uncertainty is modelled
- uncertainty surrounding the accuracy of the model

The first of these points is not very well covered by existing models and this is discussed in Section 4.3. The second point is more relevant to the application of models. This type of uncertainty arises because the model and its user do not have a complete knowledge of all the necessary variables and interactions. Uncertainty could arise for many reasons; some of the main examples are:

- accuracies in historical data
- accuracies in model parameters
- mis-specification in baseline or scenarios
- model assumptions not holding

Until recently, the level of uncertainty in results has been largely ignored in modelling exercises with results being presented as point estimates (the exception is in framing long-term scenarios, as described below). This has changed, partly as a result of climate modelling, where uncertainty in the earth's systems is more explicitly acknowledged. Advances in computing power have also allowed the issue to be tackled more thoroughly.

It is usually easy to measure the uncertainty for a single equation or model parameter, for example through t-statistics, confidence intervals or a similar measure. However, for a complex model there is no comparable measure. The procedure has thus been:

- to identify the main areas of uncertainty

- to rerun the model with revised inputs to test the sensitivity of results

The simplest example of this is through a basic sensitivity analysis where one or more inputs is given a maximum and minimum bound and the model is rerun to give a range of results. This exercise is relatively light on resources.

A more complex approach is to randomly vary a small set of inputs and rerun the model many times. A statistical analysis of the variation in outputs can then be carried out to see the likelihood of different potential outcomes. Due to the large number of model runs, however, this is much more resource-intensive.

It should be noted that both of these approaches relies on the identification of the main uncertainties prior to the analysis being carried out, and that usually only the explicitly-defined assumptions may be tested. At present there is no formal method for doing this, and this is in any case likely to vary by application. However, volatility in energy prices and the recent financial crisis have both increased the awareness of how important it is to test the sensitivity of model outcomes.

Long-term scenarios

Another way in which models have been used to consider uncertainty is in creating visions of what society could look like, particularly in the distant future. This approach is generally split into two steps, in which the first is to form a qualitative view on the key drivers of change (for example from a conceptual model). A macroeconomic model can then be applied to quantify the changes and to provide consistency between different indicators.

These views can be used to form an alternative set of baselines to which policy scenarios can be compared. The result is an assessment of policy in several different contexts, with some of the uncertainty covered in the modelling exercise.

Uncertainty in each policy theme

Table 3.6 lists some key uncertainties around each of the policy areas reflecting on the following aspects of the models:

- structure and assumptions
- data, parameters and other inputs
- non-linearities and (potentially explosive) feedback effects
- technology
- the time frame usually considered

Issues of uncertainty are discussed in more detail in Chapters 4 and 5.

TABLE 3.6: MAIN UNCERTAINTIES IN EACH POLICY THEME

Theme	Main Uncertainties
Theme 1: Socio-economic development	Economies are prone to non-linear effects, eg crises Behavioural assumptions are sometimes not validated Links with technology not well understood
Theme 2: Sustainable consumption and production	Consumption patterns are prone to fashions and trends Commodity prices are volatile
Theme 3: Social inclusion	Social groupings hide a lot of variance within groups
Theme 4: Demographic changes	Migration patterns can change quickly in response to external stimuli Long-term views are subject to more uncertainty
Theme 5: Public health	Epidemics are very difficult to predict The effects of some external environmental factors are not well understood
Theme 6: Climate change and energy	
Energy	Energy prices are volatile Prices are currently higher than they were historically Technology expected to play a key future role
Climate change	The climate system is not fully understood There are many non-linear feedback systems Long-term views are subject to more uncertainty
Theme 7: Sustainable transport	Fuel prices are volatile There can be unexpected feedbacks in modal changes
Theme 8: Natural resources	
Land Use	Agriculture prices can be volatile Land use can be subject to political interference
Biodiversity	Relationships between species can be complex Relationships with external factors may be not well understood
Fresh water	Dependent on weather and climate patterns
Theme 9: Global partnership	Lower data quality in developing regions means there is a lot more uncertainty in model relationships
Theme 10: Good governance	This is difficult to quantify so some factors are inevitably not taken into account

3.6 Summary and conclusions

Overview

After identifying the most widely-used existing models, it is clear that each of the policy themes based on the SDIs are covered in their own right, either as a main or secondary policy theme, by at least one model. The only exception to this is the good governance policy theme, for which there does not appear to be any formally-defined models, although single-equation analysis has been used.

The degree of linkage between the themes varies substantially, but many of the models have connections between the socio-economic sphere and other policy themes, particularly energy. The energy and climate change models also have a range of linkages across other policy themes, for instance there are several models that link energy and transport, or climate change and natural resources. However, in many cases the direction of the linkages within a particular model is often only one-way. For those models that include socio-economic development as a policy theme, it is often the case that the economy feeds into other areas, such as energy or transport, but not necessarily vice versa, with demographic changes an exception to this.

Variables within the models may be treated in different ways, and what is treated as endogenous in one model may be exogenous in another. Exactly what is treated as exogenous to the model, and the identity or behavioural relationships within the model, is therefore an important issue, as this would greatly affect the model outputs.

The model results can also be greatly affected by the structure of the model in question, which in turn is often determined by the economic schools of thought described in Chapter 2. By using an inappropriate tool it is quite easy to achieve results that are biased in some way. The standard modelling approach is to set up a baseline case and a series of 'what-if' scenarios to compare it to. Typically, scenario analysis is carried out ex-ante, which asks the question of what will happen to future developments if an input is changed today or at some point in the future. Ex-post analysis is also possible, but is less commonly used.

The treatment of technological change often varies across different models. Traditionally, technology was assumed to increase exogenously over time, but more recently endogenous technological change (ETC) has become a more common feature in modelling approaches. As discussed in this chapter, different representations of technology tend to be used for top-down and bottom-up analysis. More generally, the issue of uncertainty is an important one that is not fully addressed under existing frameworks.

Finally, models tend to rely on either linear or log-linear relationships, but there are many instances when in reality this assumption does not hold. For example, assuming a linear relationship ignores the role of threshold effects. This is one of the key methodological differences we will pick up on in the following chapters.

Key methodological issues

There are four key methodological issues that need to be addressed in the current range of available models:

- exogenous inputs and linkages between policy areas
- treatment of technology
- the role of non-linearities
- treatment of uncertainty

They are discussed further in Section 4.3 and in Chapter 5.

4 What Should Models Take into Account?

4.1 Introduction

Overview

The aim of this chapter is to determine the factors that the available models should cover in order to create a consensus that they are able to provide an accurate assessment of sustainable development issues[51]. Although in this chapter we give some discussion of the feasibility of these aims, this is assessed in much more depth in Chapter 5. This chapter thus represents more of a wish-list of areas of coverage.

Taking the conclusions from the two previous chapters, we split the chapter into three parts, addressing the following questions:

- What issues need to be addressed and what linkages between the aspects of sustainability need to be included?
- How should these issues be taken into account?
- How do the policy issues and the methodological constraints interact?

The first question is more policy-oriented in focus, while the second is more technical in nature and relates to model methodology. All three questions are discussed in the following sections. The final section in this chapter considers whether macroeconomics should play a central role in assessing sustainability at all, or whether, given some of the findings from Chapters 2 and 3, there would be more merit in investing in a completely new approach.

Specific issues to consider

In addition to these general aims, the original terms of reference for the study outlined a number of specific issues that should be considered; these relate to both the scope of coverage and modelling methodology (ie the first two questions above). The list has subsequently been extended to reflect the discussion at project meetings and conclusions from the previous chapters. It therefore represents the priority issues identified by a combination of all those involved in the study.

Issues of policy coverage

Issues of policy coverage are:

- weak & strong sustainability, thresholds, irreversibility
- decoupling of economic growth and resource consumption
- scarcity of specific resources
- feedback mechanisms between growth and the environment
- pressure on general environmental resources, such as land and water
- limited carrying capacity of supporting eco-systems
- climate change and energy
- sustainable consumption and production
- equality, green skills and demographic change
- green investment
- quality improvements

Issues of methodology

Issues of methodology are:

- feedback mechanisms between growth and the environment

[51] This in itself is potentially contentious, as the different economic schools of thought have different views on which issues are important (see Chapter 2). Where possible, in Chapter 4 we relate the issues to real-world observations (or from both main perspectives) and link this to the available modelling approach, and underlying theory, in Chapter 5.

- behavioural responses, for example to product labelling
- impacts of localised production
- coverage of market-based instruments
- changes in elasticities linked to environmental issues
- endogenous technological change
- how to handle large-scale change, and extreme scenarios
- how to handle non-linearities and threshold effects
- transitional effects
- treatment of irreversible change
- timeframe of analysis

These issues are also considered in the following sections.

4.2 Scope of the models

Following from the literature review in Chapter 2 this section presents and discusses the issues and parameters that would need to be modelled for there to be some consensus that the modelling was covering sustainable development issues. The description puts an emphasis on real-world links and focuses on a policy perspective, taking into account both of the main economic schools of thought. We cover the main policy issues in turn.

Overall

Weak and strong sustainability – thresholds – irreversibility

The concept of weak sustainability assumes that different forms of capital can be substituted, for example that the depletion of natural capital can be compensated via investments in other forms of (man-made) capital (such as machines, buildings and infrastructure). It is further assumed that decoupling economic growth from environmental pressure is possible, and that economic growth can help to reduce environmental pressure if it accelerates resource productivity at a faster rate than resource consumption or other environmental pressures, and population growth. Supporters of the concept of strong sustainability, on the other hand, state that natural capital cannot be (fully) substituted by other forms of capital and therefore it has to be preserved. This concerns in particular the subset of natural capital which consists of assets that are irreplaceable (also called 'critical natural capital') and needs to be preserved in physical terms to keep its core functions intact. Hence, from a strong sustainability perspective, the size of the economy relative to the ecosystem is important.

Whether it is important to represent weak or strong sustainability in a modelling framework therefore depends on the viewpoint of the model user[52]. Existing models generally provide a reasonable representation of weak sustainability and could also assess strong sustainability, if the most important forms of natural capital could be identified and quantified. One conclusion is therefore that the models should be able to take into account the substitutability of capital in a way that better reflects real-world relationships. However, this would first require a separate study to identify the key assets and the realistic degree of substitutability that is available.

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[52] As discussed in Chapter 2, theories of Environmental Economics are generally consistent with weak sustainability while Ecological Economics supports the concept of strong sustainability.

Feedback mechanisms and interlinkages

As illustrated in Figure 3.3, individual models often have a limited number of linkages between the different components of sustainable development. For example, they may not take into account the two-way linkages between the availability of resources (eg fossil fuels) and energy use or between natural resources and climate change. Moreover, long-term feedback mechanisms that do not necessarily follow historical developments are difficult to include, for example between economic growth and the environment (whereby growth increases environmental impacts which in turn affect the potential for growth). The analysis of some environmental and social linkages is also inhibited when monetary metrics dominate the models instead of, for example, physical flows or social valuation methods (such as social value added). These limits to complexity and inclusiveness in individual models can make it difficult to assess, for example, the extent to which environmental protection impacts the rate and/or structural composition of growth.

We discuss the practical implications for modelling in the following sections and in Chapter 5, but it is important to note that the units used in the assessment (ie either physical or monetary) are often linked back to the economic school of thought that underlies the analysis.

Natural resources

Decoupling of economic growth and resource consumption

While both neoclassical and ecological economic views underline the necessity of decoupling economic growth and resource consumption, the embodiment of this approach into the economy-environment interrelation is considerably different. Neoclassical economists are the technological optimists in saying that growth is not only compatible with the environmental limits, but necessary for it. Growth induces technological efficiency as well as increases in scale. All that is needed to achieve environmental goals is for efficiency to outrun impacts brought about by the scale of the economy (Jackson, 2009). Thereby, the main motivation to foster decoupling approaches is the increasing prominence of climate change and augmenting prices for commodities and energy. Consequently, the economic case for decoupling is based on more efficient use of resources.

Ecological economists argue that environmental constraints imply limits on economic scale and thus limits to growth (see Section 2.3). They are sceptical about the possibility to dramatically change technologies, investment and consumption patterns in a way that decouples economic growth from environmental impact (Jackson 2009, Pirgmaier, 2008). Victor (2008) argues that changes in the composition of GDP (such as a shift from goods to services) and technological progress are not likely to solve the problems of the overuse of natural resources, sinks and services. For example, the probability of achieving carbon emission reduction targets is very much increased by a slower than expected increase in the scale of the global economy.

EU policies such as the Thematic Strategy on the sustainable use of natural resources (European Commission, 2005), the Renewed EU Sustainable Development Strategy (European Council, 2006), the Action Plan on Sustainable Consumption and Production (European Commission, 2008b) or the Raw Materials Initiative (European Commission, 2008a) focus on the reduction of environmental impacts via increased technological efficiency and recycling. While all of these approaches are important tools when striving for a reduction of environmental impacts, following the ecological economists' arguments, this is not enough to steer towards an absolute reduction of resource consumption, in order to limit the size of the economy relative to the global ecosystem.

This point of view has been taken up by international bodies such as the OECD, which underlines the importance of an increase in resource productivity stating the necessity of absolute decoupling in various concerns (see for instance, OECD, 2002, 2007, 2008). Also the UN Environmental Programme (UNEP) stresses the need for absolute decoupling in developed economies and relative decoupling in developing economies, in order to ensure both reductions in poverty in less-developed countries and a reduction of worldwide pressure on the environment (UNEP, forthcoming). The Working Group on Decoupling refers to the UK Sustainable Development Commission (UK-SDC) which released a report in 2009 entitled *Prosperity without Growth: the Transition to a Sustainable Economy* (Jackson 2009), calling for 'prosperity' (non-material growth) which is when 'humans can still flourish and yet reduce their material impact on the environment'. The UNEP, hence, identifies the need for a precise definition of growth and the distinction between economic growth (measured by GDP) and physical growth.

Resource use in general is an area where existing macroeconomic models provide very little coverage so neither viewpoint is very well represented, with the exception of energy resources. However, as we shall discuss in Chapter 5, this is an area of potential development and, when combined with an endogenous treatment of technology, these issues could be addressed from a neutral viewpoint. From a policy perspective, the aim should be that models are able to provide answers to questions such as:

- Which thresholds could be reached through the use of different forms of natural capital (material, energy, water, land, absorption of emissions and waste, etc.) leading to tipping-point phenomena with possible irreversible consequences for ecosystem services?
- In which ways do economies depend on different forms of 'critical natural capital' and where are ecological 'hot spots' located where strong sustainability principles need to be applied in the design and implementation of policy instruments?
- What would be the economic (and social) implications of a cap on resource consumption targeted towards absolute reduction of human use of (different types of) natural resources?

Resource scarcity – stocks and flows of resources

The scarcity of – especially non-renewable – natural resources is increasingly becoming a topic of interest in both environmental and economic policy. The reasons are diverse. While classical economics, as well as ecological economics, points out that the environment sets limits to the expansion of economic activity by means of problems of scarcity (materials, land, water), neoclassical and environmental economics builds on the assumption that scarcity is only a relative phenomenon, which can be solved through the price mechanism leading to technological innovation and substitution of materials. These schools of thought therefore do not consider this issue as a fundamental problem to achieving sustainability and the importance of this issue therefore depends on the viewpoint of the model user.

From either perspective, however, scarcity is relevant to policy makers who wish to avoid the exhaustion of stocks and the high prices that could be associated with extreme scarcity. In recent years policy makers have increasingly picked up on the issue of scarcity and addressed it in different policy strategies. A good example of this is the EU Raw Materials Initiative which defines:

- the assurance of access to raw materials from international markets under the same conditions as other industrial competitors
- setting the right framework conditions within the EU in order to foster sustainable supply of raw materials from European sources

In this context the interest lies in possible strategies to secure access to resources that are crucial for current and future key economic sectors.

It therefore seems important that models should hence be able to take into account reserves and available stocks of resources respectively, in order to:

- investigate how resource scarcities might affect future economic growth
- understand which industries are highly dependent on non-renewable resources that could be affected by future scarcities
- assess how the development of 'green industries', such as renewable energy production, might be affected by scarcities of non-renewable resources (eg metals for photovoltaic cells or wind turbines)

In this context, the identification of intersectoral connections and the ability to trace the flow of specific resources through the economic system are issues which models should be able to cover. Input-output tables provide a reasonable starting point for such analysis (see Chapter 3) but for the key resources a greater degree of detail is required.

An additional consideration is that, when formulating policy, resource scarcities should be defined in terms of both short and long-term resource availabilities. Relying on market prices alone can give a poor reflection of many important aspects of scarcity because prices are often based on short-term market values. Norgaard (1990) and Reynolds (1999) demonstrate that a lack of knowledge about the true size of the resource base can obscure the actual trend in price of the resource. As a result, empirical data on costs and prices do not necessarily reflect the scarcity of a resource. A good example for this phenomenon was the development of the oil price in 2008/09.

Problems with price formation present a particular difficulty for model-based assessment as the usual approach is that prices are determined by rational agents acting on short-term supply and demand (equilibrium models) or previous relationships in times when resources were less scarce (empirical models). This is discussed further in Chapter 5.

Pressure on land and water

Land use and water use are two closely related topics in which there is a strong divergence between neoclassical or environmental economics and ecological economics.

From the viewpoint of ecological economics, both land and water are crucial for the supply of nutrition; both are used for energy production (hydro power and agrofuels). Moreover, land is the necessary resource for housing as well as the fundament for infrastructure, such as buildings and roads. The irreversible character of surface sealing increases the pressure on land supplies, as do pollution and overuse with regard to water resources. In addition, an increasing world population demanding nutrition, electricity and housing is further raising these pressures on the use of both land and water. On top of this, land and water support fauna and flora that have a high socioeconomic value.

From the perspective of a neoclassical or environmental economist these issues are given less prominence as the prevailing view is that these resources may be substituted with other forms of capital. The many potential uses of land and water are of course recognised and represented in the prices for these resources that provide the signals and economic incentives for the substitutions to take place. In the case of water, one of the main issues from this perspective is that water is not usually given a market price.

Whichever viewpoint is followed, land and water are high on the political agenda around the globe. In the case of land, as a reaction to competition between different types of land use, countries such as China and the Gulf States even go as far as to buy arable land in other continents (ie Africa) in order to ensure their citizens' nutrition. In the EU, the Directive on Environment Impact Assessment (EIA) for projects and the Directive on Strategic Environmental Assessment (SEA) for plans and programmes are the two main tools used to analyse the impact of proposed development with regard to land-use issues. In some countries, such as Germany, quantitative targets have been formulated in national sustainable development strategies to reduce the amount of newly sealed land areas. In the case of water, the focus has so far been on water quality and the management of water resources for the fulfilment of its ecosystem functions, rather than on securing a quantity of resources.

Existing models cover land use in a fairly large amount of detail and this can be linked to economic development. The treatment of water is less clear and has tended to follow the policy priorities, with specific models to cover individual river basins where pressures are high. Nevertheless, from the macroeconomic perspective it would not be difficult to estimate demand for water in the same way that demands for materials could be modelled (see Chapter 5). Eurostat provides sectoral data on water consumption, although coverage tends to be sparse.

Important topics in this context to be tackled by models include:

- the identification of specific users (such as agriculture, housing, etc) or pressures competing for resources such as land and water (for example agriculture and industry at the highest level)
- the quantification of the extent to which a user (eg an economic sector) is putting pressure on these resources
- estimation of the impacts on economic growth or different economic sectors (in particular, agriculture) brought about by this competition for resources under different scenarios
- modelling the feedbacks that these pressures on environmental resources may have on other indicators such as health or quality of life

Limited carrying capacity of supporting ecosystems

As discussed throughout this report there is a general discussion between the different schools of economic thought about the substitutability of environmental capital with other types of capital. While this debate is usually formed in the context of substituting away from using stocks of scarce resources, it can also be applied to the carrying capacity of ecosystems. The increased scarcity of fresh water is an obvious example of how these carrying capacities are being stretched, but falling fish stocks, desertification and climate change can also be included.

In the discussion on carrying capacity, the EU has put special focus on the 'Ecological Footprint' as the indicator for environmental impact brought about by consumption activities in relation to the carrying capacities of global ecosystems. The European Commission (DG Environment) assigned a study assessing the potential of the Ecological Footprint and related tools and indicators to measure negative environmental impacts related to natural resource use as called for in the Thematic Strategy on the Sustainable Use of Natural Resources (Best et al 2008). When considering the carrying capacities of ecosystems it is vital to take into account both the toxicity of specific resources and whether the level of overall resource use is within carrying capacity.

Consequently, in an ideal world, the models should be capable of framing economic activity within the carrying capacity of different types of ecosystems and of tracing which countries and world regions, and which parts of the economic system, would be most heavily affected by an ecological overshoot beyond these limits. While this is perhaps overly ambitious given current capabilities, a good starting point would be to define and quantify the key carrying capacities at global and regional levels, which could give a basis for further analysis.

Direct links from the environment to the economic system

The environmental dimension of sustainable development is largely influenced by two main factors that are linked to economic activities: the amount of inputs taken from the environment (including consequences such as resource depletion and biodiversity loss) and the amount of outputs released into the environment, as a result of production and consumption and their consequences. Inputs such as renewables, non-renewables, energy, or environmental services are of great relevance for the functioning of our economic system.

In the paragraphs above we have discussed how this could be incorporated into a macroeconomic framework, in physical terms, in relation to available environmental stocks and carrying capacities (flows). In this context, another policy area that is worth mentioning explicitly is how to the models could deal with waste, in terms of quantity, different types of waste and different methods of treatment. This is an area in which existing models operating at a global or European level offer very little coverage, perhaps because they also do not include consumption of material resources. However, there are some examples of developments at a national level[53].

Climate change and energy

Outputs of environmental sustainability

Economic outputs of production processes that enter the environment, such as emissions into air and water, waste, and related environmental implications such as climate change, pollution, biodiversity loss and groundwater depletion, are often simply treated as 'externalities' which can be included in economic models and analyses by putting prices on them.

As described above, these are examples of pressures on available stocks and carrying capacities which require a measurement in physical units to provide a full assessment. The specialised models (eg climate change models, models covering river basins) operate on the basis of physical units, so the issue is perhaps more of forming closer

[53] For an example in Norway see Bruvoll and Ibenholt (1998).

linkages to the macroeconomic framework, and putting less of a focus on purely economic indicators.

The role and value of energy

The formulation and implementation of policy strategies for sustainable development must always consider the related requirements for energy and materials for all economic activity. As the oil price shocks and fears about energy security have shown, energy is far more important than its monetary value suggests.

Energy should be treated as a key factor of production. The output of the economic system, and the maintenance of its components, are dependent upon continuous input of energy into the system. The detailed and comprehensive models of the flows of energy through different economic sectors that are used today do not include the flows of nature, such as the energy associated with the hydrological cycle, flows of rivers, solar energy, photosynthesis and other important components of the economic system. A possible, but still controversial, approach includes the energy flows of nature and the human economy. The so-called *emergy* (with an 'm') analysis, which attempts to give each energy flow a weighting according to its quality, has been applied at an aggregated level to national economies and has been used as the basis for policy recommendations.

Most energy models are based on quite simplified assumptions such as bounded (or perfect) rationality and exogenous global prices.

The understanding of the role of technology must be further improved. This could be through soft-linking existing macroeconomic models with technology-based bottom-up models (eg PACE, E3ME, see Chapter 3) or by better incorporation of technology data which could include such stock data as the power generation mix with its age structure, or the vehicle fleet, which limits substitution possibilities in the medium term. Future technology options such as renewable energy sources, efficiency potentials, or Carbon Capture and Storage (CCS) should also be analysed.

In addition, ideally models should be expanded to cover other greenhouse gases and material extraction categories, other environmental impacts and scarce biocapacity. Otherwise, the complex impacts of, for example, an international CCS strategy on energy efficiency, energy consumption, material extraction, and economic conditions and effects will not be fully covered.

The practical implications for modelling techniques are wide ranging but focus on the requirement to consider different types of energy in more ways than pure energy content. The ability to provide a constant flow of energy is clearly important, as is substitutability with other forms of energy and other technologies, and the impacts on greenhouse gas emissions. At present, it is only the specialised (partial) models that approach this level of detail, so one possible advance would be to improve the linkages between these models and those with an economic component.

Sustainable consumption and production

One of the most challenging policy topics that has emerged around the world during recent years is Sustainable Consumption and Production (SCP). This includes technical aspects such as the dissemination of new environmentally friendly technologies; green investment conditions and the costs of, and availability of, financing[54]; more meaningful prices (Victor, 2008); sustainable transport and housing; as well as the resource consumption and rebound effects which are discussed above.

[54] This is discussed in more depth later in this section.

So far, the political debate has mainly focused on environmental aspects and their technical solution. These solutions in turn usually take the form of goods and services (commodities). At the same time, economic growth is still regarded as the major indicator for a 'better life'.

Thus, the dominant debate about SCP neglects that:

- well-being is correlated with material consumption only up to a certain level
- well-being also depends on social aspects
- growth and rebound effects[55] compensate technological efficiency gains

Some authors (eg Lorek, 2009) argue that this weak approach to SCP neither meets the scope nor the urgency of the problem.

Thus, in addition to the discussion above on modelling the use of resources, for a more comprehensive analysis of SCP it would be preferable if modelling frameworks could take into account that sustainable consumption is a relation of human well-being and resource use. The production phase includes social aspects embedded in all factors, such as human and social rights, equity and decent work.

