UK National Ecosystem Assessment Follow-on

Work Package Report 2:

Macroeconomic implications of ecosystem service change and management: A scoping study

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Contents

Abbreviations and acronyms

ABS – annual business survey (ONS)
CCS – Carbon Capture and Storage
CES – constant elasticity of substitution
CICES –Common International Classification of Ecosystem Services
CGE –computable general equilibrium (Model)
DEFRA – Department for Environment, Food and Rural Affairs
DSGE –dynamic stochastic general equilibrium (model)
E3MG – energy-environment-economy (E3) model at the Global level
ECB – European Central Bank
EEA – European Environment Agency
EGSS – Environmental Goods and Services
ENVISAGE – Environmental Impact and Sustainability Applied General Equilibrium (Model)
GDP – Gross Domestic Product GDP
GFC – Green Fiscal Reform
GEM – Global Economic Model
GIDD – Global Income Distribution Dynamics (Model)
GHG – greenhouse gas
GTAP – Global Trade Analysis Project (Model)
GVA – Gross Value Added
HANPP – human appropriation of net primary productivity
IEA – International Energy Agency
IO – Input-Output
IOT – Input-Output Table
IMF – International Monetary Fund
IUCN – International Union for Conservation of Nature
JRC – Joint Research Centre of the European Commission
MCDA -- multi-criteria decision aid
MDM-E3 – Multisectoral Dynamic Energy-Environment-Economy Model of the UK economy
MEA – Millennium Ecosystem Assessment
MFA – Material Flows Analysis
MRIO – Multi-Regional Input-Output (analysis)
NACE – Statistical Classification of Economic Activities in the European Community
NCC – Natural Capital Committee
NEWP – Natural Environment White Paper 2011
NUTS – Nomenclature of Units for Territorial Statistics
OECD – The Organisation for Economic Co-operation and Development
ONS – Office for National Statistics (UK)
SEEA – System of Economic-Environmental Accounting
SIC – Standard Industrial Classification (Statistical Classification of Economic Activities)
SIOT– Symmetric Input–Output Table
SUT – Supply and Use Table
TEEB – The Economics of Ecosystems and Biodiversity - 2008
UK NEA – United Kingdom National Ecosystem Assessment
UK NEAFO – United Kingdom National Ecosystem Assessment Follow-On
UNEP – United Nations Environment Programme
WCMC – World Conservation Monitoring Centre
WIOD – World Input-Output Database
WRI – World Resources Institute

Key Findings

There is an increasing appreciation of the importance of the interactions between ecosystem services and the macroeconomy, and of the consequences of changes in ecosystem services for indicators of macroeconomic performance, such as Gross Domestic Product (GDP), trade balance and employment. Although a number of conceptual frameworks have been developed to represent interactions between the environment and the macroeconomy, they have not yet been transposed into sufficiently robust and comprehensive methods to measure those interactions in practice, or to support policy appraisal and decision-making. This is mainly due to the complexity and uncertainty of these interactions, and the limited availability of necessary data.

Mapping the interrelationships between ecosystem services and major sectors of the economy, such as agriculture or the manufacturing of food, is an important first step towards understanding the macroeconomic impacts of changes in ecosystem services at sectoral, regional and whole economy levels. For some sectors, such as agriculture, the interactions between ecosystem services and the sector are relatively well known, but links have not been made explicit for macroeconomic assessment purposes, and the range of ecosystem services covered is limited. Mapping will help to identify potentially economically important interactions and focus efforts on developing appropriate measurement and accounting methods, and practical decision support tools.

There is a range of macroeconomic modelling methods, which vary in purpose, theoretical background and analytical procedures, but no one existing approach is adequate to deal with the complex interactions between ecosystems and the macroeconomy. Most macroeconomic models are designed to assess the implications of policy change, and mainly operate within established and accepted macroeconomic frameworks. The most practical, immediate approach to bridging the gap is likely to involve 'extending' existing macroeconomic accounting procedures and modelling approaches to accommodate the interactions between ecosystem services and the macroeconomy. It may be appropriate to combine a number of macroeconomic modelling methods to suit the treatment of ecosystems services, thus avoiding any bias that might arise from the use of any one method.

Although some studies have assessed the macroeconomic performance of certain environment-related sectors (particularly agriculture, forestry and fisheries), they have generally not explicitly considered the impact of changes in ecosystem services on macroeconomic indicators, such as GDP, employment and trade. The UK NEAFO literature review did not identify any studies that comprehensively cover the contribution of ecosystem services to the macroeconomy. Yet, there are studies that focus on selected interactions between certain ecosystem services and the economy – often at a local, context-specific scale – which may help to inform wider sectoral and whole-economy appraisals.

The priority for research should be to develop and test suitable frameworks and methods for ecosystem-macroeconomy assessments, starting with selected key ecosystem services and economic sectors. This will quantify selected key interactions and adapt suitable macroeconomic modelling methods to accommodate ecosystem–macroeconomy interactions. We can then apply these methods to selected key sectors in order to demonstrate the feasibility and value of modelling ecosystem-macroeconomy interactions to support policy analysis and decision-making. Most benefit will probably be gained from developing methods of ecosystem services accounting that can fit within, and eventually extend, existing sectoral and national accounting conventions and models used for macroeconomic policy analysis.

Summary

Governments are increasingly concerned about the condition of the natural environment and the use of natural resources as this determines the sustainability of economic development and social progress (see, for example NEWP, 2011; NCC, 2013). This report provides a scoping review to help guide research priorities for understanding the effects of ecosystem service change and management in the UK on the macroeconomic performance of key sectors and the UK economy as a whole, including changes in GDP, employment and trade. It identifies appropriate analytical frameworks for assessing the interaction between ecosystem services and the macroeconomy and reviews evidence of these interactions in existing literature nationally and internationally, as well as methods and models that can support policy and decision making. These aspects are considered in turn, ending with implications for further research.

2.S.1 Conceptual frameworks for assessing the impacts of changes in ecosystem services and their management on macroeconomic indicators

The UK National Ecosystem Assessment (UK NEA, 2011a and 2011b) established a general conceptual framework that links ecosystem services with human well-being in the UK (UK NEA, 2011b, Ch.2 p. 13). The economic analysis contained within the UK NEA identified the 'final' ecosystem goods[1] that benefit people and underpin their wellbeing (**Figure 2.S.1**). The focus on final rather than intermediate ecosystem goods avoids the likelihood of double counting and is consistent with the approach adopted in macroeconomic accounting, as explained below.

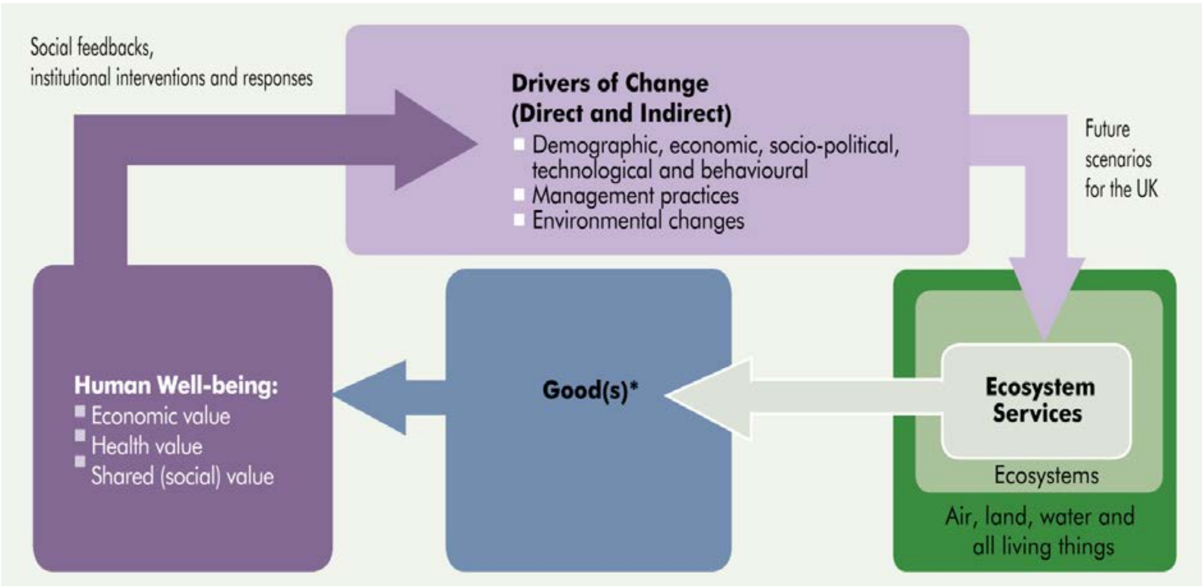

Figure 2.S.1. Overall Conceptual Framework for the UK NEA with macroeconomy.

Macroeconomics is concerned with measuring the condition and performance of the economy of a country at the national scale, and also by its regions and key sectors and, if required, by geographical regions. Conventional macroeconomic accounts focus on the valuation of the output of final goods and services bought by consumers that are produced by various sectors of the economy. The value

[1]The term good(s) includes all use and non-use, material and non-material outputs of ecosystems that have value for people.

of sales of intermediate goods and services is removed from estimates of the value of output, such as fertilisers used by farmers in producing crops for sale: to include them would double count and over estimate the value of final output. The UK NEA (2011a) sought to value final goods in its assessment of ecosystem change and this perspective is compatible with that adopted by macroeconomic accounting conventions. National accounts also do not count the production and use of domestic investment goods as output, such as investment in machinery that is not immediately used up in production systems. Rather, these are depreciated annually according to their remaining life. In addition to national accounting national statistics also records the employment of people, the distribution of expenditures in the economy on wages, rents and financing charges, and the interactions between the national and other economies, in particular regarding trade and other monetary flows.