Many of the existing macroeconomic models would be able to capture most of these effects, if they could be quantified within the available data. The challenge is thus to define and quantify these factors and determine a way to summarise them (eg either in a composite indicator or dashboard of indicators) in the model outputs.

Social issues

Equality

Although the intensity and causes vary between countries, increasing inequalities can be observed between the global North and South, across OECD countries and between EU member states. The literature review in Chapter 2 highlights three key messages:

1. more equal societies almost always benefit everyone within them – the well-off as well as the poor (Wilkinson and Pickett, 2009)
2. distributional effects should be integrated into the design of economic policies (nef, 2006)
3. equality of opportunities matters more than equality of outcomes (including income) (OECD, 2008)

Complete equality is unfair but unlimited inequality is also unfair. Policy makers are therefore challenged to seek fair limits to the extent of inequality. EU policies strongly focus on the notion of 'equality of opportunities'. The EU Sustainable Development Strategy (2006: 4) calls, under the key objective 'social equity and cohesion', for promoting 'a democratic, socially inclusive, cohesive, healthy, safe and just society [...] that creates equal opportunities and combats discrimination'. The Commission declares in its communication 'Europe 2020' (COM (2010) 2020) that the benefits of economic growth should spread to all parts of the Union to ensure access and opportunities for all. The Social agenda (2006-2010) prioritises as one of three fundamental objectives the promotion of equal opportunities.

There is recent strong evidence that the level of poverty is much less important than the level of inequality in a society (Wilkinson and Pickett, 2009), yet an all-embracing

[55] See Barker et al (2009) for a model-based assessment or Stocker et al (2007) for an assessment based on overall resource productivity.

framework to tackle inequalities explicitly is largely missing at the European level. Policies instead tend to focus on particular issues, such as gender equality or equal opportunities for elderly and handicapped persons. The uneven and widening inequalities in the distribution of wealth are not picked up as a central theme although the contradiction between increasing inequalities and economic growth provides a good reason to question the ability of the current system to redistribute wealth fairly and effectively.

Due to the absence of theories of redistribution in macroeconomic theory, equality is also barely seen as a central issue in macroeconomic models. However, as the level of equality has a strong influence on the level of well-being there is an urge to integrate equality issues into the models of present and future societies. This is discussed further in Chapter 5, where we find that the main stumbling block to providing a better treatment of inequality is the structure of the available National Accounts data.

Green skills

While concerns about climate change and the unsustainable use of natural resources are growing, the promise of green jobs currently receives unprecedented attention. Europe is on the move towards a greener and more service-oriented economy. This shift implies the need for a great 'reskilling'.

Green jobs are broadly defined as 'jobs in the environmental sector and/or jobs requiring specific environment-related skills' and touch on up to 21 million jobs in Europe (Ecorys, 2009). Estimates of how many jobs might be created in Europe's green economy vary. The Commission's 2006 renewable energy 'roadmap' points to 650,000 jobs by 2020, while a renewable energy modelling initiative produced in 2003 nearly triples that number to 2.5 million (EurActiv, 2010). It is a valid question to ask what the skills profiles for these jobs are, and how the skills needed might change in the future, and this is currently being addressed at the European level[56].

The 'green sector' is changing fast, perhaps faster than most other sectors, and, given its variety and size, green jobs cover all sorts of skills. Data on skills profiles in the green economy is generally poor. However, it is certain that demand for low-skilled workers has decreased and the demand and rewards for higher-skilled workers have increased. Skills shortages can cause a danger for the green expansion and a number of sectors already face skills shortages (Ecorys, 2009).

Policy makers can anticipate changing skills needs and provide training schemes (eg developing life-long learning and vocational training policies) so that employees gain the skills needed to adjust to the changing economic conditions and job profiles. One of seven flagship initiatives in the Commission's 'Europe 2020' communication focuses on 'An agenda for new skills and jobs'. This initiative aims at modernising labour markets and empowering people through the acquisition of new skills to adapt to new conditions. The EU SDS also highlights that education is a prerequisite for promoting behavioural changes and providing all citizens with the key competences needed to achieve sustainable development.

The modelling of skills requirements is now fairly well established in Europe (see CEDEFOP, 2010) and is tightly linked into a macroeconomic context. The main limitations to the analysis in the context of green skills relate to the level of detail that is available from the data. The analysis is able to predict impacts on the numbers of

[56] By DG Employment: Studies on Sustainability Issues – Green Jobs; Trade and Labour, European Commission contract number VC/2010/0583.

high and low-skilled jobs but not, for example, on the different skill requirements for producers of wind turbines compared to producers of other capital goods.

Demographic changes

The rapid increase in global population over the last century, and accompanying increases in incomes, has raised concerns about whether population expansion is environmentally sustainable. More people require more resources and more land. The issue of stabilizing population is a difficult and controversial one, yet one that should not be ignored when talking about environmental sustainability. The environmental movement began with a focus on population but has regularly given in to political correctness.

While in the global picture the urban areas absorb population growth, in industrialised countries, the birth rate is in decline. But even that does not bring about sustainability. Our society is ageing and the EU workforce is about to shrink. Thus, the sustainability and adequacy of pensions will remain an important issue for the coming decades (see European Commission, 2009).

The European Sustainable Development Strategy (2006: 19) indirectly refers to the demographic challenge by stating that 'Member States should analyse the possible implications of demographic change for land use and resource and energy consumption as well as mobility, and take them into account in planning and investment at all levels'. Other European policies to target this issue are marked by their absence.

This view is also backed up by a relative absence of modelling studies. While almost all the available models are able to provide some assessment of the impact of demographic change on particular aspects of sustainability, very few have been used to do so. This is partly because, in the past, there has been little requirement for such analysis, as populations have remained fairly stable, but this is an area where existing models could provide an assessment with little further development.

Transitional issues

A series of global challenges is severely impacting the EU's ability to sustain prosperity in the long term. Examples include peak oil, increasing resource scarcity and dependency, and climate change. It is difficult to be precise about the scale of the necessary transition as the challenges are multiple, complex and interrelated, and affect a wide spectrum of different sectors. The scale will also vary according to local circumstances, and the required transition will be a bigger challenge for some countries than for others. There is, however, broad consensus that major investments throughout the economy are needed over the coming decades. The case for a stimulus focused on energy and carbon is very strong and policy interventions are needed.

In the current debate such a green stimulus package is often called a 'Green New Deal' or 'Green Growth'. UNEP's Global Green New Deal initiative, for instance, aims to ensure that an appropriate policy mix reduces resource dependency and protects ecosystems, while fostering economic recovery, creating employment and restoring stability to financial, political and ecosystems (UNEP, 2009). The OECD's Green Growth strategy aims at greening the mainstream growth model in a comprehensive framework by bringing together economic, environmental, technological, financial and development issues. A first report was due to be delivered in June 2010.

A rapid increase in resource productivity and the emergence of renewable energies are definitely important, but the question is whether the extent of change can realistically be large enough in order to manage a smooth transition. The rate of transition that is needed can be shown for climate change targets. For example, if Austria wanted to achieve its Copenhagen greenhouse gas targets for 2050 only by an increase in energy efficiency, even at a stable GDP-level, the annual increase would have to be 3½%, compared to 1% annually in recent decades. With 2% annual growth added, the increase would have to be around 5½% each year (Standard, 2009). The global carbon intensity ($gCO_2/\$$) would have to go down from 768 $gCO_2/\$$ to 36 $gCO_2/\$$ by 2050 in order to achieve the 450 ppm target, if the world population rises to 9 billion people and trends in income growth continue (Jackson, 2009). The enormous reduction in carbon intensity and increase in energy efficiency, that is necessary to stay within ecological limits, if economic growth is to go on, have triggered a discussion on whether the transition will only be possible without economic growth, at least in the highly developed countries.

In order to understand and model a transition, not only technology, economy, institutions and ecology have to be considered, but also behaviour, culture and images and paradigms within the changing society (Kemp and Loorbach, 2003).

The necessity of a social transition has been increasingly acknowledged in Europe in recent years, with the Netherlands taking a leading role. In 2001, the Dutch government adopted the concept of 'Transition management' (Kemp and Loorbach, 2003). This is a governance approach that tries to overcome the main difficulties of governance for sustainability, eg short-term thinking and the uncertainty about solutions involving systemic changes, for example by focusing on long-term goals and maintaining a variety of political change options, comparable to portfolio management in finance.

A great transition imposes big challenges on macroeconomic models. Cultural changes influencing the society's members' behaviour must be allowed for. Externalities have to be included in the model, measured and included in the model's prices. At the same time, supplemental political discrimination against socially and/or environmentally destructive sectors, eg via specific taxes, should be possible in the models. Additionally, aspects of the core economy that are normally not measured in macroeconomic models will gain in importance, which will make the inclusion of factors such as home-work and volunteering desirable. Finally, better indicators of prosperity than GDP per capita should be put in place as outputs of these models.

In summary, there are many different aspects to consider when assessing this topic and when looking at large-scale changes in general. For such scenarios, it is also important to consider the path with which the targets are met as well as the endpoint. The issue of large-scale change is discussed further in Chapter 5.

Green investment

To achieve a transition such as that described above, significant levels of investment will be required throughout the world's economies. As investment is a long-term driver of economic growth, its treatment in macroeconomic models deserves special attention.

Different model structures provide different interpretations of investment which can influence the scale of impact seen from investment. In an equilibrium model the total level of investment must equal the total level of savings and, all other things being equal, an increase in green investment will lead to a reduction in (economically more optimal) investment elsewhere and a reduction in economic output. However, in other modelling approaches an increase in green investment can lead to the development of new industries and lead to a net economic benefit.

Clearly these different outcomes could have implications for policy responses. Our conclusion therefore is that this is an area where greater clarity is needed in the descriptions of the models that are used.

Cross-cutting Issues

Quality Improvements…

The models should be able to take into account that qualitative, as well as quantitative, factors have a strong influence on well-being. In particular, we consider quality of employment and quality of socio-economic development.

…of employment

The EU is working not only to create more, but also to create better, jobs particularly through the European Employment Strategy. The strategy was set up to encourage exchange of information and best practices for more and better jobs in all member states. The Employment Guidelines form an integral part of the strategy and highlight, in their first priority, for national employment, policies to: ‘implement employment policies aiming at achieving full employment, *improving quality* and productivity *at work*, and strengthening social and territorial cohesion.’ An EU agency dedicated to the improvement of living and working conditions, Eurofound, provides regular information on quality of work in member states and at the EU level. By conducting European Working Conditions Surveys (EWCS) every five years, the Foundation studies working conditions throughout Europe and indicates the extent and type of changes affecting the workforce and the quality of work.

In order to capture sustainability fully, it would be necessary that models not only deliver on quantitative data but also on targets for quality jobs, including adequate income, equal pay for equal work and good social protection systems. Some of these aims could be assessed using existing models if adequate definitions and data are available but other issues, such as quality of work, would require a quantifiable definition before being included in a model.

…of socio-economic development

Socio-economic development, expressed as GDP, is predominantly seen as the main target variable in macroeconomic models. However, recent debates have increasingly scrutinized the adequacy of current measures of economic performance, in particular the ones based on GDP figures, and the relevance of these figures for measuring societal well-being (for example the EC’s Beyond GDP initiative and the Stiglitz Commission). Concepts such as the ‘Measure of Economic Welfare’, ‘Genuine Saving Rate’, ‘Human Development Index’ or ‘Index of Sustainable Economic Welfare’ (see Section 3.3) show that, since around 1980, traditional GDP development has decoupled from ‘real’ economic performance and societal progress.

Improvements to the indicators should focus on:

- improvements to existing measures of economic performance; this relates to questions of how to measure GDP better in order to capture quality improvements and how to model the composition of growth
- complementing existing measures with environmental and social indicators to form new target variables

4.3 Methodology

Introduction

We now turn to ways in which we would like some of the more complex issues to be covered in the available suite of macroeconomic models. In Chapter 3 we identified four major methodological issues in existing models that should be explored further:

- exogenous inputs and linkages between policy areas
- treatment of technology
- the role of non-linearities
- treatment of uncertainty

These are discussed in turn below, again with the focus on what an ideal representation would look like. Section 4.4 then considers how these may relate to some of the specific policy areas in the models, for example if a particular policy linkage is subject to a high degree of non-linearity. Chapter 5 considers the practicalities of implementing the suggestions.

Linkages and exogeneity

In existing modelling approaches, the explicit level of exogeneity varies from almost complete exogeneity (eg a single equation where the values of explanatory variables are 'given') to approaches involving a small number of (exogenous) input assumptions for a systems model. It should be noted, however, that when the implicit exogenous inputs are taken into consideration, the degree of exogeneity is much higher, for all the model types.

Ideally, to provide the best possible representation of reality, nearly all model variables would be endogenous rather than exogenous; as these are links that exist in the real world. However, in practice this is clearly not possible, as the model would quickly become too complex to operate, and probably unnecessarily complex for most of the questions it is designed to answer.

We therefore address the issue of exogeneity by considering what are the most important factors that should be treated as endogenous, and address both the inputs that are explicitly defined as exogenous, and those that are implicit input assumptions. There are obviously strong links from this question to the recommended scope of the models in terms of policy areas, discussed in Section 4.2 above, and this is also picked up on in Section 4.4.

We have not found any cases where a model treats a linkage that should be exogenous as endogenous, so our task is to recommend where improvements should be made to the existing treatment in models by making more of the relationships endogenous. The most common exogenous inputs are:

- demographic development and implied rates of consumption (most model types)
- activities of government (most model types)
- stocks and prices of global resources (most model types)
- economic development (most partial model types excluding an economic component)

We discuss each of these in more detail in Section 4.4.

The role of combined models

Chapter 3 set out some of the advantages and problems associated with linking distinct modelling frameworks. At least with current capacities and institutional frameworks, it seems likely that there are some cases where the approach of combining two or more models is preferable to building a single large model. Therefore, it is not necessarily the case that a single model should cover all the policy areas. Our conclusion is that the approach should be chosen on a case-by-case basis.

Linkages with socio-economic development

Figure 3.3 shows that economics is well linked to most of the other policy areas, but these linkages tend to be in one direction. However, it should be noted that putting a price on these linkages allows an interaction in the other direction. For example, even though there is not normally a link from environment to energy, a carbon tax affects energy demand. For some of the most common analyses, it may not therefore be necessary to create a complete new set of linkages, but rather widen the factors explaining current linkages.

Implicit assumptions

In addition, it would be an improvement if the implicit assumptions described in Chapter 3 were made more open and perhaps, in some cases, made endogenous, as this would improve the linkages from aspects of sustainable development to the macroeconomy. As described in Chapter 3, these assumptions are generally that things do not suddenly change in a dramatic manner, so are closely linked to the issue of uncertainty (see Table 3.6); to identify a comprehensive list would be a separate study in its own right, but Table 4.1 provides some examples of the implicit assumptions that might be used in a macroeconomic model, based on the SDI categories.

TABLE 4.1: EXAMPLES OF IMPLICIT ASSUMPTIONS USED BY A MACROECONOMIC MODEL

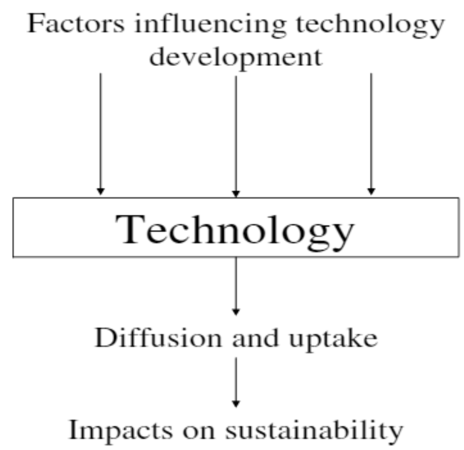
Theme 1: Socio-economic development	General financial stability
Theme 2: Sustainable cons'n and prod'n	Security of key supply routes
Theme 3: Social inclusion	Social stability, no unrest
Theme 4: Demographic changes	Role of natural disasters fixed
Theme 5: Public health	No major changes in health or productivity patterns
Theme 6: Climate change and energy	The climate remains stable
Theme 7: Sustainable transport	Fuel supplies remain available
Theme 8: Natural resources	Land remains available for general use
Theme 9: Global partnership	Countries generally cooperate
Theme 10: Good governance	Stability in democratic institutions

Technology

It is now widely accepted that it is necessary to include technology as a fully endogenous component in a model of sustainability. This means that the factors that influence technological progress need to be endogenous, as well as the indicators that are themselves affected by new technologies (see Figure 4.1).

It should be noted, however, that this first requires an understanding of how technologies develop, and indeed a way of measuring technological progress, before this representation can be incorporated into a quantitative computer model. Much research has been done in this area, but there is still no standard specification to use.

Figure 4.1: Representation of Technology



A detailed analysis also needs to make the distinction between different sorts of technologies. As described in Chapter 3, it is usually the case that only physical technologies are included in the existing models, again because these are easier to measure through available economic data. Ideally we would combine the preferential aspects of the top-down and bottom-up approaches to have:

- a wide range of technologies that are explicitly defined, covering all relevant sectors and policy areas
- detailed characteristics for each technology

Chapter 5 picks up on how realistic this approach is and indeed whether it is desirable for ex-ante sustainability analysis, given the problem with predicting future technologies described below.

Factors influencing progress

As a minimum we suggest that there are at least three important factors that may influence the development and deployment of new technologies:

- economic and financial development
- government policy
- social trends

All of these factors influence the demand for new types of products, for example from individuals, companies or government. The first two can also directly affect supply, for example through the availability of investment funding for research.

It is important to note the interaction between supply and demand, which goes beyond the standard representation of growth in neoclassical economics. This also has implications for both the top-down and bottom-up approaches described in Chapter 3 as they cannot separate supply and demand as easily as is often suggested.

Spillover effects

Another issue that is often not addressed in macroeconomic models is the spillover effects of technologies, both between sectors and between countries. It is likely that recent trends of ever-greater specialisation and global supply chains have increased the impacts of spillovers. For example, it could be argued that much of China's recent growth is the result of the adoption of technologies that already exist in other countries.

In sectors with global firms, such as the car industry, it seems quite obvious that development of technology in one country will lead to rapid adoption in other countries.

Again, this is an area of ongoing research that is made more difficult by measurement issues, but we suggest that it is a feature that is lacking from many global models.

Effects of technology

The existing approach in models, that technology influences either the quality of production or unit prices (top-down approach) or specific technologies are assigned behavioural characteristics (bottom-up approach) seems sound. Ideally the model should also be able to incorporate the development of future technologies, but this is far from easy.

Finding an empirical basis for ex-ante projections

Predicting future technology patterns is a problem that goes beyond modelling. The two methodologies that are commonly used in the models both have empirical foundations, but run up against the problem of defining and characterising something that does not yet exist.

In bottom-up models, with a range of technologies explicitly defined, the list of technologies is clearly a constraint as the model implicitly assumes that there are no alternatives available (this assumption is sometimes defined explicitly). The best possible approach is therefore to conduct as wide a review of the technologies as is possible, and possibly including speculative technologies for which some information is known.

At first glance the issue may seem irrelevant to top-down models; as they do not define historical technologies they do not need to define future ones either (and instead assume historical patterns remain the same). However, even given this assumption, the treatment is subject to two strong limitations:

- technological progress tends to come in bursts, for example after the development of the internet, with spillovers between sectors as well as between regions
- game-changing technologies (for example electric vehicles, which shift consumption away from fossil fuels for the first time) are not taken into account

In addition, the presentation of implicit indicators is less attractive, with the inevitable questions of how and why usually left outside the model structure.

Summary

In summary, it is clear that some representation of technological progress is required in a model of sustainability, and that it must be linked to other model variables, to form a central part of an endogenous system. Although current model-based treatments of technology do reflect this to some extent, it is also probably fair to say that they tend to be relatively crude and fail to recognise many of the drivers of technological development and the range of characteristics of different types of technologies. It is desirable, but not realistic, to expect a model to predict future trends in technologies that may not yet exist.

Non-linearities and assumptions in parameterisation

The short answer to whether a model of sustainability should be able to take non-linearities into account is an emphatic yes; there are many examples where it may not be appropriate to use (log) linear approximations. As discussed in Chapter 3, this is particularly the case when considering:

- large-scale changes

- long-term transitions

Types of non-linear relationships

We must also consider the different types of non-linearities that exist, as the accuracy of linear approximations varies for each type. As the approach required would differ, the possibility of taking each of these into account is discussed in Chapter 5.

- Curved relationships, as described in Figure 3.2 – the further that the model is pushed from the base position, the less accurate the assumed relationship will be.
- Threshold effects – in this type of relationship there may be no impact at all until a certain point is reached, and then a tipping point is passed. For example, in electricity production the marginal fuel that is used is gas or coal, depending on which is cheaper; relative price movements make little short-term difference in consumption of each fuel unless the prices cross, which will lead to a sudden large change. In summary, assuming a linear relationship may be inaccurate, even for small changes.
- Asymmetrical relationships – it is usually assumed that an increase in an input has the equal and reverse effect of a decrease of the same magnitude in that input. As described above, thresholds are an example of where this may not be the case, but there are more general cases where we might expect increases and decreases not to have opposite effects. This particularly relates to the interaction between stocks and flows, and the role of fixed costs in production decisions. For example, if the conditions become right for investment in new equipment, this equipment is not usually scrapped a year later if conditions revert.
- Irreversibility - an extreme example of an asymmetric relationship is one that is irreversible, where the parameter in one direction is zero. In these cases the transition period is as important as the long-run outcome and must be discussed explicitly. The most obvious example is in modelling biodiversity, where once a species is removed it does not come back. This means the path, as well as the destination, is important.

Changes to parameters over time

A key simplifying assumption in most standard modelling approaches is that behavioural relationships represented in model parameters remain constant over time. The counter argument is that individuals behave differently now compared to 30 years ago, and we would expect changes in patterns to carry on into the future.

Chapter 5 describes some of the ways in which this issue could be addressed.

Changes to parameters in response to input shocks

As well as possible gradual changes to behavioural patterns, it should also be noted that there may be sudden changes in response to shocks. Responses to shocks can be picked up through the use of dummy variables but, if these are used in a forward-looking context, it is necessary to make assumptions about the size of the effects of the shocks.

A good example is the effect of the recent financial and economic crisis; many commentators suggested that behaviour would change as a result, for example with individuals becoming more risk averse. However, the standard modelling approach would assume no change in behaviour. Once historical data become available the change in behaviour can be estimated, but for now it would have to be assumed.

The Lucas Critique essentially discusses this point from a policy perspective, noting that changing the circumstances may change the behaviour.

Summary

The common theme running through all of these points about parameterisation of models is that it is by no means ideal to assume that model parameters that have been derived from one particular situation can be applied in a different context, whether that is due to:

- input variables lying outside their historical range
- a different time period
- a different policy context

The loss of accuracy will be greater the further circumstances being considered move from the base position.

However, clearly model parameters need to be obtained somehow if we are to use models to assess sustainability in a quantitative manner. This is a key issue that is discussed in Chapter 5.

Treatment of uncertainty

Chapter 3 presents some of the sources of uncertainty and the main approaches for dealing with uncertainty. This is increasingly being recognised as an important issue and, similar to the discussion above, the level of uncertainty grows the further away we move from the base position. We see two separate issues:

- how uncertainty affects real-world behaviour
- treatment of uncertainty from the model itself

Measurement issues

It must be recognised that the term uncertainty is used as a general indication of possible deviation from the expected outcome. There are many different sources of uncertainty which will affect decisions made by different economic agents in different ways, with impacts likely to vary over time, and between population groups. To try to capture this in a single indicator is like trying to describe a statistical distribution by only using its mean and variance.

The most common approach (other than ignoring the issue) has been to use measures of volatility as proxy variables, for example in stock markets or commodity prices. However, this treatment is clearly not very satisfactory as each indicator is subject to its own variation and uncertainty.

Relationship with investment

The first of the bullet points above is particularly important when considering investment decisions as it is not difficult to imagine how higher levels of uncertainty could act as a disincentive to invest.

One policy example where this is particularly relevant is the comparison of emissions taxes and trading schemes. One of the main advantages of a tax system is that it provides a certain guaranteed price that allows businesses to invest with confidence. However, this is usually neglected in the modelling that excludes the effects of uncertainty on human behaviour. Hence the models cannot adequately answer the question of which system is preferable.

Other economic interactions

It should also be noted that investment is not the only economic indicator that is influenced by levels of uncertainty. Firms' employment decisions, especially in countries with highly-regulated labour markets, will also reflect uncertainty in their local markets. Some other recent examples have led to the build-up of economic imbalances on a global scale:

- the accumulation of large foreign reserves by countries in the far east to protect against market volatility
- a lack of public health care in these countries has driven up household savings ratios to protect against future illness

Our conclusion is that a better definition and treatment of how uncertainty affects behavioural patterns is a key area of development, and that this should play a more central role in the analysis of sustainability, especially when considering long-term outcomes or large-scale transitions. How this might be achieved is discussed in Chapter 5.

Model-based uncertainty

Model-based uncertainty is a slightly different issue. This relates to inaccuracies within the model approach and therefore encapsulates many of the points outlined in this section. However, given that an economic model will never be able to give a perfect representation of reality, how this uncertainty is interpreted is also an important issue.