Macroeconomic accounting practices follow accepted international conventions that have been developed over the last century and are designed to provide selected indicators of economic activity, performance and status. They use high level aggregates that do not in themselves provide a full account of the prosperity and wellbeing of nations, nor was this their original intention. For this reason a number of steps have been taken to extend their scope to provide more complete estimates of national welfare. These include the System Environmental-Economic Accounting (SEEA, 2013) that closely follows the UN System of National Accounts (SNA, 2013), IBRD's Adjusted Green Accounts (IBRD, 2011), and 'Satellite' environment accounts produced for the UK by the Office of National Statistics (ONS, 2013b).

Although a number of general conceptual frameworks have been developed to link changes in the natural environment to the macroeconomy (see for example, Ekins (2000) and Shmelev (2012)), these do not explicitly consider the likely impact on the macroeconomy of changes in the diverse range of ecosystem services as defined in the UK NEA (2011a). These frameworks link the environment and economy by considering the flow of services that emanate from the existing stock of natural capital as an input into the `production process' that results in the creation of aggregate final goods (one can think of this as GDP), that can be consumed and in some frameworks generates satisfaction (`utility' in economic terms). To understand the relative importance of natural capital, it is crucial to understand the degree to which it can be substituted by the other forms of capital in the production of final goods. However, in some cases the substitution between natural capital and other forms of capital might not be feasible. For example, total disruption in photosynthesis and climate regulation would lead to zero economic activity. Despite the simplicity of these general frameworks there are problems with understanding and aggregating the inputs of capital (natural and other) into the economy (see for example, Felipe and McCombie, 2013; SEEA, 2013). Therefore, a good starting point is to develop an understanding of how ecosystem services contribute to economic sectors.

Some integration of environmental (rather than ecosystems) accounting and national accounting has been carried out for some sectors in the UK, notably for agriculture (Jacobs *et al.* 2009), and in the 'satellite' environmental accounts (ONS, 2013b) that facilitate analysis of the wider impact of environmental change. These measure the environmental impacts of economic activity (due for example to pollution) and how the environment contributes to the economy (for example, through the supply and use of raw materials and associated resource efficiency), using the accounting framework and concepts of the national accounts.

The economic value of some final ecosystem services, as measured for example through expenditure on ecosystem-based recreation and the harvesting of natural foods, already features in national accounts and macroeconomic indicators. Many final ecosystem services, such as climate regulation, however, are intermediate services in a macroeconomic accounting sense. They provide inputs of natural capital (final ecosystem goods) that are combined with other inputs, such as human, social and physical capital, goods and services, within the production systems of economic sectors (**Figure 2.S.2).**

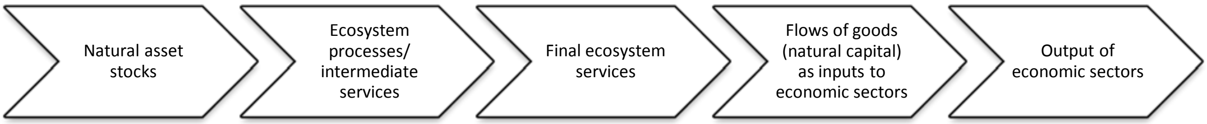

Figure 2.S.2. Links between ecosystem services and economic sectors

Furthermore, these various inputs from ecosystem services are carried through the economic system, since the outputs of one sector are inputs to another. For example, in 2010 the outputs of the agricultural sector in the UK were used as inputs by 40 other sectors, in addition to agriculture itself (ONS, 2013b). In this respect, an assessment is required of both direct final ecosystem goods consumed by households and governments (direct effect) and intermediate goods (that are used as inputs in production processes) consumed by firms (indirect effect). Furthermore, changes in demand for the final goods provided by ecosystem services due to alterations in income (induced effects) must also be assessed. In this way the contribution of ecosystem services to estimates of total value added, trade and employment in the economy can be ascertained, as well as the implications of change. **Figure S.3** provides an illustration of the effect of changes in final ecosystem services and associated final goods on the performance of an economic sector.