The current approach, as described in Section 3.5, is to produce a basic sensitivity analysis that tests model outcomes against a variable set of key assumptions, for example aggregate economic growth rates or energy prices, or puts these together to form alternative scenarios of future long-term visions of society. However, this only assesses the uncertainty around a very small number of inputs. Each input data point, parameter and assumption carries its own range of uncertainty and to assess all possible sources would be a much larger task. To our knowledge no such exercise has been carried out on a macroeconomic model, although we consider this further in Chapter 5.

4.4 The interaction between model scope and methodological issues

Introduction

In this section we briefly consider some of the most important cross-overs between the methodological issues and the policy areas (and linkages between policy areas). We discuss each of the four main methodological issues (exogenous inputs, technology, non-linearities, uncertainty) in turn, allowing us to give some examples of areas where they are important. In the final part of this section we consider the interactions between the methodological issues themselves.

Exogenous inputs

As discussed in Section 4.2, issues of exogeneity cut across all of the policy areas but, for reasons of having a manageable model, it is preferable, and probably necessary, to hold some relationships as exogenous. We discuss the most common factors below and then some more general issues about analyses where many linkages may be required.

Demographic development

The key question to ask is whether the policies that are being modelled are likely to change demographic indicators. In many cases the answer is likely to be no and, for birth and death rates, this will usually be the case[57] (meaning that current approaches are reasonable). The issue of migration patterns is potentially more problematic, however, as they can change much more quickly than underlying birth and death rates.

In Section 4.2 we note that demographic development can have important impacts on sustainability, both through consumption of resources and through the more social aspects of sustainability. Therefore in an ideal model migration is something that should be taken into account and it becomes more important as the spatial resolution of the model increases.

[57] In long-term scenarios for developing countries it is conceivable that the rate of economic development could affect population growth, although even in this case the changes will be small.

The role of government

Treating government as exogenous is such a standard assumption that it is not normally questioned. The links between policy areas are obvious, from good governance to all other areas, particularly those where government is most active.

In most cases a 'business-as-usual' approach is considered adequate. However, in more extreme situations the assumption becomes less clear cut. For example, a scenario where unemployment increases dramatically may not be politically feasible. If the model is producing unrealistic results, clearly this issue should be addressed.

Resource stocks and supplies

This issue relates mainly to the linkages from the policy areas concerning energy, natural resources and sustainable production to economic development. As discussed in Section 4.2, the fact that physical stocks of resources are usually treated as unlimited (land is sometimes an exception) is clearly a weakness in addressing issues of sustainability, particularly in cases where stocks begin to run low and limitations are placed on flows of supplies.

The reasons for these assumptions (which apply to supplies and to prices) are well documented, and picked up on in Chapter 5, however, we see it as an unambiguous fact that the models should be able to offer some treatment of this issue.

Economic view

Partial models typically use a set of economic figures as an exogenous input (in the same way that most models use a set of population figures as an exogenous input), breaking the linkages back to economic development. If the models are being applied for simulations where no change in economic activity is expected, this seems reasonable, but it is clearly not appropriate for use in assessing large-scale change.

More general issues – policy areas with many linkages

Our final point considers policy areas where there are strong linkages to many other policy areas, which may or may not be treated as exogenous in the model. The emission of greenhouse gases is a good, but by no means the only, example of this. Emissions may be the result of energy consumption, agriculture, waste, land use changes or some other form of economic production. If, as is commonly the case, a model is used to find the least-cost way of reducing emissions, it should fully cover all of these factors, with strong linkages between the different policy areas. If necessary, this could include linking models from the relevant fields.

The role of technology

Technology cuts across all of the policy areas and is also relevant to many of the linkages between policy areas. However, it is probably linkages between the economy, government policy and the other areas that are most important as these provide the context for the investment that drives technological development (social preferences was also identified as a driver of technology).

The policy areas that are most likely to benefit from the effects of technology (other than economic development) are likely to change over time as different issues gain prominence. Energy, climate change and transport are currently high on the list of priorities.

Non-linearities

It is more difficult to highlight the areas where non-linearities are most important as it requires a detailed understanding of the key relationships in each category. Climate change is a well-known example, where efforts are made to take non-linear feedbacks into account, and dose-response functions used for estimating health impacts explicitly address threshold effects, but all the areas will be subject to the issue to a certain extent, especially when considering large-scale change.

Uncertainty

Section 4.3 identified two main ways in which uncertainty should be addressed, as a variable within the model and as a feature of the model itself. These are discussed in turn below.

Uncertainty as a factor in the model

It seems quite clear that uncertainty affects economic behaviour, including investment and consumption decisions, that in turn impacts on sustainability (see also Table 3.6). Uncertainty could also be an impediment to large-scale transition, for example to sustainable structures. All of the policy areas, but particularly those related to investment, are affected.

Model uncertainty

Again analysis in all of the policy areas is subject to some uncertainty, although the sources and types of uncertainty differ. For example, while economic models are able to focus on uncertainty related to their parameters, the structure of the whole climate system, as represented by the models, is subject to uncertainty.

There is a cross-over between uncertainty and all of the other methodological issues we have highlighted (see below) but we should also note that the level of uncertainty is often related to the timeframe and scale of the model simulations.

Cross-over between methodological issues

Table 4.2 shows how these methodological issues are themselves interlinked and should not be considered in isolation.

TABLE 4.2: INTERACTION BETWEEN KEY METHODOLOGICAL ISSUES

	Exogeneity	Technology	Non-linearities
Technology	Exogenous assumptions are made about the availability of technologies, if not how they are developed.		
Parameterisation and non-linearities	Model parameters are essentially a set of exogenous assumptions.	Technology is irreversible and often happens in sharp bursts.	
Uncertainty	The assumptions made on exogenous inputs are a source of uncertainty.	By definition, there is uncertainty about future technologies.	The accuracy of parameters is a key source of uncertainty.

4.5 A completely new approach that is separated from economics?

Part of the aim of this study was to find ways in which we could bring macroeconomics and sustainable development closer together, and we have not found that macroeconomics and sustainable development are completely irreconcilable. However, one possible approach to assessing sustainability would be to remove economics from the picture altogether.

Focusing only on physical units

This could be represented in a model based in physical units, for example tonnes of production, square kilometres of land and mega-watt hours of energy, with a clear definition of the available stocks of each resource. Annual or monthly flows of each resource would then be determined to meet particular production requirements.

This type of analysis is not completely new, for example it is addressed to some extent in physical input-output tables (PIOTs) that replace the usual monetary values with equivalents based on weight or some other physical measure of volume[58]. The flows of resources between sectors are thus recorded. It should also be noted that existing models calculate energy consumption and emissions in physical units, even if they are often later converted to monetary units.

However, while the accounting relationships are straight forward, it is less clear how behavioural relationships should be covered in a model that does not include any economic component. For example, given the current preference for market-based instruments as a tool of furthering sustainable development, the value of developing a new modelling approach that does not include prices at all is more questionable even from the viewpoint that price signals can be misleading. It should also be noted that many of the issues highlighted above, such as technology and non-linearities, would still be relevant to this new approach.

Therefore our conclusion from this study is that existing economics-based approaches may be flawed in the ways that we have highlighted, and could be improved upon, as we discuss in the next chapter. However, it is clear that macroeconomics and the various types of models that go with it, does have a lot to offer to sustainability assessment. Nevertheless, it should not be forgotten that alternative approaches do exist and, as described above, there are cases where they clearly add value to the analysis.

[58] For further information see Weisz and Duchin (2006) and Giljum et al (2007).

5 The Potential for Integrated Modelling

5.1 Introduction

In this chapter we consider how well existing models cover the most important aspects of sustainability and what improvements can realistically be made to meet the main requirements. This chapter considers the findings from Chapter 4 from a practical perspective and addresses the following points:

- the degree to which the models cover the key policy areas and linkages between these policy areas
- the scope for improved treatment of the key linkages between these policy areas

Sections 5.2 and 5.3 correspond to Sections 4.2 and 4.3 in Chapter 4, which raised many of the issues that we discuss here. We first consider the coverage of policy areas and the linkages between policy areas, and then the main methodological issues. Our findings are summarised in the form of recommendations for future research and development in Chapter 6.

5.2 Coverage of key policy areas and linkages between policy areas

Chapter 3 provided a broad overview of how existing models cover the policy areas defined by the EU's Sustainable Development Indicators and identified the linkages within existing models between these policy areas. Chapter 4 considered the most important issues within these policy areas that the models should be able to cover.

This section combines and builds on both sets of results to answer the following questions:

- Do the existing models cover the policy areas in detail?
- Are the necessary linkages there?

If the answer to either of these questions is no, we consider if it would be possible to improve the existing treatment in the macroeconomic models. We expand on some of the most important issues and questions that are outlined in Chapter 4 in the paragraphs below, grouping some of the questions where relevant. There are often links to the methodological issues that we pick up on in more detail in the next section.

Weak and strong sustainability, decoupling resource use from growth

Which thresholds could be reached through the use of different forms of natural capital (material, energy, water, land, absorption of emissions and wastes etc) leading to tipping-point phenomena with possibly irreversible consequences for ecosystem services?

This issue goes beyond modelling, as the thresholds need to be recognized and understood before they can be represented in a model (although the model may be more suitable for assessing the secondary effects of crossing this threshold). Before this exercise can be carried out it is first necessary to identify the critical forms of natural capital.

It is noted that the task of determining thresholds is clearly difficult when considering situations that have never previously been encountered. We discuss threshold effects and irreversibility more in Section 5.3.

Modelling resource use

More generally, it is noted that existing models are unable to answer many of the questions that are posed because, as we showed in Chapter 3, they often do not explicitly include consumption of resources other than energy. In particular, the area of consumption of material inputs is largely unexplored within a dynamic macroeconomic framework[59]. Our findings are that, with better data and definitions available, this is an area where improvements could be made relatively easily.

A further step could be to incorporate measures of waste into a macroeconomic modelling framework. This would require some thought about different types of waste (especially toxic waste, but also differences between other types, such as agricultural and urban waste) and how to account for different methods of disposal. The timing of generation of waste, particularly from capital goods, is also difficult to determine[60].

In which ways do economies depend on different forms of 'critical natural capital' and where are ecological 'hotspots' located where strong sustainability principles need to be applied in the design and implementation of policy instruments?

Again this question relies on the most important issues and forms of natural capital being identified, which is not always the case. In cases where identification is possible, the main obstacle to modelling is likely to be either data availability (particularly at the detailed level) or a lack of understanding of the key behavioural relationships.

It should also be noted that existing estimation techniques could be used to carry out an empirical analysis of the possible rates of substitutions between different factors of production. This exercise could identify the truly 'critical natural capital' on an empirical basis.

What would be the economic (and social) implications of a cap on resource consumption targeted towards absolute reduction of human use of (different types of) natural capital?

In current macroeconomic models, an absolute cap on supply is nearly always translated into a higher price, albeit perhaps influenced by investment and technology. Existing models are very good at addressing this within the current context but they are much less adept at assessing extreme constraints where behavioural patterns will be much less predictable. Another methodological issue is how to model prices for goods that traditionally are regarded as freely available (eg water, clean air).

As has been raised throughout this report, the degree of substitutability that is assumed or estimated is also important.

Beyond these points, however, it is difficult to see how existing treatments could be improved on, without inventing a completely new modelling framework.

Natural resources – resource scarcity

Can we investigate how resource scarcities might affect future economic growth?

Which industries that are highly dependent on non-renewable resources will likely be affected by future scarcities?

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[59] See Section 3.4. It is noted that Material Flows Analysis based on static input-output relationships is much more common.

[60] Pollitt (2008) briefly describes the problems of finding an empirical relationship between consumption of materials and generation of waste.

Can we identify intersectoral connections, can we trace the flow of specific resources through the economic system?

There are two ways to approach these issues that, from a modelling perspective, are related:

- A partial analysis of industry supply chains would give an indication of industries that are sensitive to certain commodities, at a detailed level. However, this would not include the full range of intersectoral connections across the economy so could miss important second and third round effects.
- An input-output analysis or a full model-based approach (either monetary or physical) could capture all the secondary effects, but only at a pre-defined level of detail (typically one that is more aggregated than that provided through partial analysis of industry supply chains)

The first of these requires a more ad hoc approach that relies on obtaining information on production functions and supply chains from industry experts; although it could be set up relatively easily it would only be appropriate for that particular sector. The second approach requires the development of a more general approach that could be applied to other sectors. Both are technically feasible with existing modelling structures and techniques and could be combined to offer a comprehensive analysis. However, in both cases data inputs would be important for determining the accuracy of results.

Can we assess how the development of 'green industries' such as renewable energy production might be affected by scarcities of non-renewable resources?

Other than the issue identified above of how a macroeconomic model treats scarcity, the identification of 'eco-industries' remains a key weakness in existing models. This is almost entirely due to the structure of data sets, which are based on economic, rather than ecological, principles. To improve upon this situation, the most important eco-industries need to be identified and recognized in the official international classifications (eg NACE - although NACE 2.0 is recognised as an improvement on the previous version[61], coverage of the eco-industries is still limited).

Natural resources – pressure on land and water

Is it possible to identify the specific users or pressures competing for resources such as land and water (eg agriculture and industry at the highest level)?

Can we quantify to what extent each user (eg in an economic sector) is putting pressure on these resources?

There is no theoretical reason why the models cannot address both of these issues, given the level of data that are available. Even if they do not currently do so, the models should be able to cope with irreversible change (eg pollution of a water source or rainforest destruction) with only a limited amount of development. Furthermore, a large-scale model could be able to handle the interaction between these users of resources.

What are the impacts on economic growth of different economic sectors (in particular, agriculture) brought about by competition for resources?

The models are well-suited to address this issue as competition can be measured using price impacts (as long as the price impacts are adequately estimated). It is true that a

[61] European Commission (2009b).

detailed analysis requires close integration of an economic model with one of agriculture, but this is certainly possible and there is a relatively wide range of agricultural models available. For example, all the models that are based on the GTAP database have access to a wide range of agricultural commodities, with links to other economic sectors.

More generally, there is no reason why existing macroeconomic models could not be used to assess scenarios where economic growth slows or stops completely (see Section 2.6). Such an exercise would need to be carefully thought out so as not to introduce bias (for example through misleading assumptions) but the framework at least exists to carry out such an analysis. This could be a useful tool for framing future policy debate about the composition of future growth patterns.

Can we model the feedbacks that pressures on environmental resources have on aspects such as health and quality of life?

This issue highlights one of the differences between traditional and ecological economics. Most existing models represent these feedbacks in simple monetary values which are added to, or subtracted from, aggregate GDP or utility. This implies substitutability between outcomes and ignores factors such as irreversibility.

A better approach would be to include the effects directly, such as demand for health care (eg poorer health is likely to increase demand for nurses), although it would be better still in this example not to focus purely on economic outcomes. This could possibly be met through linking existing models and could fit into current modelling frameworks.

Natural resources – limited carrying capacity

Models should be capable of defining the carrying capacity of different types of ecosystems and of tracing which countries and world regions, and which parts of the economic system, would most be heavily affected by an ecological overshoot beyond these limits.

The implicit treatment in existing modelling approaches is that the carrying capacity is greater than the rate of withdrawal. If the maximum carrying capacity is known, there is no theoretical reason that the models cannot take this into account; however, a preliminary exercise to identify and quantify carrying capacities is required first. Given the level of detail in the available data, there is also no reason why this analysis cannot be linked to the sectors that are most reliant on inputs from the ecosystem.

What is less clear is how the models would be able to deal with a situation where carrying capacities are stretched or are exceeded. Again this comes back to threshold effects, and the issue is not dissimilar to that of how to deal with limited supplies of resources, except it is to do with flows rather than stocks. However, the issues are strongly related; partly because there is usually no empirical basis, but also because relationships are likely to be unpredictable and highly non-linear (eg behavioural responses to water shortages, or collapsing fish stocks).

Natural resources – direct links from the environment to the economic system

Can macroeconomic models be used to assess issues related to the generation of waste?

Although the existing models do not provide a comprehensive analysis of the generation of waste, this would be technically feasible with an extension to existing capabilities. However, it would be preferable (although not absolutely necessary[62]) to include physical indicators for consumption of materials first and the following issues would need to be addressed:

- finding an empirical link between the consumption of materials and generation of waste, including delays between purchase and disposal of goods
- determining different types of waste (especially toxic waste)
- determining different methods of waste management
- whether it is possible to include price effects or other behavioural determinants

Can macroeconomic models be used to consider loss of biodiversity?

The links between economic activity and biodiversity (with land use as an intermediate step) are highly complex and dependent on geographical location. Although it would be possible to represent these links in a general model a substantial development would be required and it is not clear where the feedbacks to the economy would occur, or if they should be included at all.

Climate change & energy – outputs of environmental sustainability

Starting from a biophysical basis, models should treat externalities as fundamental components of the total economic model.

It is true that the neoclassical approach regards externalities as a cost to be subtracted at the end of a GDP calculation. However, this also partly reflects policy makers' desire to summarise results into a single indicator that can be easily interpreted.

This does not have to be the case, as the integrated energy-environment-economy models produce economic and environmental outputs in their own units. In the case of greenhouse gas emissions, Integrated Assessment Models go a step further and use the environmental outputs to predict changes in the climate (although this again is sometimes later reduced to an economic cost).

Our response is therefore that this is an issue that can be addressed without a large amount of additional development work, as it relates to how the models are applied as well as to their underlying structure.

Climate change & energy – the role and value of energy

Can we take into account supply-side developments, like crude oil stocks and supply constraints, and their medium-term price implications?

This question is a specific case of the general issue of limited stocks of supply, but is one that has been discussed at length. Most of the existing models[63] use an extreme assumption, that supply is perfectly elastic, so any changes in demand are matched by changes in supply and prices are unchanged. However, the opposite extreme, that supply is perfectly inelastic (ie fixed), has more recently been put forward[64].

The implications of these assumptions are quite strong. If the supply of oil is fixed, any reductions in demand in one country or region will be matched by increases in demand (via a lower price) in others. A European policy to reduce domestic demand would therefore have no net impact on global consumption.

The reality is, of course, somewhere in between the two extreme cases. While it is true that oil fields do often operate at maximum capacity, regardless of demand, there

[62] An example is the REEIO model, see http://www.scpnet.org.uk/downloads/REEIO/REEIO%20Manual%20(Version%203).pdf

[63] Other approaches, such as in the QUEST model, are noted (see Conte et al, 2010) but are less common.

[64] See Sinn (2009).

are some sources, such as tar sands, that only become economic when the oil price reaches a certain level.

To incorporate this into a model, however, is extremely difficult due to the number of uncertain factors involved, many of which would usually be regarded as exogenous in the modelling framework. The range of elasticities that have been estimated using empirical methods is wide enough[65] to make the use of any single point estimate potentially controversial. There are also strong non-linearities and threshold effects, such as the example with tar sands above.

Our recommendation is that, where possible, separate model runs should be carried out with different assumptions about the effects of oil (and other energy) supplies on prices (ie representing the uncertainty in scenarios). Once the prices are determined the models are well-equipped to consider the secondary effects.

Can the models show an understanding of the role of technology?

Future technology options such as renewable energy sources, efficiency potentials, or carbon capture and storage (CCS) should be analysed.

As described in Chapters 2 and 3, there are two main treatments of technology in the existing set of models, each with its own advantages and disadvantages. The bottom-up approach is able to take specific technologies, such as CCS, into account and, increasingly, bottom-up approaches are being incorporated into fully-specified macroeconomic models.

However, whichever approach is followed, the issue of predicting patterns of development and uptake in future technologies that do not yet exist is insurmountable. Our response to this is that something that is so inherently uncertain should be dealt with explicitly in this manner; we describe this in more detail in Section 5.3.

Models should be expanded to cover additional greenhouse gases and material extraction categories, other environmental impacts and scarce biocapacity.

It is an important point to note that the sources of greenhouse gases cover several different model and policy areas (including energy, agriculture, waste, industrial processes) so this is also a question of model scope, which is picked up in Section 5.3.

In terms of material extraction (including mineral products but also biomass and water), as discussed above this is something that can be linked to a macroeconomic or land-use model (GINFORS and E3ME are examples of economic models that include this), but only at the resolution (typically NACE 2-digit sectors) that that model offers, which is often far too aggregated for an analysis of limited stocks. More detailed material analysis therefore requires a partial approach, for example through separate estimated equations or supply-chain analysis; as long as the necessary data are available this is not conceptually difficult, but misses the economic feedbacks due to changing prices and issues of scarcity.

Sustainable Consumption and Production

Modelling frameworks need to take into account that sustainable consumption is a relation of human well-being and resource use.

The macroeconomic models, and the indicators that they tend to focus on, usually pay little attention to the different types of consumption. This need not necessarily be the

[65] Longo et al (2007), Möebert (2007) and Kilian (2008) provide examples of price elasticities with respect to supply, Chevillon and Rifflart (2007), Kilian (2008) and Longo et al (2007) estimate demand-based price elasticities.

case, as relatively detailed consumption data are available, for example specifying manufactured products and consumer services.

Integration of the social aspects, as discussed below, is a more problematic issue however, as these are often more difficult to quantify or are missing from the standard data sets. In addition, a method for presenting these indicators in a summarised form that can be easily interpreted is a requirement.

Social inclusion – equality

Equality is barely seen as a central issue in macroeconomic models. There is an urge that greater equality becomes grounded and built in to the models of present and future societies.

In terms of income inequality, at an international level the main obstacle to measuring policy impacts is a lack of consistent data about the different income groups. There are national models[66] that place more emphasis on the behaviour of different income groups using national data sources.

The issue of equality tends to be left to microsimulation models, such as Euromod. These can be linked to macroeconomic models but, as far as we are aware, the linkages are usually one way, so the level of inequality is not able to influence macroeconomic outcomes. Again the reason would appear to be data availability; data for each income group are taken from surveys and are usually only available for a single year and are inconsistent with other published data, making it difficult to derive model parameters. Otherwise this would be a reasonably straight forward expansion to make.

The issue of environmental inequality is much more difficult to address as there are many ways in which environmental degradation affects different social groups, and these are often difficult to quantify. The best approach to dealing with this, given current capabilities, is to build a qualitative conceptual model and then to link this to quantitative data where possible.

Social inclusion – demographic changes

Member states should analyse the possible implications of demographic change for land use and resource and energy consumption, as well as mobility, and take them into account in planning and investment at all levels.

The link between population and resource consumption is usually indirect via economic activity. However, as population is usually treated as exogenous (see Section 5.3) it tends not to be seen as either a driver of over-consumption or a possible solution, although analysis could easily be carried out testing different population assumptions. Migration is also usually treated as exogenous, outside the specialised demographic models, but for issues of planning, both within and between countries, it is very important.

In summary, these are linkages that could be improved upon, possibly by combining expertise from different areas of modelling. It should be noted that for some resources, such as food and land, an increase in population would be expected to lead to an automatic increase in consumption.

Transitional issues

In order to understand and model a transition, not only technology, economy, institutions and ecology have to be considered, but also behaviour, culture and images and paradigms within the changing society.

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[66] For an example in Germany see Drosdowski and Wolter (2008).

Cultural changes influencing the society's members' behaviour must be allowed for.

These statements suggest that the macroeconomic models should be able to offer coverage of large-scale change and recognise that this may involve changes in behavioural patterns. Existing models tend to assume that behavioural patterns remain unchanged, meaning that there is a possible bias due to the inherent assumptions in their parameters. This is a major issue that is discussed in detail throughout the following section.

Aspects of the core economy, such as home-work and volunteering, should be included.

There is no reason that the models would not be able to include these factors in their analysis, as long as the necessary data are available. However, with current data this is not something that is immediately achievable.

Cross-cutting issues – quality of employment

It is crucial that models not only deliver on quantitative data but also on targets for quality jobs, including adequate income, equal pay for equal work and good social protection systems.

Various indicators exist that can be used as a starting point as a measure for the quality of jobs. Employment itself can be disaggregated by sector and by occupation, and wage rates and working hours are also considered. More recent developments[67] to link this to skills and qualifications can also be used as inputs to an assessment.

However, the level of detail within the models is not high enough to adequately address this issue, so it must be supplemented by a more qualitative analysis. An agreed standard definition on the quality of jobs would be helpful in this respect. It is noted that the current situation partly reflects the data available, primarily based on the Labour Force Survey.

In the case of pay differentials due to discrimination, macroeconomic models have little to offer, partly because any differential contradicts the theory on which many of the models are based[68]. Where quantitative, analysis has tended to be partial, for example based on specific estimated equations, although there is no reason that results could not be passed into an economic model.

The final issue on social protection systems is one that usually falls into the exogenous category of government activities. This is an important issue in the medium term, given the effects of the economic crisis and, in particular, the ageing population on government balances. This is picked up more generally in Section 5.3.

Cross-cutting issues – quality of socio-economic development

Can models complement existing measures of socio-economic development with environmental and social indicators?

The models are capable of producing measures for all of the policy areas that they cover and these are often based in physical units. Therefore our view is that this issue lies mainly outside that of modelling capabilities but reflects on how the models are used and how their results are interpreted. The biggest step forward would be an

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[67] For an example in Europe, see CEDEFOP (2010).

[68] Disequal pay for equal work implies irrational behaviour and so is excluded by assumption from optimising models. Although an empirical analysis could identify inequalities, to correct for this would require a behavioural change, but model parameters are usually assumed to remain constant.

agreement to give greater prominence to these other indicators; this means they need to be transparent and clearly understood.

As is discussed in Chapter 3, the use of composite indicators is another possible option, as long as the indicators are used in an appropriate manner.

5.3 Methodological issues

In this section we discuss how our four main methodological issues may be addressed, considering the issues that were raised in Sections 4.3 and 4.4. Once again, they are:

- degree of exogeneity
- the treatment of technology
- parameterisation and treatment of non-linearities
- treatment of uncertainty

Our assessment and recommendations include both possible developments to model structures and the way in which models are applied and their results are interpreted. These points are summarised in our final recommendations in Chapter 6.

Degree of exogeneity

As we have discussed previously, it is not realistic to build a detailed model that covers all the aspects of sustainability. The model will therefore inevitably be 'partial' in some respects and it is up to the user to choose a tool that is suitable for any given analysis; at the start of a modelling exercise the question should be asked whether any exogenous factors are likely to be affected in the chosen scenarios. It would be helpful in this respect if all the linkages between policy areas (see Table 3.4) were covered by at least one model but there is also the possibility of linking models.

In Section 4.4 we listed some of the main exogenous inputs to models and discussed if existing treatments could be improved.

Demographic development

Our key recommendation is that migration patterns should be brought into the modelling framework, as demographic development has impacts on both the environmental and the social aspects of sustainability. We see no theoretical reason why this should not be possible, as the process essentially links a demographic model with a macroeconomic model. However, it should be noted that different treatments would probably be required for inter and intra-EU migration.

Activities of government

It is not realistic to expect government actions to be endogenously modelled, but it is acknowledged that checks need to be carried out to make sure that scenarios are politically feasible. Our suggestion is that this is made more explicit by the model operator, with a qualitative assessment carried out at the end of each set of model simulations (with feedbacks to the model itself if necessary).

Treatment of stocks of resources

One of our key findings is that, to properly model sustainability, models cannot continue to assume infinite resources, and should acknowledge explicitly impacts on stocks of natural resources. The first task is to identify the key resources.

If existing stocks are known, or can be estimated, it is not a substantial development to include them in the model, although the level of detail of the model is likely to be a limiting factor (this is probably reasonable for energy products but for other materials, where included at all, model classifications are much more aggregated).

What is much more difficult, but also very important, is the effects that changes in the supply (and indeed demand) of resources might have on prices, given all the uncertainties in the system. The standard treatment of exogenous commodity prices almost certainly leads to bias in results but alternative approaches tend to rely on fairly crude assumptions. With no preferred method, the assumption must be that a set of model runs is carried out based on different assumptions.

However, the situation becomes even less clear when dwindling stocks puts a limitation on available supply, as even rough parameter estimates become less appropriate to use. This problem is closely linked to that of parameterisation, described below, in that the existing behavioural patterns are a poor guide to extreme cases and the level of uncertainty around parameter estimates grows. However, it is likely to become a more pressing issue in the future.

Our final point on this topic is that the models rarely distinguish between the use of virgin and recycled resources, despite strategies for waste management and recycling being set at a European level.

The economic view

As described in Section 4.4 it is appropriate for partial models without an economic component to impose a view exogenously. It would also add robustness to the results, however, to test alternative views.

Implicit assumptions

Finally, it would add a lot to the transparency of the modelling process if the implicit assumptions were made much clearer so that they could be assessed in the context of any set of model simulations. It should not be forgotten that the implicit assumption of financial stability undermined macroeconomic models in the build up to the recent crisis.

Treatment of technology

The first point to note is that many models now do include some endogenous treatment of technology, either through a bottom-up or top-down approach (described in Chapter 3, both have their relative merits). This is an area of ongoing development, however, and we suggest some of the ways in which existing treatments could be improved.

Development and diffusion

Our first suggestion is that the models address development and diffusion separately to try to address the question of why some apparently successful technologies are not widely adopted in all countries. This could fit into the bottom-up approach (which tends to assume optimal take-up), although it is more difficult to see how the top-down approach could incorporate it.

Spillover effects

Our next suggestion is that spillover effects are taken into account. Sustainability is a global issue that requires a global solution, including technological innovation. However, relatively little is known about the mechanisms through which these spillovers take place. It is acknowledged though that this is the subject of ongoing research, so we do not make further recommendations.

The basic problem

Whether a top-down or bottom-up approach is used, and however sophisticated this approach is, for ex-ante analysis it is difficult to see past the fundamental problem that it is not possible to predict future technological developments that do not yet exist. The response must be therefore to recognise this explicitly in the model results. In the case of bottom-up approaches this means stating that it is assumed that there are no technological alternatives outside those in the model structure.

In the case of top-down approaches it means stating that the assumption is of only gradual technological development and not of new products that lead to structural or step changes, like electric vehicles changing the energy source used by the road transport sector. These could then be addressed outside the modelling framework, for example in the design of hypothetical scenarios.

Parameterisation and the approach to non-linearities

In Chapter 4 we suggested that improving the accuracy of model parameters and the treatment of non-linear (or non-log-linear) relationships was possible. Although we note that there are some specialised types of models that do allow for non-linear relationships (some of which are described below), we focus on the standard existing treatment of a single elasticity to explain a behavioural relationship.

These elasticities are usually based on theories of perfect rationality (a feature of neoclassical economics), where an exact value is chosen based on all the available information, or bounded rationality (new and ecological economics), where the direction of the relationship is chosen (eg price elasticities are negative) but the magnitude is freely estimated on empirical grounds. In both cases the assumption of linearity is usually added afterwards for practical reasons.

In the paragraphs below we consider how this basic approach could be improved upon to take into account the specific issues outlined in Chapter 4. We then look at two of the new approaches to forming model parameters that are under development.

Asymmetries

Asymmetries occur when increases and decreases in inputs do not have equal and opposite effects. The first point to note is that it is not clear how asymmetrical relationships can be incorporated into an equilibrium-based model that assumes perfect rationality and perfect foresight. However, in a model that takes uncertainty into account, it is not a difficult feature to add, with separate parameters for positive and negative relationships. Existing treatments are in fact a specific example of this, with the positive and negative coefficients forced to have the same value.

The main cost is that relatively few published studies can offer such parameters and the data requirements to estimate them are effectively double that of current methods. In addition, the interpretation of results from a simulation where an exogenous input repeatedly moves up or down in a single time period (eg the oil price in a five-year period) could also be more difficult. Our suggestion therefore is that this is a factor that should be considered for key relationships where it is reasonable to expect asymmetrical responses (which could be tested statistically).

It should be noted that a proper treatment of asymmetrical relationships requires an analysis of transition paths and not just the end point, particularly in the special case of irreversibility.

Threshold effects

It is relatively easy for the model operator to take threshold effects into account in terms of model structure or parameters but, crucially, the level of the threshold must be known. In microeconomics, discrete-choice modelling provides an example that could be used at the macro level; health economics is able to make use of dose-response functions because the threshold effects have been documented on scientific grounds.

The real problem, which arises repeatedly at the macro level, is how to define the thresholds that have never been reached. In the case of climate science the models attempt to do this themselves, based on physical properties. In economic behavioural relationships there is often no basis with which to estimate these levels.

Approximation of curved relationships

In our view, this is only a major issue when considering large-scale change as the linear approximations are reasonably accurate near the base position. It is therefore partly an issue for the model operator when running particular simulations.

It is not difficult to add quadratic or logistic elasticities but this is simply making further assumptions about the shape of the relationship and, in most cases, probably does not offer significant improvement.

Changes over time

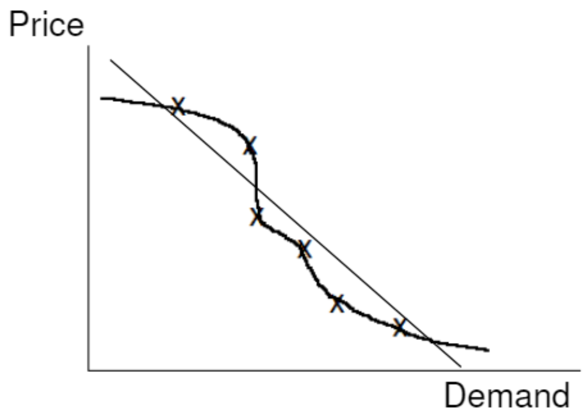
The implicit assumption in the modelling is that parameters do not change over time or, if they do, it is in a linear, trended, fashion. For econometric parameters it is possible to test this assumption using 'rolling' regressions based on different time periods (this is a common practice in finance where daily data are available), and these could offer alternative suggestions for how elasticities develop over time. The next requirement would be to determine why they may be changing.

New approaches

An alternative empirical approach to deriving model elasticities is a group of methodologies referred to as non-parametric approaches[69]. These are based on quantitative computer methods that determine the best function to fit the available data points, without making an a-priori judgement about the shape of the relationship (see Figure 5.1 for an example with a smoothed curve compared to a linear estimate). We see this as an ongoing area of research which currently suffers from two drawbacks:

- the properties of the approach are not yet well enough understood for policy analysis
- there are practical issues of how to store and use the information on a model database

FIGURE 5.1: EXAMPLE OF NON-PARAMETRIC ESTIMATION



Crucially, however, there is a third issue that this approach is not able to offer much help in the case of large-scale changes and moving into previously unexplored territory (in Figure 5.1 when prices get very high or are very low). In fact there appears an inherent contradiction in Figure 5.1 in that the curve frequently changes direction in the part that we have information on, but an extrapolation is assumed in the unknown parts.

[69] See Ecorys and Cambridge Econometrics (2009) for a more comprehensive review of methods.

The other modelling approach that is receiving increasing attention is the agent-based approach. In this type of model individual agents are defined according to a set of basic characteristics and behavioural patterns, and a complex system evolves out of the interaction of the agents. The only parameters in the model relate to the behavioural patterns, which can be assigned randomly.

Although the recent general recognition of the economy as a complex system has led to a rapid development in agent-based modelling approaches, as yet there is no general macroeconomic specification. There are instances, however, where an agent-based approach could provide a partial assessment. An example that relates to large-scale transitions in Europe is presented in Whitmarsh et al (2006).

Conclusions

While we have been able to make some suggestions about how the general accuracy of model parameters could be improved, the common theme we come across is that it is difficult to predict responses to large-scale change, because:

- empirical approaches struggle when there is no historical basis from which to carry out the analysis
- theory-based approaches fail to take into account high levels of uncertainty (see below)

In the longer run, agent-based approaches may be able to fill this gap in the analysis. Under current capabilities, however, care must be taken in interpreting model outputs from simulations that include large-scale transitions.

Treatment of uncertainty

We have defined two separate issues related to uncertainty, the treatment of uncertainty within the model, and uncertainty resulting from the model and its various assumptions. These are discussed in turn.

Uncertainty as an explanatory factor

In our view it cannot be disputed that uncertainty affects human behaviour, particularly in the case of investment decisions, and should therefore be included in a model of sustainability. This does, however, contradict the standard economic theory on which many models are built[70] so is an easier step to incorporate in non-equilibrium approaches.

The question of how uncertainty should be represented in a model of sustainability is more difficult. Proxy variables that have been used tend to focus on volatility in price variables but these are subject to their own specific factors and different groups in society face different types of uncertainty. We recommend this as an area for future research.

Uncertainty in model results

As a simplification of reality based on a series of assumptions, there will always be uncertainty in model outputs. Attempts to address this issue should therefore be outside the structure of the model. It is worth considering the main sources of uncertainty in turn:

- Data – Data sources are usually provided, along with a description of treatment of missing data. It is difficult to see how this could be improved upon, beyond improving the data itself.

[70] Frydman and Goldberg (2007) suggest imperfect knowledge is the main shortcoming of the neoclassical model and build a model of risk to take this into account.

- Model structure – This is mainly covered in the section on exogenous inputs above, under implicit assumptions. The key issue is whether the (often implicit) assumptions may be tested by the simulation in question.
- Parameters – In the simplest models, for example single equations, it is possible to provide a statistical estimate of uncertainty but this is infeasible for complex models. Issues of non-linearity and function specification are examples that are discussed above.
- Exogenous input variables – Key inputs are often tested via sensitivity analysis, although this is often treated as an afterthought and is claimed as an assessment of all sources of uncertainty. The exercise can be expanded by combining alternative inputs to form scenarios of future developments with internal consistency ensured by the model's own structure.

In the case of the last two sources, it is possible to test the level of uncertainty by running the model repeatedly with small variations in inputs. This has, for example, been used as a means of testing key parameters in climate models. However, the scale of the exercise means that only a few of the thousands of inputs may be tested at any one time and it is up to the model operator to select the most important ones to test. As computational power increases, we expect this type of analysis to become more common.

6 Conclusions and Recommendations

6.1 Our main conclusions

A brief overview of our findings

This report provides a comprehensive investigation of what a macroeconomic model of sustainability should look like. Starting with an assessment from the main schools of economic theory it sets out, from a theoretical and philosophical perspective, how the economy relates to society and the natural environment, and where the most important linkages between each part lie. There are fundamental differences between the different economic approaches and we conclude that the standard neoclassical model is not well-placed to carry out a comprehensive sustainability assessment.

Coverage of policy areas

Using the structure provided by the EU's Sustainable Development Strategy, we have considered how the main linkages could be represented in a macroeconomic modelling framework and to what extent such a treatment already exists. We also considered direct linkages between the different areas of sustainable development.

Most of the aspects of sustainable development are covered by existing models and many of the models have links to the economy. However, the linkages often tend to be one-way from the economy to the environment and not vice versa, which is consistent with the standard neoclassical approach of treating the environment as a set of 'externalities'. This means that the impacts of environmental degradation on the economy are often neglected in the analysis.

Methodological issues

There are a small number of more general methodological issues in the standard modelling approaches that cut across all the policy areas considered. These are mainly employed for practical purposes but could lead to a bias or misinterpretation of results. They are:

- exogenous assumptions
- treatment of technology
- parameterisation
- treatment of uncertainty

Chapters 4 and 5 discuss how these cross-cutting issues interact with the policy areas and with each other and lead to recommendations for how existing models can be adapted to better address the key questions of today.

We consistently find that the model-based approximations are suitable for looking at marginal changes, but are less accurate when considering large-scale transitional change (and may require more assumptions from the user). In particular, in our analysis of current techniques we have failed to answer the question of how to make accurate quantitative assessments in a global context that is very different to that which currently exists.

6.2 Our responses to the original questions

Before providing our recommendations for future research, we briefly return to the questions that were put forward in Chapter 1. They are addressed throughout the report, but are summarised in turn below. We then give some further thought to the questions that were raised in the original Terms of Reference for the study.

Responses to the questions from Chapter 1…

What is the value-added of a macroeconomic perspective of sustainability?

All of the main schools of economic theory acknowledge that economic behaviour has an impact on the surrounding environment, even if they treat these impacts differently. Macroeconomics attempts to understand this behaviour and to represent it in the models by the linkages from economic development to the environmental and social dimensions of sustainable development.

Can this perspective help to achieve sustainable development?

Yes, because understanding human behaviour and its impacts is crucial to achieving the goal of sustainable development. Economic interactions, for example through investment or price signals, will be important to determining future patterns of development. More generally, the approach of incorporating environmental components into models that are primarily designed for economic purposes helps to identify measures that reduce the driving forces and pressures on environment and resource use.

The socio-economic system is embedded in the larger biosphere and its 'industrial metabolism' (Ayres, 1989) and thus it interacts with the surrounding ecosystems. However, the ability of the latter to adapt to the consequences of these interactions is limited. This poses a challenge for macroeconomic modelling, as it requires a good understanding of both socio-economic and natural processes. Knowledge about the various inter-linkages between the natural and the economic systems is of essential relevance in sustainability-oriented modelling.

Problems like the loss of biodiversity or climate change are complex and involve multi-dimensional cause-effect-impact relationships and time-lags. These problems are closely related to the overall volume of production and consumption (Schmidt-Bleek, 1992), which can be affected by economic interactions.

What modelling tools exist for such macroeconomic analysis?

Chapter 3 provides a comprehensive overview of the main models that are available. They are described further in Appendix A.

To what extent do these tools address sustainability issues?

All the broad policy areas are covered to some extent, with the possible exception of good governance. However, there are more gaps at the detailed level, often due to the availability of data. In addition, the degree of linkage between the different areas of sustainability is less well covered and there is no existing model that can cover all of the issues. Recommendations for further model development are presented in Section 6.3.

Can these tools identify the most important policy levers and possible synergies?

This depends on the linkages between the different areas of sustainability. Links from the economy to the environment are commonly included in models, but linkages in the other direction are less common. Nevertheless, models tend to adapt to the most important issues, so in most cases an assessment can be provided.

However, an approach strongly rooted in economics is not able to reach a complete integration of the ecological and economic systems with their various linkages and feedbacks.

Ideally, what indicators should these tools take into account?

The most important indicators will reflect the main issues of the present day. They should be presented in their own units rather than converted to monetary values, which suggests simple trade-offs that do not exist.

Indicators that are based on biophysical data (for example ecological footprint, MFA), and are aimed to reduce overall resource consumption, are important as they can provide a link to problems that refer to the quality of environment (like climate change, biodiversity loss, etc.). They are able to quantify some of the interrelations between socio-economic driving forces and the scale of resource and energy use. Since problems like loss of biodiversity are closely related to increasing volumes of worldwide production and consumption, and the associated use of natural resources (such as energy or materials), the reduction of resource use is an important step toward a higher quality of environment (see Giljum et al, 2009).

How feasible is it for existing tools to meet this ideal?

Our conclusion is that it is possible to adapt the models to meet the requirements but there are some obstacles which are yet to be overcome. While it is of great importance to increase our capability of understanding the (yet) unknown, the evidence of existing and increasing environmental and social problems calls for immediate action. Working with and improving existing models enables the research community to provide answers to immediate urgent policy questions. However, more research will have to be put into the development of a modelling framework able to deal with sustainability in a comprehensive way.

…and the questions from the study's original Terms of Reference

What are the implications of a conventional growth scenario (and the factors underlying it) for sustainable development?

From the perspective of neoclassical economics, a conventional growth scenario will lead to sustainable development in the long term (see Chapter 2.2). This conclusion is based on the assumption that economic growth is a pre-condition for achieving rapid technological progress, efficiency improvements and innovation that lead to a decoupling of economic growth from its negative environmental impacts. What has to be achieved is to 'get the prices right'. The internalisation of negative externalities through the price mechanism solves our ecological problems and steers the economy towards a sustainable pattern of growth. A high degree of substitution of natural resources with manufactured capital stocks is assumed.

In contrast, ecological economics underlines the scarcity of natural resources and limited substitutability. A conventional growth scenario does not lead to sustainable development, as the limited carrying capacity of the Earth sets limits to economic expansion. Ecological economists are sceptical about the possibility to dramatically change technologies, investment and consumption patterns in a way that decouples economic growth from environmental impact. There is strong evidence that efficiency achievements are outweighed by increased consumption (rebound effects).

Macroeconomic models and other quantitative approaches could be used to test some of the differences between the two approaches. One example is to assess empirically the substitution parameters, based on historical data. Another option, put forward in Section 2.6, would be to use the models to examine the effects of a scenario in which there is little or no economic growth.

What change in the factors underlying growth would be needed to result in sustainable development? Does the literature suggest that we move to a zero-growth scenario, or that we push for absolute decoupling?

Neoclassical economists perceive economic growth, measured in GDP, as a prerequisite for achieving sustainable development. Changes are necessary with regard to the composition of GDP (eg 'Green Growth' or a 'Green New Deal'), but not to the rate of growth. Ecological economists, however, argue that changes in the composition of GDP and technological progress are not sufficient to solve the problems of the overuse of natural resources, sinks and services and related social problems. The rate of GDP growth cannot be sustained in the long term; hence, alternative approaches that are not solely based on GDP growth are suggested.

Both schools argue for the necessity of absolute decoupling. Neoclassical economists believe in technological progress as the solution, while ecological economics disagrees with this point of view and suggests that the target will only be achievable by abandoning the current growth paradigm, seriously rethinking standard economic assumptions and theories and creating an alternative macroeconomic framework that explicitly includes the environment and its services to the economy.

How do macroeconomic conditions affect the implementation of environmental policy: for example, the financing of green investment (or crowding out)?

This is an issue that we have only touched on in this report, as existing models do not cover the policy area of good governance (see Chapter 3). Investment financing is an example of one of the few areas where the models (particularly those that include a financial component) could provide a quantitative analysis. However, as discussed in Section 4.2, they are often subject to restrictive assumptions that have a strong influence on results.

To what extent does environmental protection simply change the structural composition of growth rather than changing the rate of growth?

Environmental policies are crucial for steering the economy towards a more service-oriented base, resulting in a structural change of GDP growth. There are many examples of policies where environmental protection and economic growth can be mutually reinforcing (so-called win-win situations, see Rayment et al, 2009, for examples at the European level). There are, however, also many other examples that prove that environmental policies often come at the expense of GDP growth.

In the case of climate change, Stern (2007) reports on analysis by Barker et al (2006) that compares the results from a broad range of modelling exercises, showing cases where there are both economic benefits and costs to taking mitigation action.

To what extent does the environment (and environmental protection) impact on whether growth is good for people's well-being?

The environment is of vital importance for human flourishing and is consequently good for people's well-being. Section 2.4 focused on two important dimensions of well-being, employment and equality, and addressed the question how economic growth, as an overall determinant of the macroeconomy, relates to these dimensions.

However, we note that GDP growth per se does not guarantee a high level of well-being, as prosperity is dependent on many other factors; the same argument applies to environmental sustainability. Consequently, it is not possible to establish a direct relationship between the local environment, economic growth and human well-being. However, the direction of the relationship is clear.

What are the assumptions and scenarios required for an alternative growth path that would be consistent with sustainable development and how would this square the apparent paradox that the more efficiently we use our resources and energy, the more we consume?

Referring to the arguments outlined above, neoclassical and ecological economics have different answers to the question of whether an alternative growth path, measured in GDP, is both possible and desirable. While neoclassical economics argues that a conventional growth scenario will lead to sustainable development in the long term (see Chapter 2.2), ecological economists advocate alternative policies that do not solely depend on GDP growth in order to solve current environmental and social problems. They suggest that rebound effects are only another argument for an absolute reduction in current consumption and growth patterns, respectively. Empirical analysis that finds strong rebound effects (Barker et al, 2009, Stocker et al, 2007) supports this view.

6.3 Recommendations for future development

Our main recommendations from Chapter 5 are summarised below. They encompass model inputs, structures and assumptions, and methods of use.

Model inputs

- Data – The model's representation of reality will only be as detailed or reliable as the data that it uses, and data is recognised as a source of uncertainty. Several gaps in existing data sets were identified:
  - the definition of the eco-industries does not fit into standard classifications, which puts a severe limitation on their economic assessment
  - in assessing the social aspects of sustainability, one key missing input was identified, which was incomes and spending for different household groups
  - when considering long-term transitions it would be beneficial to include non-economic contributions, such as housework or voluntary work, that could be affected by the changes
- The models would be able to make a better targeted assessment of sustainability if the key natural resources (critical natural capital) were identified and, where possible, quantified in terms of available stocks and maximum carrying capacities. At present, there is no single list of the key factors that should be accounted for.

Incorporation of material resources into the model structure

- Incorporation of material demands – As the models already include material demands in an economic context (through input-output relationships), it would not be a difficult step to add a physical measure (in tonnes) in the same basic way that existing models combine economic and energy analysis. Examples of resources that could be included are mineral products, biomass and water.

- This treatment could also be extended to include generation of waste. Although this is perhaps a more substantial development, in our view it is technically feasible given existing structures, and has previously been done at national level.

- Inclusion of stocks of natural resources and environmental carrying capacities – Where the key stocks and carrying capacities have been identified (see above), macroeconomic models should take these into account, at least given the available disaggregation. At a minimum, model results should be compared to available capacities to check that natural boundaries are not exceeded. Ideally, these limits should be allowed to influence prices and behaviour, although it is noted that further research is required to determine outcomes when boundaries are reached. This would allow models to highlight which sectors or groups in society are most vulnerable to constraints on supply.

Other changes to structure and assumptions

- Demographics and the impacts of migration – The economic crisis has shown that population trends can change quite quickly in response to economic stimuli. Population movement inevitably has an effect on sustainability, so migration effects (both inter and intra-EU) should be included in the models. A more immediate exercise would be to vary exogenous population assumptions to assess the effects of different paths of growth on sustainability.

- Links from the environment to the economy – While this report suggests that aspects of ecological economics could provide a sound basis for comprehensive sustainability analysis, it is acknowledged that no such modelling framework yet exists. One of the main gaps in the available tools is the linkages from environment to economy. A comprehensive treatment of sustainability requires two-way linkages so this is an area that should be explored further. In some cases the links are missing due to measurement or data issues, but this remains an obstacle to a full assessment, even through linking models.

- Links between environmental and social issues – The existing models tend to link these aspects only indirectly through economic development. Examples of direct linkages, such as green jobs and impacts on the quality of labour are still largely unexplored.

- Threshold effects and non-linear relationships – Where it is possible to identify these possibilities, model parameters should be adapted to take them into account. Where it is not possible, this should be acknowledged and an assessment of the impact on results provided.

- Technology – As future technologies cannot be predicted it is important that as much information as possible regarding current technologies is used. This requires an interaction between experts in a particular sector and economists, for example as represented in the recent coupling of macroeconomic models with bottom-up technology models.

- Uncertainty – The models should take into account the fact that uncertainty does affect human behaviour. An empirical assessment of how uncertainty can be represented in a model would be very helpful in this regard. In particular it is noted that any model-based analysis that compares the relative merits of a carbon tax with an emission trading system must take economic uncertainty into account.

Methods of use

- Focus of outputs – Part of the reason that existing models tend to summarise outputs in monetary units is that this is the form in which they are demanded. A preference for model outputs in physical units, or in an appropriate composite indicator (or set of indicators), would reduce pressures to produce results solely in terms of GDP and monetary values.

- Testing the theories of ecological economics – Although no model of ecological economics currently exists, it would be possible to test some of the theories using existing methods and tools. For example an empirical analysis could estimate rates of substitution or existing models could be used to assess scenarios without economic growth.

- Exogenous factors – For each set of model simulations, the model user should assess the accuracy of assuming that exogenous factors remaining unchanged. This should include testing the plausibility of scenarios, for example without national governments taking corrective action.

- Implicit assumptions – Implicit model assumptions should be documented more clearly and assessed with each set of simulations.

- Description of uncertainties – Current sensitivity analysis tends to focus on how dependent results are on exogenous factors. Uncertainty goes a lot further than this, however, for example covering model structure and parameters. A much better understanding of the main uncertainties is required to aid interpretation of results. *This is particularly the case when assessing large-scale changes in society.*

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Appendix A: List of Existing Models

AIM The AIM comprises three main models - the greenhouse gas emission model (AIM/emission), the global climate change model (AIM/climate), and the climate change impact model (AIM/impact). The AIM/emission model estimates greenhouse gas emissions and assesses policy options to reduce them. The AIM/climate model forecasts concentrations of greenhouse gases in the atmosphere and estimates the global mean temperature increase. The AIM/impact model estimates climate change impacts on natural environment and socio-economy of the Asian-Pacific region.

The research program has made major contributions to policy deliberations at the nations, regional and global levels. The AIM model has been used to provide global and regional emission scenarios and regional impact assessments to the IPCC. The AIM model has been evaluated at the Stanford Energy Modelling Forum for the international comparison of emission scenarios and impact assessments. Other uses have included contributions to Eco Asia (the Congress of Asian Ministers for the Environment), the Global Environmental Outlook Program of UNEP, the UN Global Modelling Forum, and the Asian-Pacific Network Program.

Research is focused on:

- climate change
- sustainable material cycles
- environmental risk
- Asian environment

The aim model has several distinct characteristics:

- integrates emission, climate and impact models
- prepares both country modules for detailed evaluation at the state and national level and global modules to ensure consistency across individual modules
- integrates bottom-up national modules with top-down global modules
- is designed to assess alternative policies
- contains a very detailed technology selection module to evaluate the effect of introducing advanced technologies
- uses information from a detailed Geographic Information System to evaluate and represent the distribution of impacts at the local level
- focuses on the Asian-Pacific region and is based on a collaborative network of international research institutes.

ASF ASF is an integrated assessment model, which provides a framework for developing scenarios of future emissions based on consistent demographic, economic, and technological assumptions. Its strength is in its links between the use of biofuels, land use, technological development and GHG policy. It is therefore an appropriate tool for evaluating the land-use impacts of response measures.

The current version of ASF includes energy, agricultural, and deforestation GHG emissions and atmospheric models and provides emission estimates for nine world regions.

In the ASF model balancing the supply and demand for energy is achieved ultimately by adjusting energy prices. Energy prices differ by region to reflect regional market conditions, and by type of energy to reflect supply constraints, conversion costs, and the value of the energy to end users. ASF estimates the supply-demand balance by an iterative search technique to determine supply prices. These supply prices, which energy producers charge for the fuel at the wellhead or at the mine, are used to estimate the secondary energy prices in each region. These secondary prices are based on the supply price for the marginal export region, the interregional transportation cost, refining and distribution costs, and regional tax policies. For electricity, the secondary prices reflect the relative proportions of each fuel used to produce the electricity, the secondary prices of those fuels, the non-fossil costs of converting the fuels into electricity, and the conversion efficiency.

The agricultural ASF model estimates the production of major agricultural products, such as meat, milk, and grain, which is driven by population and gross national product (GNP) growth. This model is linked with the ASF deforestation model, which estimates the area of land deforested annually as a function of population growth and demand for agricultural products.

The ASF GHG emissions model uses outputs of the energy, agricultural, and deforestation models to estimate GHG emissions in each ASF region. These emissions are estimated by mapping GHG emission sources to the corresponding emission drivers and changing them according to changes in these drivers. For example, CH_4 emissions from landfills are mapped to population, while CO_2 emissions from cement production are mapped to GNP.

Finally, the ASF atmospheric model uses GHG emission estimates to calculate GHG concentrations, and corresponding radiative forcing and temperature effects. A detailed description of the ASF is provided in the ASF 1990 Report to Congress (Lashof and Tirpak, 1990), and recent applications of the model are reported in Pepper et al (1998) and Sankovski et al (2000).

ASTRA The ASTRA model was built to provide analyses of the long-term impacts of the European common transport policy. The model can provide forecasts for the EU27, Norway and Switzerland, up to 2030 and uses a zoning system of up to 4 regions per country.

The model is mainly used for:

- assessment of the impact of different policy packages, such as combinations of pricing policy, taxation, infrastructure policy or technology policy, on transport
- R&D policy assessment
- assessment of the economic impact of regional scale environmental and transport policies

ASTRA is a genuine integrated assessment model, consisting of 8 modules, which integrate both macro- and microeconomic elements.

The main features of the model are:

- annual solution up until 2030
- 8 detailed modules: population (POP), macroeconomics (MAC), foreign trade (FOT), regional economics and land use (REM), transport (TRA), vehicle fleet (VFT), environment (ENV) and welfare assessment (WEM)
- 5 emission types
- detailed treatment of demand-supply interactions
- regional treatment of passenger and freight flows

- detailed treatment of welfare
- population forecast calibrated to match Eurostat projections

In summary, the characteristics of ASTRA are such that the model is:

- elaborated at a European level, with a specific focus on analysis of the effects of different policy packages
- an integrated model, with its component modules combining both the macro and microeconomic dimensions
- a classical 4-stage transport model with a simplified representation of transport networks and network capacity feedback, but with a detailed treatment of the economic interactions
- based on feedback loops between the different modules

Bertelsmann Transformation Index

Advocating reforms targeting the goal of a constitutional democracy and socially responsible market economy, the Transformation Index BTI provides the framework for an exchange of best practices among agents of reform. Within this framework, the BTI publishes two rankings, the Status Index and the Management Index, both of which are based on in-depth assessments of 128 countries.

The Status Index explores the state of development achieved by 128 countries on their way to democracy under the rule of law and a market economy flanked by socio-political safeguards. In contrast to minimalist definitions of electoral democracy, the BTI's understanding of democracy includes the rule of law and representativeness.

Development in our understanding entails not only economic growth, but also overcoming poverty while extending freedoms of action and choice to the largest possible share of the population. The underlying BTI concept of a socially responsible market economy implies not only free markets and property rights, but also principles of social justice, equal opportunities and sustainability.

Democracy and a market economy are considered interdependent and mutually reinforcing and therefore aggregate the respective ratings into a single Status Index. Neither does this imply that there is only one path of transformation nor that economic transformation has to precede democratic transformation or vice versa. But sustained economic growth and effective poverty reduction require a government that is transparent, non-corrupt, and responsive to the needs of its people. Only a democracy based on the rule of law can ensure the equal playing field for all citizens that is essential to sustained development. On the other hand, only a market economy flanked with sociopolitical safeguards can provide all citizens with opportunities to realize their potential in the open marketplace of goods and ideas that is essential to a prosperous democracy.

The BTI's key innovation is its focus on the steering and management of development and transformation processes. The Index reviews and evaluates the reform activities of political decision makers, thus providing valuable information on the key factors of success and failure for states on their way to democracy and a market economy. Governments must be determined in pursuing their goals, they must be prudent and effective in using their resources, and they must combine the capacity to govern with consensus-building while cooperating reliably with neighbouring states and external support organizations. The BTI is the only ranking worldwide to focus so thoroughly on political leaders' management performance with self-collected data.

The level of difficulty evaluation accounts for the fact that the quality of transformation management is shaped by each state's unique structural conditions. The more adverse a country's structural conditions and the more limited its available resources, the higher good governance is scored in the Management Index.

Bruno, R. L. **Bruno, R L – Unique Equilibrium in a Model of Rule of Law**

This paper presents a model of Rule of Law in which a continuum of agents plays against the State for the appropriation of the economic assets of a stylised economy. The model shows how each agent can either challenge the State or acquiesce, with the latter having the choice of either protecting property rights or abandoning the economy to anarchy. Players' payoffs are affected by strategic complementarities, not only between State and agents but also among agents themselves. As a consequence of this, a Coordination Failure is generated. The solution of the game is given by two Pareto-ranked Nash equilibria. Introducing idiosyncratic information and sequential play generates a unique equilibrium, according to the global game approach. On the one hand, this model predicts that high uncertainty and sunk costs in law enforcement have a negative effect, pushing the economy towards a Pareto-dominated equilibrium. On the other hand, the high value given to the economy's assets (embedded social norms) has a positive in°uence, leading to a Pareto-dominant equilibrium.

CAPRI CAPRI is short for ‘Common Agricultural Policy Regionalised Impact’. It is a global agriculture sector model developed to assist in assessing the effect of CAP policy instruments on production, income, markets, trade, and the environment at EU or member state levels as well as sub-national level. The typical use of the model is to simulate and compare ex-ante for medium-term time horizon impacts of different sets of agriculture policies. It combines the representation of regional agricultural policies and production with political and economic conditions on regional, Member State, EU and global agricultural commodity markets. An activity based approach allows the direct implementation of relevant CAP policy measures and the technological definition of appropriate environmental indicators related to the agricultural production activities. Product and activity coverage are in line with the Eurostat’s Economic Accounts for Agriculture (EAA) by a combined top-down/bottom-up approach.

The model is mainly used for:

- simulating EU27, Norway and the Western Balkans wide impacts of the Common Agricultural Policy (CAP) on production, income, markets, and the environment
- the simulation of Agenda 2000 and MTR scenarios
- modelling agricultural reform under new WTO proposals
- sugar and dairy market reform options
- developing / modelling of passive environmental indicators for the European Agriculture
- assessing environmental impacts of agricultural policies
- impacts of agricultural policies on specific markets
- tradable permits for Global Warming emissions from agriculture
- effects of a compulsory insurance scheme for foot and mouth disease

The model is split up into a supply and a market component. An iterative process between the supply and the market component establishes a comparative static equilibrium and returns market clearing prices for tradable agricultural products and young animals.

Supply module The supply module of CAPRI consists of independent regional models that incorporate regional characteristics and the relevant farm policy measures (eg premiums, setaside obligations) and ensure that simulation results are consistent with general resource constraints. The objective functions maximise gross value added including CAP premiums minus a (quadratic) cost function. The choice of the optimal production mix is restricted by a relative small number of constraints:

- availability of arable and permanent grass land
- selling quotas for milk and sugarbeets
- set-aside obligations
- base area related premium reductions
- and upper bounds for voluntary set-aside according to CAP regulations

Feed costs are minimised endogenously by determining the optimal mix of a limited number of aggregated marketable (eg cereals) and non-tradable feeding stuffs (eg hay) subject to requirement constraints, ensuring a technologically plausible mix. Nutrient requirements of crops can be covered either by mineral or organic fertilisers, the latter restricted to the amount produced by the regional herds. Constraints ensure that a crop specific percentage of the nutrient need is covered by mineral fertiliser.

Since elasticities were not available for the differentiated set of crop production activities, the team explored the possibility to estimate multi-output quadratic cost functions based on a cross-sectional sample. The supply part includes the coupled and decoupled premiums schemes of the CAP in a very rich detail, as closely as possible to current legislation.

Market module The market module is a spatial multi-commodity model and covers both primary and processed agricultural products. Flexible functional forms are applied for the behavioural equations with clear regional markets, where the Armington assumptions whereby consumers differentiate products by origin and attach different willingness to pay to these origins, determines the composition of demand from domestic sales and imports from different trading partners. The parameters for these functions are calibrated to elasticities found in literature.

The model represents bi-lateral specific and ad valorem tariffs, where necessary depending on the Tariff Trade Quota mechanism. For the EU, market interventions and subsidised exports are modelled endogenously depending on market and administrative prices.

Processing of oilseeds is modelled explicitly assuming fixed extraction rates for cakes and oils from crushing. In the case of dairy products, constraints equilibrate fat and protein content of processed quantities of raw milk and with the processed products. The price of raw milk and processed milk products is derived from fat and protein prices weighted with their contents plus a processing margin.

The model distinguishes between producer and consumer prices, where the margin between the two is endogenously determined for dairy products, oils and cakes, and fixed for of all other products.

CETAX CETAX is model developed to help analyse the effects of tax policies on national labour markets. It can also be used to illustrate the effects of different forms of international tax coordination.

The model was build using the previous OECDTAX model and it incorporates the EU25 plus 9 other OECD countries, a tax haven jurisdiction (a place where no taxes are paid), as well as specific features of tax the system of a given country.

The model is mainly used for:

- analysis of the effects of a unilateral change in tax policies
- analysis of the outcomes of various forms of international tax cooperation

The model benefits from an elaborate treatment of capital markets and capital taxation.

Features of the model include:

- a tax haven that facilitates tax evasion
- stationary equilibrium , with each country producing and trading the same homogeneous good and an integrated trade market
- imperfect capital mobility
- immobile labour
- detailed treatment of capital flows
- in-depth treatment of capital taxation, distinguishing between different types of investors (eg household investors and institutional investors, foreign direct investment and portfolio investment), different types of assets, and between debt and equity
- a static solution, with a long-run equilibrium and no capital stock adjustment costs

CLUE The CLUE (Conversion of Land Use and its Effects) model was built to provide detailed analysis of land-use changes. The model can be used to track past changes in land use and to explore possible land-use changes in the future. These are run as scenarios, with a time horizon of 20 years. The drivers of the model are bio-geophysical changes (eg climate, soil type) and human drivers (agriculture). The CLUE project is organised in the form of different case studies for specific countries.

The model is mainly used for:

- analysing land-use dynamics for different land types and agricultural trends
- simulating the effects of different land-use and protection policies
- estimating the effects of macro-level changes, such as demographics and economic development, on land use

The CLUE model's parameters are based on historical relationships. The model is GIS-oriented, meaning that it splits the selected region into a set of smaller areas; the size of these areas varies according to the quality of the local data.

The main features of the model are:

- yearly solutions for a time horizon of 20 years
- spatial connectivity across regions, with activities in one region affecting activities in nearby regions, but less so in regions further away
- hierarchical organisation of processes (eg a new fruit-tree farm nearer to the market might influence prices in such a way that it is no longer profitable for farmers to produce fruits in more distant areas)
- stability and resilience (land use systems are able to absorb disturbances before the structure of the system is changed)
- a large set of driving factors, such as socio-economic and biophysical factors

In summary, the characteristics of CLUE are such that the model is:

- GIS oriented, with the spatial resolution varying across case studies
- designed to be applied at a regional level, with data representation and other features differing from case study to case study
- taking into account both bottom-up and top-down land use changes, through a multi-scale approach
- based on historical relationships (similar to the methodology for econometric economic models)

E3ME The E3ME model has been built as a framework for assessing energy-environment-economy issues and policies. It covers the EU-27 plus Norway and Switzerland. E3ME provides an econometric one-model approach in which the detailed industry analysis is consistent with the macro analysis (ie the aggregate European results are obtained by summing the countries and sectors).

The model is mainly used for:

- general macro and sectoral economic analysis – for example to assess detailed economic impacts (including impacts on international competitiveness and on the labour market) of R&D spending
- more focused analysis of policies relating to greenhouse gas mitigation – for example to assess detailed energy, environmental and economic impacts of energy and carbon taxation and the emission trading scheme
- assessing incentives for industrial energy efficiency – for example the impacts of extra investment in new technologies
- analysing sustainable household consumption – for example to assess impacts of raw material taxation on household consumption patterns and other economic variables

The econometric techniques used in E3ME are based on the concepts of cointegration and error-correction methodology (see E3ME manual for more information: http://www.camecon.com/Libraries/Downloadable_Files/E3ME_Manual.sflb.ashx). This technique allows E3ME to be used for assessing short and medium-term effects as well as long-term impacts of E3 policies.

Features of the model include:

- annual solution up to 2030
- detailed sectoral disaggregation allowing industrial factors (such as increases in the unit costs of one industry in one region) to influence the macroeconomic picture (such as overall European level of unemployment and GDP)
- an in-depth treatment of changes in the input-output structure of the economy over the forecast period to incorporate the effects of technological change, relative price movements and changes in the composition of each industry's output
- different sets of assumptions, eg changes in world oil prices, income taxes, government spending and exchange rates, to illustrates the response of the main model indicators under different circumstances
- integrated energy-environment-economy analysis
- endogenous technical change, with technology modelled as a function of investment and R&D

In summary, the characteristics of E3ME are such that the model is:

- elaborated at a European rather than at a national level, with the national economies being treated as regions of Europe
- dealing with energy, the environment, labour market and the economy in one modelling framework
- designed from the outset to address issues of central importance for economic, energy and environmental policy at the European level
- capable of providing short- and medium-term economic and industrial forecasts for business and government
- incorporating detailed parameters estimated from annual historical data to quantify the relationship between the model's E3 variables in the forecast period
- calibrated to recent outcomes and short-term forecasts
- capable of analysing long-term structural change in energy demand and supply and in the economy
- focused on the contribution of research and development, and associated technological innovation, on the dynamics of growth and change

E3MG E3MG is a sectoral econometric model for 20 world regions that has been developed with the intention of analysing long-term energy and environment interactions within the global economy and assessing short and long-term impacts of climate-change policy. The model consists of an in-depth treatment of changes in the input-output structure of the economy over the forecast period and incorporates the effects of technological change, relative price movements and changes in the composition of each industry's output.

The model is mainly used for:

- forecasting up to 2100 (annually to 2020, then ten year intervals)
- dynamic multiplier analysis, illustrating the response of the main economic indicators, industrial outputs and prices to standard changes in assumptions, eg changes in world oil prices, income taxes, government spending, and exchange rates
- scenario analysis (differentiated according to sector and to country), across a range of greenhouse gas mitigation and energy policies at the global level, including carbon taxes and emissions trading, incentives for investment in renewable, and other energy technologies
- analysis of long-term structural change in energy demand and supply and in the economy focused on the contribution of research and development, and associated technological innovation, on the dynamics of growth and change

E3MG version 2 has been built by teams at the University of Cambridge (http://www.landecon.cam.ac.uk/research/eeprg/4cmr/index.htm) and Cambridge Econometrics as a contribution to the work of the UK Tyndall Centre for Climate Change Research (http://www.tyndall.ac.uk/). The features of E3MG, including the econometrics techniques, are very similar with those of the European E3ME model.

ECOMOD Ecomod is a dynamic, multi-sector, multi-country, multi-regional general equilibrium model. The model covers 87 world regions and distinguishes a maximum 69 (57 for most countries) types of commodities. It is based on the latest GTAP database. For countries where enough data is available, the model is capable of distinguishing different regions within the country and different types of households.

The model is mainly used for:

- general macro and sectoral economic analysis – for example assessing the economic impact of R&D spending
- macro and sectoral economic forecasting

Features of the model include:

- imperfect competition
- increasing returns to scale
- an oligopolistic framework: the sectors differ in their location, the number of operating firms and the degree of the economies of scale
- four economic agents in each country: firms, households, government and the rest of the world
- 87 world regions and 57 commodities
- a time horizon of 25 years, which can be extended in a flexible way

The region, household, sector, and commodity disaggregation is fully flexible and can be adjusted depending on the scenario run.

A measure of technical change is included in the model through efficiency gains. This includes accumulation of sectoral R&D and education stocks.

The Greenmod model is an extension of Ecomod used for analysis of energy/environment interactions, pollution abatement and investment in low-carbon technologies.

In summary, the characteristics of Ecomod are such that the model is:

- general equilibrium that allows for detailed interactions between labour and goods markets
- designed for impact and scenario analysis
- capable of medium and long-term sectoral and regional analysis

ECOSENSE EcoSense is an Impact Assessment Model that was designed for the analysis of impacts resulting from emission of pollutants into the atmosphere.

The model is mainly used for:

- simulation of the impacts of atmospheric emissions of primary and secondary particulates, NOX, SO2, CO, heavy metals, persistent organic pollutants (POPs) on human health, agricultural crops, and material surface area of buildings
- assessment of pollution control costs
- cost benefit analysis for measures aimed at protecting human health
- assessing technologies
- estimating welfare indicators affected by air pollution, as well as pollution impacts and damage costs

Impacts and damage costs can be estimated for the following three areas: 1) human health (life expectancy, morbidity); 2) materials (mostly building material: eg limestone, sandstone, paint, zinc) and 3) crops (yield change, need for liming, fertilising).

The main features of the model are:

- detailed geographical/spatial information on European countries (geographical information organised in gridcells of 2500 km2 and 100 km2)

- elevation data for the whole of Europe on a 10 x 10 km grid
- 4 secondary pollutants (SO2, NOx, NMVOC, NH3)
- where possible the physical impacts of air pollution are evaluated in monetary terms

In summary, the characteristics of EcoSense are such that the model is:

- focused at a European level
- based on geographical/spatial information, not taking into account country borders
- able to provide detailed physical damage estimates (and where possible monetary estimates) of air pollution (such as increased mortality, morbidity, crop losses and increased maintenance effort)
- incorporating a relational database holding information on model specifications such as chemical equations, dose-response functions, technology, emission scenarios, costs and detailed geographical/spatial information

The 'single source' version of EcoSense can be obtained for a small handling fee after signing a licence agreement. Other versions of EcoSense ('transport' for calculating external costs of transport, 'multi-source' to calculate external costs for all sources of a sector and/or country or for the whole EU, 'WATSON' for water and soil pathways) can currently only be operated at the site of the developer, IER. EcoSenseLE is an online free tool that can be used in estimating costs due to emissions of a typical source (eg power plant, industry, transport) or all sources of a sector in an EU country or group of EU countries. It is a parameterised version of EcoSense and can be found at: http://ecoweb.ier.uni-stuttgart.de/ecosense_web/ecosensele_web/frame.php.

EFISCEN

EFISCEN is a forest resource projection model. The model can be uses to analyse changes in wood demand and forest area. The model is suitable for the projection of forest resources for a period of 50 to 60 years.

EFISCEN was developed for analysis of large forest areas, such as regions or countries. It is possible to apply the model to smaller areas; however no studies have been made to determine the minimum size and the effects of scale on uncertainty of the projections. The model was developed for approximately same-aged, managed forests and is currently not suited to simulate fast growing tree species (because of the structure of input data). EFISCEN can handle small decreases in forest area, but is not capable of dealing with large-scale deforestation issues.

The model is mainly used for:

- analysis of sustainable forest management regimes
- exploring wood-production possibilities
- analysis of climate change impacts on forests
- analysis of natural disturbances
- analysis of carbon balance issues

So far EFISCEN has been applied for 30 European countries and some regions of Russia.

The main features of the model are:

- it is a area based matrix model
- it has 6 to 15 age classes and 10 volume classes with widths that vary depending on the forest under study

- the possibility of splitting forest types by administrative unit, ownership, tree species and site class
- it is a policy oriented model

To sum up, the main characteristics of the EFISCEN are such that the model is:

- a policy orieted model suitable for analisys of even-aged, slow growth managed forests
- a matrix based model
- not very data intensive, the basic data required being forest inventory data
- designed for large forest areas

ENTICE-BR ENTICE-BR is a modified version of the DICE model (Nordhaus, 1994; Nordhaus and Boyer, 2000) that includes endogenous links between climate policy and energy innovation. Like DICE, ENTICE-BR is a dynamic growth model of the global economy that includes links between economic activity, carbon emissions, and the climate. The model includes fossil fuels as an input to production, as in the more detailed RICE model (Nordhaus and Yang 1996, Nordhaus and Boyer 2000). However, ENTICE-BR retains the global framework of the DICE model, rather than dividing the world into separate regions.

ENTICE-BR is a dynamic growth model of the global economy that includes links between economic activity, carbon emissions, and the climate. The model includes endogenous links between climate policy and energy innovation, making it an appropriate tool for modelling both technological options and economic impacts.

ENTICE-BR is mainly used for:

1 analysing the impacts of R&D spending in the energy sector (in particular climate-friendly)

2 studying the effects of various climate stabilization policies

ETA ETA (European Tax Analyzer) is computer-based model designed for calculating and comparing tax burdens of different partnerships and corporations, including their shareholders that are located in different countries. It can produce results for the EU25 and other OECD countries over a period of 10 years.

The model is mainly used for:

- comparing the international tax burden and structure
- evaluating the impact of fiscal returns
- comparing different forms of domestic legal companies
- investigating combined effects of tax reforms and company investment behaviour

ETA allows for the following sensitivity analyses:

- changes in investment
- changes in financing (debt, equity) and profitability
- personnel or capital insensitivity
- distribution policy
- changes in the fiscal regime

The main features of the model are:

- 10 year forecast period
- detailed treatment of corporate taxation

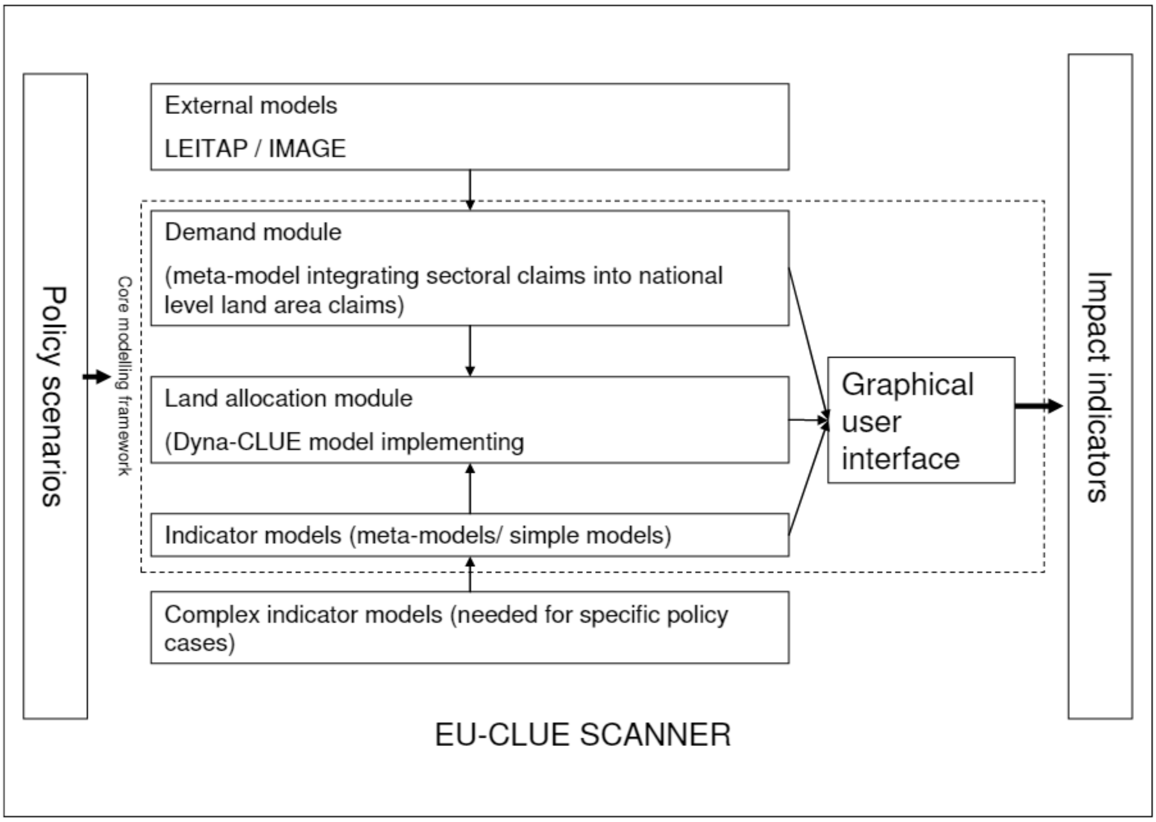
- results for the EU25, USA and Canada
- no assumption or restrictions made about market structure
- non-restricted sectoral coverage

In summary, the characteristics of ETA are such that the model is:

- focused on corporate taxation policies, allowing for a flexible design of the tax systems
- focused on the EU25
- able to focus on a particular company

EU-Clue Scanner The ‘EU-Clue Scanner’, is a modular system, which is able to link models at different scales and standard indicator models. The established structure allows for an easy linkage of different models depending on the specific questions being addressed. For example in the case of the renewable energy policy packages, global models are coupled with the land allocation model, while in the case of questions related to spatial European policies the use of the land allocation model is sufficient. The land allocation module of Dyna-CLUE, which is the core of the system, is combined with the numerical algorithm of the Land Use Scanner model to optimise its performance for use on desktop computers within the Data & Model Server (DMS).

The EU-Clue Scanner application was especially developed for DG Environment. It involved the implementation of the land allocation model (CLUE) in a new environment Date and Model Server (DMS).



EUFASOM EUFASOM is a model constructed for the European Agricultural and Forestry sectors and can be used to analyse changing policies, technologies, resources, and markets. The model focuses only on the forestry sectors, while the rest of the economy is taken as given (exogenous). Also, the model is well suited to analyse the effects of new agricultural and forestry technologies. The model runs in 5-year periods from 2005 to a given end period and produces forecast for 25 EU countries and 11 non-EU international regions.

The model is mainly used to:

- forecast production quantities, including agriculture and forest harvests and land-use transfers
- forecast equilibrium prices and trade for all products and regions included in the model

The main features of the model are:

- 25 EU countries and 11 non-EU world regions
- 5-year period forecast up to a given end date
- coverage of 3 greenhouse gases (carbon dioxide, methane, nitrous oxide), as well as sediment transport and nitrogen-phosphor leaching
- broad land management adaptation (irrigation, fertilisation, tillage, conservation, thinning, forest rotation length, choosing species)
- land use change between agriculture, forestry, nature reserves, and energy crop plantations
- endogenous prices, supplies, demands and trade for the covered commodities

To sum up, the main characteristics of the EUFASOM are such that the model is:

- a bottom-up optimisation model
- focused only on the agricultural and forestry sectors, treating the rest of the economy as given (partial equilibrium model)
- focused at the European level
- able to forecast the impact of new technologies that have not been used on a large scale, outside experimental plots

EUROMOD

EUROMOD is a tax benefit model, initially covering the EU15. In 2005, under the FP6 Research Infrastructures Action as a Design Study the model was expanded to cover 4 of the EU10 and look at the feasibility of the other 6.

The model is mainly used for:

- estimating the distributional impact of changes in personal tax and transfer policy
- evaluation of the efficiency-equity trade-off in different types of welfare reform
- comparison of different fiscal policies at a European level

The model calculates disposable income for each household in the dataset provided by using information from survey data and data simulated by the model (such as taxes and benefits).

The main model results are the Household Disposable Income (HDI), which is made up of wage and salary income, self-employment income, property income, other cash market income and occupational pension income and cash benefit payments, of which direct taxes and social security contributions are subtracted. Other variables may be added, depending on the particular analysis (either at household level or at the level of any identifiable group of individuals within the household).

The main features of the model are such that it is:

- a static model, designed to calculate the immediate effect of policy changes (it does not incorporate behavioural and long-term changes/effects)
- dependent on the EUROMOD database
- limited to simulating policies which depend on variables that exist in the model database
- run over a variable time period, as original data used for deriving the EUROMOD database refer to different time periods for different countries

In summary, the characteristics of EUROMOD are such that the model is:

- static, focused on 'morning-after' effects
- a micro-simulation model
- a country level model, but has the capacity to simulate the effects of common policies in EU member states
- made up of individual 'policies', collections of tax-benefit instruments such as income taxes, social insurance contributions and social assistance benefits

FAIR The FAIR model is an interactive, decision-support tool to analyse environmental and costs implications of climate mitigation regimes for future commitments for reducing emissions of greenhouse gases. The model links long-term climate targets and global reduction objectives with regional emissions allowances and abatement costs, accounting for the used Kyoto Mechanisms. The results can be analyzed at various geographical scales, ie for the 26 world regions (FAIR region model), 27 EU Member States (FAIR EU model) and 224 UN countries (FAIR world model).

The main areas of research cover:

- policy analysis in the field of environment, nature and spatial planning
- quantitative analysis of global targets

FAMOUS FAMOUS is an atmosphere-ocean general circulation model (AOGCM) based on the Met Office Hadley Centre HadCM3 model. FAMOUS is a global model which can be used to create long-term (centuries) climate change simulations. The model is made up of and atmosphere component and an ocean component.

The model is mainly used for:

- long-term scenarios of climate change impacts (air temperature, precipitation, sea level)

The main features of the model are:

- integrated modules, which function as a single unit
- long-term forecast outlook (centuries)
- grid-based model, data is split in standard longitude/latitude degree cells

The atmosphere component of FAMOUS is split in 7.5o longitude x 5o latitude grid with 11 vertical levels and a 1-hour timestep. The ocean component is split in 3.75o longitude x 2.5o latitude with 20 levels, the same as HadCM3L, with a 12-hour timestep.

In summary, the characteristics of FAMOUS are such that the model is:

- elaborated at a world level, grid-based
- designed for long-term simulations
- focused on main climate change impacts, such as mean temperature, precipitation and sea level

FUND The Climate Framework for Uncertainty, Negotiation and Distribution (FUND) is a so-called integrated assessment model of climate change. FUND was originally set-up to study the role of international capital transfers in climate policy, but it soon evolved into a test-bed for studying impacts of climate change in a dynamic context, and it is now often used to perform cost-benefit and cost-effectiveness analyses of greenhouse gas emission reduction policies, to study equity of climate change and climate policy, and to support game-theoretic investigations into international environmental agreements.

FUND links scenarios and simple models of population, technology, economics, emissions, atmospheric chemistry, climate, sea level, and impacts. Together, these elements describe not-implausible futures. The model runs in time-steps of one year from 1950 to 2300, and distinguishes 16 major world regions.

FUND further includes the option to reduce emissions of industrial carbon dioxide. Reductions can be set by the user, or calculated so as to meet certain criteria set by the user.

An integrated assessment model, FUND is used to advice policymakers about proper and not-so-proper strategies. The model, however, always reflects its developer's world views. It is therefore regularly contrary to the rhetoric of politicians, and occasionally politically incorrect.

GAINS GAINS is an integrated systems model designed to explore synergies and trade-offs between local and regional air pollution control and the mitigation of global greenhouse gas emissions. The model can help to explore different pollution control strategies across the world and determine the ones that maximise benefits. GAINS covers 77 countries, including the EU27 explicitly, up to 2030.

The current GAINS model incorporates the latest version of RAINS-Europe model as it was prepared for the 2006 revision of the NEC directive (http://www.iiasa.ac.at/rains/CAFE_files/timetable_NECD_JC.html).

The model is mainly used for:

- analysing changes in emissions and possible measures to control emissions over a given time period
- creating different emissions scenarios and calculating emission control costs
- analysing the main economic activities that cause emissions, such as energy production and consumption, transport and other industrial and agricultural activities
- presenting the impacts of air pollution on the ecosystem and on human health

Features of the model include:

- emissions' assessment over a medium-term period, with projections for five year intervals up to 2030
- coverage of 43 European countries including the European part of Russia
- detailed results for 7 types of emissions (some versions of the GAINS model may include 10, see classifications)
- several emissions reductions technologies for controlling emission costs and levels
- two modes of model operation: optimisation mode, which can be used in identifying least-cost emission reduction schemes, and scenario mode, which can be used to follow emissions from their sources to their impacts

- impact data of pollution on human health (loss of statistical life expectancy caused by pollution)

In summary, the characteristics of GAINS are such that the model is:

- focused on control and cost optimisation for user-specified policies and targets
- able to produce multi-pollutant, multi-impact pollution strategies
- able to provide optimisation solutions across various economic sectors across all European countries meeting user defined health targets
- a policy-analysis tool focused on environmental targets and the implications of achieving these targets
- capable of incorporating existing and adopted national and EU legislation in its baseline projections

GCAM Model Type: Partial-equilibrium model (energy and land-use) including numerous energy supply technologies, agriculture and land-use model, and a reduced-form climate model. Emissions include CO2, CH4, N2O, and SO2. 15-year timestep. Run period 1990 - 2095.

Developer/Home Institution: Joint Global Change Research Institute (PNNL). Contacts: Kate Calvin (katherine.calvin@pnl.gov) or Marshall Wise (marshall.wise@pnl.gov).

Sector Detail: Three end-use sectors (Buildings, Industry, and Transportation). Supply sectors: fossil-fuels, biomass (traditional & modern), electricity, hydrogen, synthetic fuels.

Regional Detail: Global coverage with 14 regions (United States, Canada, Western Europe, Japan, Australia & New Zealand, Former Soviet Union, Eastern Europe, Latin America, Africa, Middle East, China [& Asian Reforming Economies], India, South Korea, Rest of South & East Asia)

Technology Detail: Electric generation (Coal, Oil, Gas, Biomass, Hydro, Nuclear, Wind, Solar PV), Hydrogen production (Coal, Oil, Gas, Biomass, Electrolysis), synthetic fuels (liquids and gases from coal, oil, gas, biomass), geologic carbon sequestration from fossil fuels (electric generation, hydrogen generation, synthetic fuel production). Tradiational, residue, and biomass crops. Biomass crops generated regionally by an AgLU model.

Energy Demand: Technology-based U.S. end-use sectors. Transportation by mode (Passenger: light duty vehicles, bus, train, air, motorcycle; Freight: truck, ship, rail, air) and technology (eg, ICE cars, ICE light trucks, hybrid cars, electric cars, fuel-cell cars). Separate commercial and residential buildings by service (heating, cooling, lighting, hot water, other) and technology (eg, gas or oil furnace, electric baseboard, electric heat pump). Industrial energy use by sector (9 manufacturing sectors; 4 non-manufacturing) and end-use (boilers, process heat, machine drive, HVAC, electro-chemical, feedstocks, other).

ObjECTS Framework: The GCAM is implemented within the Object-Oriented Energy, Climate, and Technology Systems (ObjECTS) framework. ObjECTS is a flexible, modular, Integrated Assessment modeling framework. The component-based structure of this model represents global energy, land-use, and economic systems through a component hierarchy that aggregates detailed technology information up to a global macroeconomic level. Input is provided by the flexible XML standard, where data is structured in an object hierarchy that parallels the model structure.

Special Features: Ability to understand the impact of technologies and policies related to GHG emissions in a national and global context. Ability to quickly evaluate technologies including carbon sequestration. Biomass land competes with food and fiber uses in the agriculture/land-use model. MAGICC provides GHG concentrations, radiative forcing, and climate change. Flexible object-oriented structure allows new technologies and sectors to be quickly implemented.

G-CUBED G-Cubed is a multi-country, multi-sector, intertemporal general equilibrium model that has been used to study a variety of policies in the areas of environmental regulation, tax reform, monetary and fiscal policy, and international trade.1 It is designed to bridge the gaps between three areas of research – econometric general equilibrium modelling, international trade theory, and modern macroeconomics – by incorporating the best features of each.

From the trade literature, G-Cubed takes the approach of modelling the world economy as a set of autonomous regions – eight, in this case – interacting through bilateral trade flows. Following the Armington approach (Armington 1969), goods produced in different regions are treated as imperfect substitutes.3 Unlike most trade models, however, G-Cubed distinguishes between financial and physical capital. Financial capital is perfectly mobile between sectors and from one region to another, and is driven by forward-looking investors who respond to arbitrage opportunities. Physical capital, in contrast, is perfectly immobile once it has been installed: it cannot be moved from one sector to another or from one region to another. In addition, intertemporal budget constraints are imposed on each region: all trade deficits must eventually be repaid by future trade surpluses.

Drawing on the general equilibrium literature, G-Cubed represents each region by its own multi-sector econometric general equilibrium model.4 Production is broken down into twelve industries and each is represented by an econometrically-estimated cost function. Unlike many general equilibrium models, however, G-Cubed draws on macroeconomic theory by representing saving and investment as the result of forward-looking intertemporal optimization. Households maximize an intertemporal utility function subject to a lifetime budget constraint, which determines the level of saving, and firms choose investment to maximize the stock market value of their equity.

Finally, G-Cubed also draws on the macroeconomic literature by representing international capital flows as the result of intertemporal optimization, and by including liquidity-constrained agents, a transactions-based money demand equation and slow nominal wage adjustment. Unlike typical macro models, however, G-Cubed has substantial sector detail and is its parameters are determined by estimation rather than calibration.

This combination of features was chosen to make G-Cubed versatile. Industry detail allows the model to be used to examine environmental and tax policies which tend to have their largest direct effects on small segments of the economy. Intertemporal modeling of investment and saving allows G-Cubed to trace out the transition of the economy between the short run and the long run. Slow wage adjustment and liquidity-constrained agents improves the empirical accuracy with which the model captures the transition. Overall, the model is designed to provide a bridge between computable general equilibrium models, international trade models and macroeconomic models by combining the best features of each approach. The cost of this versatility is that G-Cubed is a fairly large model. It has over 5,000 equations holding in each year, is typically solved for annually for 100 years in each simulation, and has over 100 intertemporal costate variables. Nonetheless, it can be solved using software developed for a personal computer.

GEM-CCGT GEM-CCGT is a general equilibrium model designed for analysing the effects of multilateral agreements on climate change and trade. As a general equilibrium model, it implies that resources are allocated efficiently (all the markets of an economy are in equilibrium).

The model is mainly used for:

- impact analysis of current and future trade agreements
- impact analysis of green-house gases abatement strategies under the Kyoto Protocol
- impact analysis of the interaction between trade and environmental policies

The main features of the model are:

- 45 world regions, 50 commodities and 7 consumption categories (consistent with GTAP 4 database)
- yearly solution up until 2030
- imperfect competition with product differentiation and firms competing in quantities (Cournot framework)
- exogenous capital flows, fixed costs at firm level
- the number of firms changes in such way that the output price equals average cost
- perfect competition in the labour market

All commodities are traded in world markets. Crude oil and coal are imported and exported as homogeneous products with single world prices determined by global demand and supply. All other goods are characterised by product differentiation and imperfect substitutability between imports and domestically sold domestic output.

In summary, the characteristics of GEM-CCGT are such that the model is:

- a general equilibrium model with imperfect competition and variable number of firms
- focused at a world level
- focused on policy analysis
- dealing with energy consumption and CO2 emissions

GEM-E3 The GEM-E3 model was designed to provide details on the macroeconomy and its interactions with the environment and the energy system. It is an empirical, large-scale model, representing 2 World regions/24 European countries, linked through endogenous bilateral trade. It is a general equilibrium model, meaning it computes the equilibrium prices of goods, services, labour, and capital that simultaneously clear all markets.

The model is mainly used for:

- simulating the effects of market-based instruments (such as taxes) for energy-related environmental policy on key economic and environmental indicators
- evaluating European Commission programmes aimed at promoting sustainable economic growth
- burden-sharing analysis

- public finance, stabilisation policies and their implications on trade, growth and the behaviour of economic agents

The main features of the model are:

- 24 European Union countries (the EU27 excluding Cyprus, Malta and Luxembourg) for GEM-E3 Europe, 20 world country/region modules involving (including USA, China, India, Japan) for GEM-E3 World
- 18 products and sectors
- 11 non-durable goods and 2 durable goods
- 6 emissions types for GEM-E3 Europe, 2 emission types for GEM-E3 World;
- backward-looking expectations
- exogenous technical progress

GEM-E3 can be used either in the single-country version where the rest of the world is an aggregate of all other countries/regions or the multi-country version where individual countries are linked by endogenous (price dependent) bilateral trade flows or trade pools.

In summary, the characteristics of GEM-E3 are such that the model is:

- a multi-country model, treating separately each region and linking them through endogenous trade of goods and services
- sectoral, incorporating economic agents (households, firms, government and foreign sector), thus allowing for a consistent evaluation of distributional effects of policies
- multi-period model, involving dynamics of capital accumulation and technological progress, stock and flow relationships and backward-looking expectations

GENIE The GENIE model is focused on long-term paleo-climate change, and the future long-term response of the Earth system to human activities. It includes modules of the atmosphere, ocean, sea-ice, marine sediments, land surface, vegetation and soil, ice sheets and energy.

The model is mainly used for:

- long-term (millennia) climate variation simulations
- investigating carbon cycles during deglaciation and the changes in vegetation and carbon storage during Holocene, a geological epoch which began approximately 10,000 and continues in the present
- long-term projections of climate change and carbon cycling

Features of the model include:

- different modules that look at distinct earth entities (eg atmosphere, ocean) and enable them to be modelled independently
- grid based modelling and results
- the ability to run scenarios by making changes in more than one module
- traceability of simulated climate, ocean circulation, and other key variables
- Bayesian approach in regarding uncertainty, calibration and estimating the probability of future events

To summarise GENIE is:

- elaborated at a world level

- designed for long-term simulations relating to different periods of the planet's evolution
- modular, with the possibility of running the different modules independently
- grid based model

GINFORS The Global INterindustry FORecasting System (GINFORS) is an economy-energy-environment model with global coverage. GINFORS also includes a module for material consumption.

GINFORS includes explicitly all EU countries, all OECD countries and their major trade partners. The model is based on time series of international data covering the period 1980 to 2004. An update with data until 2006 will be finished in spring 2009. Behavioural parameters are estimated using econometric methods and are based on empirical relationships.

GINFORS is based on a series of closely-linked modules which are solved simultaneously. The bilateral trade model is the heart of the system. This guarantees consistent linkage of trade volumes and prices for 25 commodities and a service sector. Exports of one country have to be imports of another country and so the global level the trade system is closed.

Within each country, the economies are modelled using either a macro model (MM) or input-output model (IOM). The difference is the sectoral coverage, which is missing from the macro model; where possible the IOM is used but due to data limitations this is restricted to 21 countries.

The IO models describe the production technology in the countries as reflected in the input structures. Energy-emission models (EEM) are based on energy balances of the International Energy Agency and are available for all countries and regions distinguished in the model. In the EEM energy demand and supply are consistently linked for 12 energy carriers to the economic driving forces that are explained in the economic part of the model. Carbon emissions result from the use of fossil fuels.

Material inputs have also been integrated into the modelling system. For all countries resource use extraction in tons is explained for 6 categories. Their development is either driven by economic activity or energy demand for fossil fuels.

GLOBIO The GLOBIO (Global Methodology for Mapping Human Impacts on the Biosphere) model was created to explore the impact of environmental change on biodiversity. The model draws on information from current scientific studies on environmental impacts and relates this to infrastructure development to create different scenarios up to 2050.

The model is mainly used for:

- analysing current levels and future developments of land areas that are directly urbanised
- analysing current levels and future developments of land areas that are converted for agriculture or infrastructure, or are fragmented and under conversion
- analysing current levels and future developments of land areas that are still relatively intact ecosystems
- analysing the impacts of land-use policy options and scenarios with different social, demographic or economic assumptions

The model's parameters are estimated using historical data sets and these drive future trends. The model uses the assumption that in most areas, infrastructure occurs in clusters, which expand gradually from the original point, with the highest density present in urban areas.

Features of the model include:

- detailed analysis of biodiversity trends (looking into the future and backwards over history)
- links to socio-economic and environment (eg climate change) models
- clear aggregation and presentation of the results; policy-focused presentation
- aquatic, marine and terrestrial and agricultural ecosystems, which can be aggregated into habitats
- solutions up to 2050
- results for seven world regions (including Europe) and at the global level

To summarise, GLOBIO is:

- laborated at a global level
- designed to provide analysis on environmental changes in a format suitable for policymaking
- focused on infrastructure, its probable impact and future development, as a proxy of human expansion
- supported by current scientific studies on environmental impacts and risks to ecosystems
- based on both statistics and satellite imagery

GTAP The standard GTAP (Global Trade Analysis Project) model was built as a general-equilibrium model, assuming perfect competition and constant returns to scale, for 87 world regions and 57 commodities. The model allows for a sophisticated treatment of consumer demands, detailed treatment of international trade and transport costs and a global banking sector.

There are two main extensions to the main model: the dynamic version of GTAP (GTAP-Dyn) and the environmental extension (GTAP-E). The dynamic GTAP incorporates all the features of the standard model, with a revised (dynamic) treatment of investment behaviour and new accounting relations to keep track of the foreign ownership of capital. The GTAP-E model was built for the analysis of climate change issues. The extension can be used to evaluate the abatement costs and spill-over effects of greenhouse gas reduction policies through international trade and interactions between sectors.

Two other extensions of the model refer to migration and poverty research.

The main uses of the GTAP model and its extensions are:

- general macro and sectoral economic analysis, for example assessing the implications of changes in policies, technology, population and input factors (land, labour, capital, natural resources); examples include the economic impacts of tax reform, the effects of agricultural liberalisation or removal of trade barriers
- investigating economic and regulatory integration and trade patterns
- detailed assessment of the impact of climate-change policies, such as emissions trading and carbon taxes

Features of the GTAP model include:

- regional solutions for 87 world regions
- general-equilibrium solution and use of Walras' Law (meaning demands are always met by production somewhere in the world)
- detailed treatment of the regional differences such as economic structure, household income and spending, investment and transport
- partial-equilibrium assumptions, such as exogenous income, non-food output levels and prices and wages
- switching between products according to price and preference

Features of the GTAP-E model include:

- a top-down economic approach to analysing energy inputs (meaning a fixed amount of energy is required to meet demands)
- exogenous elasticities for inter-fuel and fuel-factor substitution, determining rates of switching between fuels
- separation of energy and non-energy commodities

To summarise, the characteristics of the GTAP model and its extensions are:

- a general equilibrium model based on neoclassical economic assumptions
- it is elaborated at a regional level, with detailed results shown for each region and year
- focused on policy analysis and trade

GTEM

GTEM – the global trade and environment model – developed at the Australian Bureau of Agricultural and Resource Economics (ABARE) is an analytical tool that is global in coverage, encompasses all markets and takes in account all resource constraints and their dynamics.

As general equilibrium model it captures the interlinkages between the markets of all commodities and factors, taking into account resource constraints, to find a simultaneous equilibrium in all markets. A global general equilibrium model extends this interdependence of the markets across world regions and finds simultaneous equilibrium globally. A dynamic model adds onto this the interconnection of equilibrium economies across time periods. For example, investments made today are going to determine the capital stocks of tomorrow and hence future equilibrium outcomes depend on today's equilibrium outcome, and so on.

GTEM, has the capability of addressing total, sectoral, spatial and temporal efficiency of resource allocation as it connects markets globally and over time. Of course, being a recursively dynamic model, its ability to address temporal issues is rather limited. In particular, GTEM cannot address issues requiring partial or perfect foresights. However, it does have the capability to project the economic impacts over time of given changes in policies, tastes and technologies in any region of the world economy on all sectors and agents of all regions of the world economy.

GTEM was developed out of the MEGABARE model (ABARE 1996), which contained significant advancements over the GTAP model of that time (Hertel 1997), and has been evolving ever since. As more data become available, more features are added. As understanding of the theoretical system improves or software becomes more intelligent or new and complex questions need to be addressed, the model is further improved. By doing so, the model becomes even richer.

ICLIPS ICLIPS seeks to provide Integrated Assessment of Climate Protection Strategies to support the decision-making community in the realization of the United Nations Framework Convention on Climate Change (UNFCCC). A new approach, the Tolerable Windows Approach (TWA) consists of a separation of normative settings for 'tolerable windows' on climate impacts, negotiable allowances for greenhouse gas emissions, and desirable socioeconomic development scenarios. It also includes the scientific analysis which provides the set of all climate protection strategies which are compatible with these settings.

The ICLIPS project is an international and interdisciplinary research activity whose aim is to provide an Integrated Assessment of Climate Protection Strategies in order to support the decision making community in the realization of the United Nations Framework Convention on Climate Change. One cornerstone of this project is the Tolerable Windows Approach (TWA): on the basis of a set of pre-defined constraints that exclude intolerable climate changes on the one hand and unacceptable mitigation measures on the other, the admissible scope for action is sought by investigating the dynamic cause-effect relationships between society and climate. These relationships are described in an integrated manner by a model that takes into account climate impacts, the climate system itself, relevant biogeochemical cycles, emissions of different greenhouse gases, the allocation of emission rights to different nations, possible instruments for emission mitigation, and the dynamics of socio-economic development. The different model components were developed jointly with experts from leading institutes in the respective fields of Global Climate Change. The modelling efforts are coordinated by the Potsdam Institute for Climate Impact Research, which has initiated the project and integrates the various model components within the framework of the TWA.

IGSM This comprehensive tool analyzes interactions among humans and the climate system. It is used to study causes of global climate change and potential social and environmental consequences.

The IGSM seeks to answer such questions as:

- How effective and costly would specific policy measures be in alleviating climate change?
- What are the advantages and risks of waiting for better scientific understanding of such change?
- How will the oceanic and terrestrial uptake of carbon dioxide and other greenhouse gases be affected by changing climate?
- What nations, regions, and economic sectors are most likely to be affected?

The IGSM consists of three primary components:

- economics, emissions, and policy cost model for analysis of human activity as it interacts with climate processes, and to assess proposed policy measures
- climate and earth system component: coupled dynamic and chemical atmosphere, ocean, land, and natural ecosystem interactions and feedbacks
- land ecosystems and biogeochemical exchanges models, within a Global Land System framework, for analysis of the terrestrial biosphere

These components then inform a component that analyzes the feedbacks and impacts of climate change. Within the current formulation of the IGSM the consideration of climate change impacts emphasizes terrestrial ecosystems and sea levels, feedbacks of changed climate onto the carbon cycle and natural emissions of CH4 and N2O, effects of climate change and ozone pollution on agriculture, and the interaction of climate chemistry with its counterparts in urban air pollution.

IIASA/VID Educational Attainment Model

The IIASA/VID educational attainment model was developed by the International Institute for Applied Systems Analysis (IIASA) and the Vienna Insitute of Demography, Austrian Academy of Sciences and was used in the reconstruction of educational attainment distributions by age and sex from 1970 to 2000 and projections through alternative scenarios to 2050.

The model is mainly used for:

- detailed analysis of the population and education mix (the full composition of the population by age, sex, and levels of educational attainment)
- exploring the mechanisms of population and education dynamics
- running education scenarios
- analyse the impacts of different kinds of trends and policy environments on global human capital

The model is designed as a scientific tool for projections but can be used as support tool to show the long-term implications of improvements in schooling at country level (other administrative/geographical units can be used). IIASA and VID have made projections for 120 countries using four different scenarios.

Features of the model include:

- 120 countries
- forecasts up to 2050
- explicit variation of fertility and mortality rates with the level of education
- great flexibility in making scenarios
- flexible number of education attainment categories

To summarise, the IIASA/VID education attainment model is:

- oriented towards projections, but can be used for policy analysis
- focused on education dynamics
- made up of a reconstruction model and a projections model

The IIASA/VID model can be linked to other projection models with more detail on the schooling processes. Such joint models could translate specific aspects of schooling policies into alternative enrolment, educational transitions and ultimately attainment distributions.

IMACLIM

The computation of long term economic pathways and the assessment of sustainable development policies require models able to embark information and expectations from economists, engineers, earth scientists and stakeholders. CIRED has drawn the architecture of modelling IMACLIM in order to cope with this scientific challenge at the interface of environment and development issues, in particular to assess climatic and energy policies.

It relies on a hybrid model which combines a macroeconomic approach with sectional-engineers views. The model is currently available in a static version, Imaclim-S (Ghersi and Hourcade, 2006), and a recursive version Imaclim-R (Crassous and al, 2006).

- Imaclim-S projects the economy of a country or a region to a given forecast (for instance 2030), while taking into account constraints linked, on the one hand, to the macroeconomic equilibrium and on the other hand to the range of technical means. It is particularly used to assess macroeconomic impacts of a carbon constraint (taxes, quotas) according to several details of implementation (recycling, receipts, green tax reform…). Recent studies have especially focused on France.
- Imaclim-R projects the economy as series of annual static equilibrium whose evolution is guided by demographic trends. 12 detailed sectional modules (electricity, transport, fossil fuels, residential…) applied in 12 regions are connected to the input-output model of the static version. Imaclim-R is used to make long term evolution of energetic systems scenarios and assess GHG reduction emissions.

IMAGE IMAGE is a multi-disciplinary, integrated system of models designed to simulate the dynamics of the global society-biosphere-atmosphere system. The model can forecast up to 2100 and has a spatial scale grid of 0.5 x 0.5 degrees latitude-longitude for climate, land-use and land-cover processes, and region-level split for socio-economic indicators.

The model is mainly used to:

- investigate linkages and feedbacks in the global society-biosphere-atmosphere system
- assess consequences of global policies
- analysing relative effectiveness of various policy options addressing global change

The socio-economic activities are explored at a 24-region level, while the climate, land-cover and land-use processes are represented on the 0.5 by 0.5 degree grid scale. Model simulations generally cover the period 1970-2050 and for climate scenarios, often the period 1970-2100. Simulations are made on the basis of scenario assumptions on, for example, demography, food and energy consumption and technology and trade.

The interlinked models in IMAGE are:

- PHOENIX (population model) and WorldScan (World economy) - supply the basic information on economic and demographic developments for 17 socio-economic regions (Canada, USA, Central America, South America, Northern Africa, Western Africa, Eastern Africa, Southern Africa, OECD Europe, Eastern Europe, Former USSR, Middle East, South Asia, East Asia, South East Asia, Oceania and Japan
- TIMER model - regional energy consumption, energy efficiency improvements, fuel substitution, supply and trade of fossil fuels and renewable energy technologies
- ecosystem, crop and land-use models - compute land use and local climatic and terrain properties. The terrestrial models perform its simulations on a grid scale
- atmospheric and ocean models - calculate changes in atmospheric composition, by taking oceanic CO2 uptake and atmospheric chemistry into consideration
- impact models - make use of specific features of the ecosystem and crop models to depict impacts on vegetation

In summary, the characteristics of IMAGE are such that the model is:

- multi-disciplinary, integrated model, dealing with socio-economics and global climate change in one modelling framework

- designed as a policy analysis tool
- focused on long-term dynamics of global environmental change, which are determined by human activities

The Judicial Reform Index

The Judicial Reform Index was developed by the American Bar Association.

The JRI is:

- an assessment of judicial reform indicators
  - broad-based: thirty categories examined
- structured around comparative analysis
  - draws on European and U.S. legal approaches
- a CEELI product that has been vetted internally and externally
- a platform for unprecedented comparative legal research

The JRI reform factors include:

- quality, education and diversity
  - judicial qualification and preparation
  - selection/appointment process
  - continuing legal education
  - minority and gender representation
- judicial powers
  - judicial review of legislation
  - judicial oversight of administrative practice
  - judicial jurisdiction over civil liberties
  - system of Appellate review
  - contempt/subpoena/enforcement
- financial resources
  - budgetary input
  - adequacy of judicial salaries
  - judicial buildings
  - judicial security
- structural safeguards
  - guaranteed tenure
  - objective judicial advancement criteria
  - removal and discipline of judges
  - case assignment
  - judicial associations
- accountability and transparency
  - judicial decisions and improper influence
  - code of ethics
  - judicial conduct complaint process
  - public and media access to proceedings
  - publication of judicial decisions
  - maintenance of trial records
- efficiency
  - court support staff
  - judicial positions
  - case filing and tracking systems
  - computers and office equipment
  - distribution and indexing of current law

LEITAP The LEITAP model was developed by Landbouw Economisch Instituut (LEI). It extends the existing GTAP model to include land use.

The GTAP model was improved with a new land allocation method that took into account the degree of substitutability between different types of land use. It was designed to make the GTAP model more appropriate for the analyses of the agricultural sector. Information from the OECD's Policy Evaluation Model (PEM) was used to improve the production structure.

The original version of the GTAP model represents land allocation in a CET structure. It is assumed that the various types of land use are imperfectly substitutable, but the substitutability is equal among all land use types. In the LEITAP model, the land use structure was extended by taking into account the fact that the degree of substitutability of types of land differs between types.

The detailed PEM distinguishes different types of land in a nested 3-level CET structure, covering several types of land use more or less suited to various crops. Each of the levels assumes a different elasticity of transformation, with the elasticities being taken from the PEM. In this way the degree of substitutability of types of land can be varied between the nests.

In the standard GTAP model, the total land supply is exogenous. Total agricultural land supply is modelled using a land supply curve which specifies the relation between land supply and a rental rate. Land supply to agriculture as a whole can be adjusted as a result of unused agricultural land, conversion of non-agricultural land to agriculture, conversion of agricultural land to urban use and agricultural land abandonment. The GTAP model therefore assumes that when there is enough agricultural land available, increases in demand for agricultural purposes will lead to land conversion to agricultural land and a modest increase in rental rates. However, if almost all agricultural land is in use then increases in demand will lead to increases in rental rates. The LEITAP model assumes a different land supply function.

In the GTAP model yields are only dealt with implicitly and the feed livestock linkage is calculated using the input-output coefficients. To improve the treatment of these issues, the adjusted GTAP model was linked with the IMAGE model.

MAGICC MAGICC (Model for the Assessment of Greenhouse-gas Induced Climate Change) is an interactive model that allows users investigate future climate change and its uncertainties at both the global-mean and regional levels. MAGICC is coupled with SCENGEN (a Regional Climate Scenario Generator). MAGICC calculates the estimates at the global-mean level, using upwelling-diffusion, a phenomenon that involves the movement of cooler water towards the ocean surface, replacing the warmer, usually nutrient-depleted surface water, and energy-balances techniques similar to those employed by the IPCC (Intergovernmental Panel on Climate Change). SCENGEN uses the calculations to produce spatially detailed information on future changes in temperature, precipitation, mean sea level pressure, changes in their variability, as well as a range of other statistics.

The model is mainly used to:

- compare the global-mean temperature and sea level implications of any two scenarios

- determine the sensitivity of the temperature and sea level results for any chosen emissions scenario to changes in model parameters (and uncertainties relating to model parameters)

SCENGEN is used to construct geographically explicit climate change projections for the world using the results from MAGICC together with an Atmosphere/Ocean General Circulation Model (AOGCM) and other information sources. To produce these projections, SCENGEN adds the climate change information to observed baseline climate data (1980-99 means). These results are displayed as maps, with the data split in standard 2.5x2.5 degree latitude/longitude grid.

The main features of the model are:

- 1990 to 2100 default output period, but projections can be made up until 2400
- integrated modules, which function as a single package
- 11 types of emissions resulting from human activities
- the ability to compare output from 2 different scenario runs
- a library of emission scenarios from which the user can choose

SCENGEN features include:

- the ability to produce spatial pattern results, such as changes in inter-annual variability
- probabilistic output display

In summary, the characteristics of MAGICC are such that the model is:

- elaborated at a world level, grid-based
- designed for long-term simulations
- focused on main climate change impacts, such as mean temperature, precipitation and sea level

MARKAL-TIMES

The MARKAL family of models (see model specification for details) is a set of generic models that can be modified depending on the input data used. The models can generate sustainable energy production scenarios at a given spatial background (national, regional, province, community) in Europe and the rest of the world over a period of 40 to 50 years. MARKAL relies on a consistent energy technology database and projections for energy demand and resource costs to create scenarios that minimise energy system costs depending on abatement policies. The models choose the abatement technologies on the basis of future required reductions of emissions.

The models are mainly used for:

- identifying least-cost energy systems
- exploring cost-effective responses to emission control policies
- creating and analysing long-term energy balances under different scenarios
- evaluating new technologies for R&D purposes
- analysing the effects of different regulations and policies (eg taxes and subsidies)
- forecasting inventories of greenhouse gas emissions
- estimating the value of regional cooperation in energy policy

MARKAL is a bottom-up dynamic and mostly linear programming model, meaning that the model solution is the optimum, given the constraints.

Features of the models include:

- extensive detail on energy-producing and consuming technologies

- results over a period of 40 to 50 years
- flexibility and a user-friendly interface for non-technical users
- the ability to analyse environmental policy issues, including sectoral and system-wide emissions restrictions. This can be done annually or cumulatively over time

MARKAL was merged with EFOM to create the TIMES model (The Integrated MARKAL-EFOM System). TIMES incorporates the features of both models, as well as a new climate model. The model is generally applied at country level. TIAM (TIMES Integrated Assessment Model) is a global version of the TIMES model (it contains 15 word regions).

MERGE MERGE is a model for estimating the regional and global effects of greenhouse gas reductions. It quantifies alternative ways of thinking about climate change. The model is sufficiently to flexible to explore alternative views on a wide range of contentious issues: costs of abatement, damages from climate change, valuation and discounting. MERGE contains submodels governing:

- the domestic and international economy
- energy-related emissions of greenhouse gases
- non-energy emissions of ghg's
- global climate change – market and non-market damages

Each region's domestic economy is viewed as a Ramsey-Solow model of optimal longterm economic growth. Intertemporal choices are strongly influenced by the choice of a ‘utility’ discount rate.

Price-responsiveness is introduced through a top-down production function. Output depends upon the inputs of capital, labor and energy. Energy-related emissions are projected through a bottom-up perspective. Separate technologies are defined for each source of electric and nonelectric energy. Fuel demands are estimated through ‘process analysis’.

Each period's emissions are translated into global concentrations and in turn to the impacts on mean global indicators such as temperature change. MERGE may be operated in a ‘cost-effective’ mode - supposing that international negotiations lead to a time path of emissions that satisfies a constraint on concentrations or on temperature change. The model may also be operated in a ‘benefit-cost’ mode - choosing a time path of emissions that maximizes the discounted utility of consumption, after making allowance for the disutility of climate change.

Individual geopolitical regions are defined. Abatement choices are distinguished by ‘where’ (in which region?), ‘when’ (in which time period?) and ‘what’ (which greenhouse gas to abate?). There may be tradeoffs between equity and efficiency in these choices.

MESSAGE MESSAGE is an optimization model used for medium- to long-term energy system planning, energy policy analysis, and scenario development. The model provides a framework for representing an energy system with all its interdependencies from resource extraction, imports and exports, conversion, transport and distribution, to the provision of energy end-use services such as light, space conditioning, industrial production processes, and transportation. The model also covers all six Kyoto GHGs, their drivers and mitigation technologies.

MESSAGE is relevant in analysing the development of 'greener' technologies, as well as looking at the diffusion of technology across countries. The model can also be used to analyse the trade flows of different energy products.

MIASMA MIASMA was developed to model the health impacts of global atmospheric change for: 1) vector-borne diseases (such as malaria, dengue fever, and bilharzia), 2) thermal heat mortality and 3) UV related cancer caused by ozone depletion.

The model is based on cause and effect relationships between atmospheric changes and human population health and it includes an environmental and a human submodel. The environmental submodel focuses on ozone depletion, climate change and air pollution, which in turn feed into food and clean water availability and the occurrence and distribution of vector borne diseases. The human submodel centres on socio-economic development and treatment, as well as age, sex and the type of exposure.

The model is mainly used for:

- the analysis of future health impacts of global environmental changes

Features of the model include:

- annual solutions up to 2100
- a flexible methodology, which enables the user to include different sets of determinants and disease-specific modules
- climate input which is module or disease-specific; for example, for skin cancer the thickness of the ozone layer over the given area is required to determine the potential level of UV-B radiation that reaches the ground

The model is driven by population and climate/atmospheric scenarios applied across baseline data on disease occurrence, climate conditions, and the state of the ozone layer.

MIRAGE MIRAGE is general-equilibrium model developed for the analysis of trade policies. The sectors and regions in the model are defined by the GTAP database (up to 57 commodities and 87 regions, including the EU27 member states). The model offers a detailed treatment of Foreign Direct Investment (FDI) and optional modules can be used to analyse different agricultural trade policies, including intervention prices and subsidies.

The model is mainly used for:

- the detailed analysis of trade policies
- explicit modelling of Foreign Direct Investment (FDI)
- detailed modelling of the agricultural sectors

The MIRAGE model integrates imperfect competition with a Cournot oligopolistic framework (a market with few sellers, who compete over the amount they produce).

Other than capital, the inputs to production, such as land and labour, are set exogenously.

Features of the model include:

- explicit treatment of FDI, empirical results regarding determinants and their order of magnitude
- horizontal product differentiation (products have different features but cannot be ranked), with two quality ranges depending on the product’s country of origin

- detailed trade barriers data, such as tariff quotas, prohibitions and anti-dumping duties at a bilateral level
- choice of time span for solution (eg annually, every 5 years), with the equilibrium being solved in turn for each time period

To summarise, the MIRAGE model is:

- a general equilibrium model for trade policy analysis
- based on Cournot oligopolistic competition, with two quality ranges for products and detailed treatment of FDI and its determinants
- useful in modelling peculiarities of the agricultural sectors
- easily adaptable to different research topics (applications)

NEAC The NEAC model consists of a detailed database for the inter-regional freight transport flows. It was originally developed to answer questions about Western European transport policy but has since been used as a forecasting tool and for scenario work (up to year 2030), and for policy analysis for wider Europe.

The NEAC database can be used in combination with models to make analyses as well as forecasts of national and international transport flows.

Several NEAC models have been developed for different purposes:

- trade model
- modal-split model
- assignment model
- container forecasting model
- environment model
- EcoNEAC model

The trade model makes uses of the NEAC database which contains information on flow between the regions of origin and destination of a commodity and on the route followed, resulting in transport information. The underlying theory is that trade is the result of the specialisation of countries/regions. Besides the supply and demand factors there is also a 'resistance' on the trade such as transport costs, imposed tariffs, and cultural differences. Also there can be favourable circumstances to trade within a group of countries due to the establishment of free-trade zones. It is expected that, all other things being equal, the larger the distance between countries the less trade will take place. On the other hand comparative advantages due to natural resources can explain why a country exports a certain commodity to a larger extent than other countries.

The ‘modal-split model’ determines new market shares of different transport alternatives based on changes in cost and time (as a result of changes in the organisation of the transport mode, changes of attributes of the transport mode or changes in infrastructure) of these different transport alternatives.

The ‘assignment model’ makes use of transport and trade data between regions, commodity groups, and modes of transport for the base year and forecast years to analyse the routes used to transport this goods. The model is used to load the traffic flows onto a transport network.

The ‘container forecasting model’ starts from a disaggregate level; container flows are directly related to trade flows by commodity. The development of container flows is determined, amongst others, by the development of commodity trade; ie a higher growth of high-valued goods with a high containerization rate will result in a higher growth of container transport in the future.

The ‘environment model’ calculates current and future emissions (CO2, CO, NOx, SO2 and particulates) of European transport by linking the relationship between transport volumes and emissions.

The ‘EcoNEAC model’ describes the relation between the economy and transport. For example, modal-split models give indications of the changes in the modal-split resulting from the new infrastructure. However, new infrastructure affects not only the modal-split, but it also influences the economy in that area around the new infrastructure project. It is possible that because of new infrastructure, the GDP of specific regions will increase and this economic growth generates more transport demand. This transport demand has an effect on the transport flows and these changed transport flows have an effect on the economy.

The model is mainly used for:

- transport flow analysis
- corridor analysis
- infrastructure analysis
- market potential analysis
- transport policy impact analysis including impact on the environment

NEMESIS

NEMESIS is a multi-country macro-sectoral econometric model for EU27 countries plus USA and Japan, which can be used for assessment of structural policies, mainly environmental and R&D policies. The main mechanisms of the model are based on the behaviour of representative agents: enterprises, households, government and outside.

The model is mainly used for:

- assessment of short and medium term consequences of energy and environmental (air pollution) policies, R&D, technology-related and economic policies on EU economies and on the state of the environment
- short-medium term (2-8 years) forecasts at a macro and sectoral level
- forecasting baseline scenarios for 30 years' time, including sustainable development scenarios

The main features of the model are:

- 32 production sectors and 27 household consumption categories
- 29 countries (including the EU27)
- yearly solution over a 30 years
- endogenous R&D decisions, process/product innovations and technological/knowledge spillovers between sectors and countries
- detailed modelling of the power/steam generation sector
- energy-environment module
- imperfect competition, with firms setting the prices
- exogenous extra EU data and energy-environment assumptions (excise duties, carbon and energy tax rates)

All trade is treated as if it takes place between two regions: the European pool and the rest of the world.

In summary, the characteristics of NEMESIS are such that the model is:

- focused at the European level
- dealing with energy, the environment, and the economy in a single framework
- calibrated to recent outcomes and short-term forecasts
- focused on the contribution of research and development, and associated technological innovation, on the dynamics of growth and change
- dynamic, with annual steps, and includes more that 160 thousand equations, with all behavioural equations estimated econometrically

NIEIR Multi-purpose model

NIEIR Multipurpose model is an energy modelling system comprised of: 1) macroeconomic and industry activity models for the whole country and Australia's states; 2) an energy forecasting model (EFM); 3) an energy technology model (ETM); 4) an energy environmental impact model (ENVI); and 5) an energy production and pricing model.

The model is mainly used for: 1) analysing impact of removal of cross-subsidies in electricity prices; 2) forecasting of electricity demand and load growth; 3) projecting of greenhouse gas emissions; 4) evaluating alternative power station options; and 5) assessing the impact of increased penetration of energy-efficient technologies and renewable energies on energy demand and supply and greenhouse gas emissions.

The NIEIR model is relevant in analysing the development and diffusion of carbon-neutral technologies in Australian electricity generation. The model can also be used in assessing the impacts of changes in subsidies and energy-efficiency rates.

OECD-GREEN

The GREEN Model, originally developed by the OECD Economics Department in the early 1990s, has been used extensively to assess the impacts of reducing (energy related) carbon emissions. The assessments are based on a baseline (or reference) scenario, sometimes referred to as the Business-as- Usual scenario (BaU). In other words, the BaU scenario is one where no active measures are undertaken to deal with carbon emissions (save perhaps no-regrets policies). Carbon limitation scenarios are thus compared to the BaU scenario. There are various ways to implement carbon limitation scenarios. Countries can implement carbon limits on an individual basis using country specific carbon (or energy) taxes. Regions can implement carbon limits using a region-wide tax. Under this latter implementation, the level of reduction may vary by country within the region. Regions can also implement carbon limits using tradable permits. This will have similar impacts as a region-wide carbon tax, but the impact on each country's real income will depend on the initial allocation of emission rights. GREEN consists of 12 economic regions, some of which are individual countries.

PACE

PACE is a flexible system of general equilibrium models, integrating the economy, energy, and environment dimensions. The model has a standard multi-sector, multi-region core made up of global trade and energy use, which was designated to assess major policy initiatives in a world that is increasingly integrated through trade. Around the core module, other various PACE modules allow for the problem-specific analysis of policy interference at different regional and sectoral levels as well as time treatments.

The model is mainly used for:

- economic analysis of energy and environmental policy initiatives
- problem-specific investigation of trade, tax, and labour market policies

PACE regularly contributes to Stanford University's Energy Modelling Forum (EMF) and was used for the Impact Assessment of the Climate and Energy Package [SEC(2008)85/3] and the recent Communication of the EC on the 30% target and carbon leakage [SEC(2010) 650].

The main features of the model are:

- module base, with the possibility of choosing problem specific modules around the core
- general equilibrium model, with detailed solutions for a chosen year
- currently 24 sectors, with a focus on energy-intensive industries, and few sectors in a bottom-up representation
- currently, 13 world regions (easily extendable)
- constant elasticity of substitution among inputs (labour, capital, etc.)
- zero profit and market clearance conditions
- exogenous energy efficiency emissions and carbon emissions profile

In summary, the characteristics of PACE are such that the model is:

- a general equilibrium energy, economy, environment model
- module based model, enabling the user to analyse specific problems
- constructed at a global level

PAGE2002

The third assessment report (TAR) of the Intergovernmental Panel on Climate Change (IPCC) is generally accepted to be the most comprehensive assessment of climate change ever conducted. The report of Working Group II, which looked at impacts, adaptation and vulnerability, listed five reasons for concern about projected climate change impacts:

- risks to unique and threatened ecosystems
- risks from extreme climate events
- distribution of impacts
- aggregate impacts
- risks from future large-scale discontinuities

PAGE2002 is an updated version of the PAGE95 integrated assessment model and allows all five of the IPCC's reasons for concern to be captured in an integrated assessment framework.

PAGE95 was able to include the first four of the IPCC's reasons for concern, by virtue of its sectoral and regional structure, and its aggregation of impacts into a global net present value.

The main structural changes in PAGE2002 are the introduction of a third greenhouse gas (SF_6 in this investigation) and the incorporation of possible future large-scale discontinuities into the impact calculations of the model. Default parameter values have also been updated to reflect changes since the IPCC Second Assessment Report in 1995.

PAGE2002 contains equations that model:

- Emissions of the primary greenhouse gases, CO_2 and methane, including changes in natural emissions stimulated by the changing climate. PAGE2002 allows the explicit modelling of a third gas whose forcing is linear in concentration, and models other greenhouse gases such as N_2O and (H)CFCs as a time-varying addition to background radiative forcing.

- The greenhouse effect. PAGE2002 keeps track of the accumulation of anthropogenic emissions of greenhouse gases in the atmosphere and the increased radiative forcing that results.
- Cooling from sulphate aerosols. The direct and indirect reductions in radiative forcing are separately modelled.
- Regional temperature effects. For the eight world regions in PAGE2002, the equilibrium and realised temperature changes are computed from the difference between greenhouse warming and regional sulphate aerosol cooling and the slow response as excess heat is transferred from the atmosphere to land and ocean. Sulphate cooling is greatest in the more industrialised regions, and tends to decrease over time due to sulphur controls to prevent acid rain and negative health effects.
- Nonlinearity and transience in the damage caused by global warming. Climatic change impacts in each analysis year are modelled as a polynomial function of the regional temperature increase in that year above a time-varying tolerable level of temperature change, $(T - T_{tol})_n$, where n is an uncertain input parameter. Impacts are aggregated over time using time-varying discount rates.
- Regional economic growth. Impacts are evaluated in terms of an annual percentage loss of GDP in each region, for a maximum of two sectors; defined in this application as economic impacts and non-economic (environmental and social) impacts.
- Adaptation to climate change. Investment in adaptive measures (eg, the building of sea walls; development of drought resistant crops) can increase the tolerable level of temperature change (T_{tol}) before economic losses occur and also reduce the intensity of both noneconomic and economic impacts.
- The possibility of a future large-scale discontinuity. This is modelled as a linearly increasing probability of occurring as the global mean temperature rises above a threshold.

The PAGE2002 model uses relatively simple equations to capture complex climatic and economic phenomena. This is justified because the results approximate those of the most complex climate simulations, and because all aspects of climate change are subject to profound uncertainty. To express the model results in terms of a single ‘best guess’ could be dangerously misleading. Instead, a range of possible outcomes should inform policy.

PAGE2002 builds up probability distributions of results by representing 31 key inputs to the marginal impact calculations by probability distributions, making the characterisation of uncertainty the central focus,

Most parameter values are taken directly from the IPCC Third Assessment Report.

PHEONIX The PHEONIX model was created to provide analysis on long-term population development at various geographical aggregation levels (global, regional, national and grid cells). The different modules of the model cover 19 world regions and 224 countries, including the EU27 member states.

The model is mainly used for:

- comparing different demographic scenarios
- analysis of changes in population size and structure with respect to socio-economic and environmental transitions
- fertility and mortality patterns

Demographic developments are modelled dynamically (allowing outcomes in one year to influence results in future years), as the mixture of the underlying fertility and mortality trends, which in turn depend on the simulated environmental and socio-economic conditions.

Features of the model include:

- different geographical aggregation levels (PHOENIX World -19 world regions, PHOENIX Countries – 224 countries, PHOENIX Europe – 40 European countries including Turkey, PHOENIX Grid – grid cell of 0.5 x 0.5 degrees, giving results for detailed regions
- year range 1950 – 2100 (1700-2100 for the PHOENIX Grid module)
- the possibility for the user to enter his/her assumptions about for fertility rate, life expectancy and net migration
- the possibility for the user to modify the underlying processes that estimate births and deaths

In summary, the characteristics of PHOENIX are such that the model is:

- an interactive simulation model which enables the user to analyse and visualise demographic changes
- a flexible model which enables the use of user-defined assumptions and processes
- able to produce animations of historical and future population densities at a country or regional detail

POLES The POLES model is a partial equilibrium model for the world energy system up to 2030. Market equilibrium is simulated by matching energy supply and demand which reply to changes in the international prices with a certain time lag. The model is designed by connecting international, regional and national submodels. Each region is modelled using four modules: 1) final energy demand by sector; 2) new and renewable energy technologies; 3) conventional energy and transformation system; and 4) primary energy supply.

In the European Commission, this model is in use at JRC-IPTS (http://ipts.jrc.ec.europa.eu/).

The model is mainly used for:

- running world energy scenarios (energy demand, supply, trade, prices) by world region
- inter-technology substitution over time
- simulation of CO2 emission constraints and emissions trading
- analysing the impact of technological change on emission baselines and constrained cases

The main features of the model are:

- yearly solution up to 2030
- 40 world regions, with the G7, European Union (North and South), Mexico, Brazil, India, China and South Korea treated by a detailed model made up of four main modules
- 12 renewable energy technologies and 12 electricity generation technologies
- 12 sectors
- an oil and gas production module

For each region, the model has four main modules dealing with:

- final energy demand by main sector
- new and renewable energy technologies
- the conventional energy and electricity transformation system
- fossil fuel supply

In summary, the characteristics of POLES are such that the model is:

- constructed at a world level, with detailed treatment of several large countries
- focused on technological change
- designed for detailed modelling of the energy sector
- constructed on a hierarchical structure of interconnected submodels

PRIMES PRIMES is a simulation model of the energy markets in the European Union. It simulates market equilibrium for energy supply and demand in the Member States by finding the equilibrium prices for each energy source. The equilibrium is static (within each time period) but repeated in a time-forward path, with dynamic relationships. The model is highly disaggregated and has very differentiated technologies.

The model is mainly used for:

- analysis of standard energy policy issues: security of supply, strategy, costs etc
- analysis of environmental issues
- looking at the impact of technology standards, new technologies and renewable resources
- looking at energy efficiency, alternative fuels, trade and EU energy provision
- analysis of policy issues regarding electricity generation, gas distribution and refineries

The main features of the model are:

- 7 types of atmospheric emissions
- it is based on a modular design, which allows each sector to be represented in an appropriate way
- solution up to 2030, running at 5-year intervals
- 35 countries, including the EU27
- 24 energy forms
- 5 demand sectors (with up to 30 sub-sectors each) and 3 supply sectors
- electricity is modelled in large detail (148 different plant types, per country for the existing thermal plants; 678 different plant types per country for the new thermal plants; 3 different plant types per country for the existing reservoir plants; 30 different plant types per country for the existing intermittent plants)

In summary, the characteristics of PRIMES are such that the model is:

- elaborated at a European rather than at a national level, with the national economies being treated as regions of Europe
- focused on policy analysis of the energy sector
- a disaggregated energy model, with detailed treatment of the electricity generation sector and energy technology choice
- modular, allowing for flexible treatment of different sectors

QUEST QUEST II is dynamic macroeconomic model of the world economy. It is designed to analyse the economies in the member states of the European Union and their interactions with the rest of the world, especially with the US and Japan. The focus of the model is on the transmission of the effects of shocks and economic policies, both on the domestic and the international economy.

The model is mainly used for:

- simulating of the effects of fiscal and monetary policy
- evaluating the European Commission structural policies (eg Structural Funds, Trans-Europe transport networks, Internal Market)
- analysis of long-term issues (eg demographic changes)
- analysis of short-term shocks (eg exchange rate shocks)
- medium term projections (over 5 years)

The model was primarily constructed to serve as a tool for policy simulation.

The main features of the model are:

- EU14 (EU15 excluding Luxembourg) and the new member states (the ageing model contains the EU15, USA, Japan and the Rest of the World split into slow aging and fast aging)
- 3 sectors and 2 consumption categories
- monopolistic competition
- forward looking expectations
- exogenous technical progress

QUEST II can be used either in the single-country version where the rest of the world is an aggregate of all other countries/regions or the multi-country version where individual countries are linked by endogenous (price dependent) bilateral trade and financial flows.

In summary, the characteristics of QUEST are such that the model:

- is used either as a single-country model or at the European level
- is focused on policy simulation
- is highly aggregated (only 3 sectors and 2 consumption categories)

Rigobon, R. & Redrik, D.

Rule of Law, Democracy, Openness, and Income: Estimating the Interrelationships - Roberto Rigobon and Dani Rodrik

An estimation of the interrelationships among economic institutions, political institutions, openness, and income levels, using identification through heteroskedasticity (IH). The cross-national dataset was split into two sub-samples: (i) colonies versus non-colonies; and (ii) continents aligned on an East-West versus those aligned on a North-South axis. The difference in the structural variances in these two sub-samples was exploited to gain identification. It was found that democracy and the rule of law are both good for economic performance, but the latter has a much stronger impact on incomes. Openness (trade/GDP) has a negative impact on income levels and democracy, but a positive effect on rule of law. Higher income produces greater openness and better institutions, but these effects are not very strong. Rule of law and democracy tend to be mutually reinforcing.

The research was interested in estimating the relationships among income, political institutions (democracy), economic institutions (rule of law), openness, distance from the equator, land area, and population. It was assumed that the last three are exogenous to the first four allowing for a large set of over identifying restrictions. So the system includes four endogenous variables (income, democracy, rule of law, openness) and three exogenous variables (distance from equator, area, population).

The equation for each of the endogenous variables was allowed to include all the exogenous variables as well as the (other) endogenous variables.

The data come from the standard sources: Penn World Tables and World Development Indicators for economic data, Polity IV for indicators of democracy and constraint on the executive, and Knack and Keefer (1995) and Kaufmann et al (2002) for the rule of law.

Second Generation Model

SGM is a computable general equilibrium model with emphasis on demographics, resources, agriculture, energy supply and transformation, energy intense industries, household consumption, and government expenditure. The model is used to project energy consumption and greenhouse gas emissions but its main relevance is its use in evaluating the economic impacts of climate change policies and the use of technologies for emissions mitigation.

Model Type: Set of 14 multi-sector regional CGE models. Regional models may be run independently or as a system for international trade in emissions permits. Regional models are dynamic-recursive, with a time frame of 1990 through 2050 in five-year time steps.

Developer/Home Institution: Pacific Northwest National Laboratory/Joint Global Change Research Institute at the University of Maryland. Contacts: Ron Sands (Ronald.Sands@pnl.gov) or Hugh Pitcher (Hugh.Pitcher@pnl.gov)

Sector Detail: Agriculture (primary agriculture, food processing); services; energy production (oil, natural gas, coal); energy transformation (coke, electricity, refined petroleum, gas distribution); energy-intensive industries (paper and pulp, chemicals, cement, iron and steel, non-ferrous metals, other industry); transportation (passenger transport, freight transport)

Regional Detail: 14 regions (United States, Canada, Mexico, Western Europe, Eastern Europe, former Soviet Union, China, India, Brazil, Japan, South Korea, Australia/New Zealand, Middle East, Rest of World)

Technology Detail: Each production process is represented by a CES or Leontief production function. Electricity sector is broken into subsectors (oil-fired, gas-fired, coal-fired, hydro and renewables, nuclear).

Special Features: Many of the regional models are developed jointly with analysts from that region. Capital stock is segmented into five-year vintages by sector; elasticity of substitution between inputs is greater for new capital than for old capital vintages. Hybrid input-output tables are constructed for consistency with base-year energy balances.

TRANS-TOOLS

The Trans-Tools Model is a European wide computer-aided transport planning tool. It replaces the previous SCENES model. The model aims to produce a European transport network model covering both passengers and freight with interactions to an economic model and impacts models. The model supports transport policy makers in two ways. First, to monitor trends in the operation of the transport system in the EU and to identify issues for which policy intervention may be required. Second, to assess the impact of specific transport policy measures on the transport system in the EU, as well as on selected economic end environmental issues.

The model is based on flexible software adoptable to user needs which is IPR (intellectual property right) free.

The model is mainly used for:

- analysis of construction and improvement of transport infrastructure
- analysis of implementation of infrastructure charging systems
- analysis of charge of transport costs due to policy interventions, increases in fuel prices etc.

The model covers passenger transport at NUTS-III level in EU25+2, using of recently updated networks. Data from most recent other projects, like ETIS-BASE, is also used.

Features of the model include:

- a multi-modal network model, covering the EU-25 with links to external zones
- transport demand responses to changes in infrastructure, transport costs and times
- changes in transport demand that are linked to changes in traffic on TEN-T and main national networks links (direct transport network effects)
- congestion modelling of road transport, based on the interaction of transport supply and demand
- modelling of indirect transport effects, based on the changes in economic activity and regional development
- measurement of environmental impacts in terms of emissions and fatalities, in relation to network assignments
- calibration to the base year 2000
- provision of projections for years 2010 and 2020
- links between VACLAV and ASTRA; the economic part of the model increase the economic effects on the transport model
- explicit modelling of logistics, leading to a better understanding of factors affecting freight mobility is obtained
- assignment models, which reflect the stochastic nature of travel behaviour achieving acceptable accuracy at link level
- consistency between assignment procedures and modelling of freight and passenger demands

T-REMOVE

TREMOVE is a policy assessment model, designed to study the effects of different transport and environment policies and technologies on the emissions of the transport sector. The model covers both passenger and freight transport, annually over the 1995-2030.

TREMOVE is made up of a land transport model and a maritime model. The land transport section has been set up to model all transport within a selected country. Currently, there are 31 countries in the input databases.

The TREMOVE 2.52 model has been developed by Transport & Mobility Leuven in a service contract for the European Commission, DG Environment. The most recent TREMOVE 2.7 version includes further developments made in the 6th Framework Programme GRACE project. TREMOVE is owned by the European Commission and is maintained by DG Environment.

The model is mainly used for:

- simulating the effects of various types of individual or combined transport policy measures on transport flows, on the size and composition of the vehicle stock, vehicle usage and on emissions

The main features of the model are:

- 31 countries, including the EU27
- 8 sea regions
- yearly solution up to 2030
- 9 specific passenger transport modes
- 4 main freight transport modes
- 16 emission types
- its dynamic specification, every year is linked to the previous year via the stock of transport means and the available infrastructure

Within each country or regional module, passenger and freight transport is analysed simultaneously. Both use the same road transport network and influence each other through congestion.

In summary, the characteristics of T-REMOVE are such that the model is:

- constructed at a country level
- modular
- focused on policy analysis, however policy measures cannot include a displacement of transport demand from one country to another

VACLAV VACLAV is a network-based Europe-wide passenger traffic forecasting model and was developed at IWW (Institute for Economic Policy Research, part of Universität Karlsruhe). The model structure follows the classic four-step approach of trip generation, trip distribution, modal choice and trip assignment, considering the trip purposes business, private and holiday.

The model is mainly used for:

- forecasting network demand and traffic loads
- determining regional indicators, such as access by mode of transport, based on changes in network capacities and capacity constraints
- modelling freight transport

The zonal system underlying the passenger transport demand modelling is NUTS 3, which results in around 1,300 traffic cells. The geographical scope of the model is the whole European continent (including Ireland and UK), as well as Turkey.

The main features of the model are:

- 4-step approach: trip generation, trip distribution, mode choice, route choice/assignment
- representation of physical road and rail networks, airport, ferries
- 100,000 road network links and 5,000 rail network links

The network models used by VACLAV are based on the GISCO and UIC networks, which were subject to careful updating for the purposes of the TEN-STAC project, as well as the ETIS-BASE project. Within the EUN-STAT project the network models have been extended to the neighbouring countries of the EU, in the TINA Turkey project to Turkey.

In summary, the characteristics of VACLAV are such that the model is:

- constructed at the European level
- based on the classic 4-step transport model approach
- reliant on current transport infrastructure and planned investments

Vera Institute The Vera Institute developed indicators to measure the rule of law in a 2008 report. The report describes a pilot project to develop rule of law indicators and was supported by the American Bar Association's World Justice Project. It was produced by the Vera Institute of Justice together with three other members of the Altus Global Alliance. They developed a set of 60 rule of law indicators and tested them in four cities: Chandigarh, India; Lagos, Nigeria; Santiago, Chile; and New York City, USA.

According to the authors, this 'pilot project shows that a single set of indicators can be flexible enough to be used in extremely diverse jurisdictions internationally yet concrete enough to be meaningful to local policy makers, justice system professionals, and members of civil society.' Moving beyond the pilot phase, they 'will refine the indicators - eliminating or revising some and deciding which ones should receive greater weights.' They 'aim to produce strong individual indicators that, when used in clusters, can reliably measure crucial aspects of the rule of law such as transparency, participation, and equal access to justice.'

VLEEM VLEEM has been designed under a EU research project to support R&D policy decisions in the field of energy, in relation with sustainability objectives in the very long term, making it a suitable tool for analysis of the response measures.

VLEEM can be used for very-long-term analysis of possible technological solutions to climate change, with the main policy inputs being changes to energy-focused R&D.

The 21th century will have to face tremendous challenges related to the climate change, the depletion of fossil fuel resources and the management of nuclear wastes. The development of the technologies necessary to face these challenges and the long reinvestment cycles especially for buildings, power generation and energy intensive manufacturing, require to consider all these issues over the whole century, in the broad context of sustainability.

The VLEEM project has been designed to address these challenges, combining two methodological innovations which are imposed by the very long time-frame:

- an innovative approach of the very long term future, particularly suitable for RTD
- strategies elaboration in the context of sustainability: the back-casting approach
- a re-foundation of the energy-environment modelling structures, in order to properly
- assess very long term modification of social and cultural preferences and technology
- evolution dynamics in relation to them

WaterGAP WaterGAP (Water - a Global Assessment and Prognosis) was developed to model water availability, use and quality on a global level. The water availability and use modules have already been implemented, and the water quality module is still under development. WaterGAP comprises of hydrological module, used in determining global water resources and water availability, and a water-use module, which looks at consumption from different economic sectors, including a sub-model for an assessment of global irrigation requirements.

The model is mainly used for:

- assessing the impact of global developments (eg climate change on water availability and water demand
- determining different water-stress conditions of different regions

WaterGAP is an integrated environmental model, combining socio-economic drivers and climate change in a single integrated framework.

Features of the model include:

- results for water flow and storage for 6 main categories (see classifications)
- consumption and withdrawals of water in 5 main sectors (see classifications)
- annual results for household and industry water consumption
- daily results for irrigation and livestock water consumption
- estimation of structural and technological changes that affect water consumption
- estimations of both natural and actual water discharge
- world coverage (except Antarctica), at a spatial resolution of 5 degree (55 x 55 km at the equator), giving a relatively detailed regional coverage

WATSIM WATSIM is world trade model for agricultural commodities. It currently covers 12 regions, including the EU, and 29 commodities. The model integrates different types of trade policies, such as tariffs and quotas, safeguards and export subsidies. The model can generate yearly solutions until 2010 (check if updated).

The model is mainly used for:

- medium-term analysis of trade policy changes
- analysing trends of agricultural world markets

The model focuses on the Common Agricultural Policy (CAP) of the European Union. The EU trade policies covered by WATSIM are: intervention price systems and export subsidies, WTO-limits on export subsidies, quotas on sugar and milk production and tariff-rate quotas for imports.

In the model all non-agricultural trade variables, such as capital, labour and GDP are assumed to be exogenous.

The main features of the model are:

- annual dynamic solutions with developments in one year influencing outcomes in later years
- a focus on trade flows between regions
- synthetic, elasticities in the behavioural functions of the model are not estimated, but are calculated exogenously using other sources

In summary, the main characteristics of WATSIM are such that the model is:

- a trade flow model of agricultural produce
- focused on trade policy analysis
- designed for analysis in the European Union
- a partial-equilibrium model

Weingast, B. R. **The Political Foundations of Democracy and the Rule of Law – Weingast, B. R.**

This paper developed a game-theoretic approach to the problem of political officials' respect for political and economic rights of citizens. It models the policing of rights as a coordination problem among citizens, but one with asymmetries difficult to resolve in a decentralized manner. The paper shows that democratic stability depends on a self-enforcing equilibrium. It must be in the interests of political officials to respect democracy's limits on their behaviour. The concept of self-enforcing limits on the state illuminates a diverse set of problems and thus serves as a potential basis for integrating the literature. The framework is applied to a range of topics, such as democratic stability, plural societies, and elite pacts. The paper also applies its lessons to the case of the Glorious Revolution in seventeenth-century England.

The model is developed in two stages, emphasising two independent impediments to policing the state. The first stage studies the pure coordination problem induced by sovereign transgressions; the second embeds the problem of coordination in a political context.

World Energy Model (WEM)

WEM is a large-scale mathematical model designed to replicate how energy markets function. The model is made up of six main modules: final energy demand; power generation; refinery and other transformation; fossil-fuel supply; CO2 emissions and investment. Its main relevance to the response measures is its use for assessing policy changes and, in particular, changes in technology patterns.

The model is mainly used for: 1) analysing global energy prospects; 2) estimating the environmental impact of energy use; 3) analysing the effects of policy actions and technological changes; and 4) estimating investment in the energy sector.

The WEM is relevant in analysing the development and diffusion of less carbon-intensive technologies, given activities in energy markets.

WorldScan

WorldScan is a recursively dynamic general equilibrium model, developed by CPB (Netherlands Bureau for Economic Policy Analysis) to explore and analyse long-term issues in the world economy. The model is used as a tool to construct long-term scenarios and as an instrument for policy impact assessment. WorldScan fits into the tradition of applied general equilibrium models in that it builds upon neoclassical theory, has strong micro-foundations and explicitly determines simultaneous equilibrium on a large number of markets. The model is solved as an equation system and thus is cast in a Computable General Equilibrium (CGE) format.

Dedicated versions of WorldScan exist and they are extensions of a core version in separate directions. These extensions are:

- a climate change version
- an energy version
- a version with R&D spillovers
- a version with imperfect competition

Though the model structure of WorldScan similar to many other CGE models, it has distinguishing features in that WorldScan is flexible in its ability to address a wide range of policy issues. The mechanisms of the model are founded on empirical analysis wherever this is feasible. WorldScan can also be adapted to arbitrary sector and country classifications if corresponding input-output tables connected by bilateral trade flows are available for a certain base year.

The model is mainly used for:

- analysis of wage, employment or production
- analysis of R&D effects
- analysis of different scenarios for implementing the Kyoto Protocol, and post Kyoto policy issues
- analysis of the link between OECD and non-OECD countries
- analysis of the spillover effects between EU countries
- analysis of EU enlargement issues
- scenario analysis up to 2100

Features of the model include:

- it is based on recursively dynamic general equilibrium concept
- it solves for up to 87 world regions and up to 57 sectors
- solutions up to 2100
- an ability to address various policy issues as it enables to address policy questions in the fields of climate change, trade, European integration and R&D
- the mechanisms of the model are founded on empirical analysis where possible

Worldwide Governance Indicators

The Worldwide Governance Indicators (WGI) project by the World Bank reports aggregate and individual governance indicators for 212 countries and territories over the period 1996–2008, for six dimensions of governance:

- voice and accountability
- political stability and absence of violence
- government effectiveness
- regulatory quality
- rule of law
- control of corruption

The aggregate indicators combine the views of a large number of enterprise, citizen and expert survey respondents in industrial and developing countries. The individual data sources underlying the aggregate indicators are drawn from a diverse variety of survey institutes, think tanks, non-governmental organizations, and international organizations.

The statistical methodology underpinning the WGI (the unobserved-components model) explicitly assumes that the true level of governance is unobservable and that the observed empirical indicators of governance provide imperfect signals of the fundamentally unobservable concept of governance. This formalizes the notion that all available indicators are imperfect proxies for governance. The estimates of governance that come out of this model are simply the conditional expectation of governance in each country, conditioning on the observed data for each country. Moreover, the unobserved-components model allows one to summarize uncertainty about these estimates for each country with the standard deviation of unobserved governance, conditional on the observed data. These standard deviations can be used to construct confidence intervals for governance estimates, often referred to informally as margins of error. Intuitively, the larger the number of data sources available for a given country, the smaller these margins of error should be. The variance of the error term can be estimated in each individual underlying governance indicator using this methodology, following a calculation that generalizes the simple one discussed above.