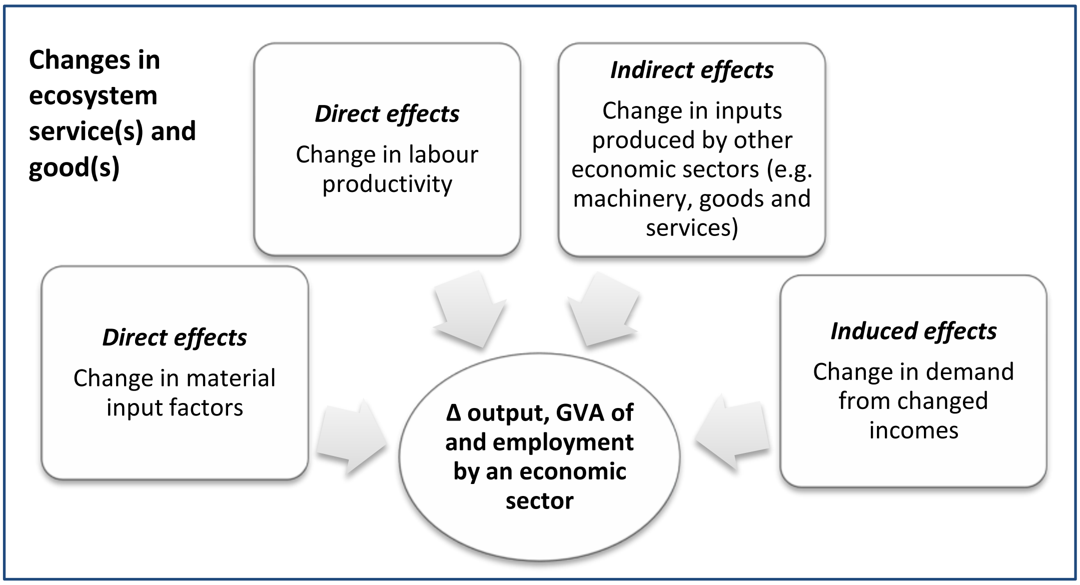

Figure S.2.3. A simplified presentation of ecosystem service change and management impacts on an economic sector in the national economy.

2.S.2 Mapping the Interactions between Ecosystems Services and the Macroeconomy

During the UK National Ecosystem Assessment Follow-On Phase (UK NEAFO, 2013) an expert consultation to assess the feasibility of mapping final ecosystem services onto individual economic sectors, and hence the macroeconomy as a whole, was held. It was found that although it was possible to identify and describe these interactions in broad terms, there is currently insufficient data and knowledge to quantify and value comprehensively and confidently the flows of ecosystem services between and within the major economic sectors of the economy and the consequences for macroeconomic performance.

An exploratory mapping exercise showed that it would be necessary to compile relatively detailed input- output tables to represent the flows and uses of intermediate and final ecosystem services in key sectors and the economy as a whole. While this is possible in theory, considerable effort would be needed to disaggregate and reconfigure estimates of the economic value of ecosystem goods and services by economic activity, by key sector and by type of ecosystems service.   Furthermore, compilation of input–output tables to apportion ecosystem flows between and within sectors would require considerable expert judgement and interpretation of available literature until such time as more detailed reported data are available. This is particularly true for mapping non-market ecosystem services. A good starting point would be to use Eora multi-regional input-output (MRIO) database that is compiled for up to 511 economic sectors (Lenzen *et al.* 2013) and follow the ecosystems accounting standards outlined in SEEA (2013).

It is also noted that, although the focus in national accounts tends to be on flows of income and expenditure, with allowance for changes in net capital investment, the stock value of natural capital has particular importance in ecosystem accounting. Declining stocks of natural capital, associated for example with biodiversity loss, soil degradation and decline in water quality, require particular attention in ecosystem-macroeconomy accounting, especially where tipping points exist or minimum threshold values are required to secure future service flows. Although a comprehensive mapping of ecosystem services and economic sectors remains outside the scope of UK NEAFO, it is considered a priority for future work and could be carried out, for the example, with the help Bayesian belief networks methods.

2.S.3 Methods and models for assessing ecosystem services' contributions to macroeconomy

There is a wide range of methods and tools that could in principle be developed and used to assess the two way relationship between ecosystem services and the macroeconomy, and the implications of changes in policy and practice. However, reflecting limitations of existing data and methods, there are currently no existing models that are entirely fit for this purpose.

There are two broad categories of estimation methods and decision support tools of relevance here, namely: those specifically designed to assess the performance of macroeconomy with limited or without explicit reference to environmental services, and those developed to assess environmental interactions that could be expanded to ecosystem services and used to supplement existing macroeconomic models. It appears, however, that no single currently known method or model can address all important aspects of the interaction between ecosystems and the macroeconomy. The use of a combination of macroeconomic and environmental/ecosystem methods is likely to be an appropriate strategy for ecosystem-macroeconomy modelling.

Given the established, albeit sometimes contested, position of macroeconomic accounting and modelling that has been developed and refined over the last hundred years or so, a pragmatic approach requires that these are extended to include changes in the stocks and flows of ecosystem services. This would require detailed disaggregation of the flows of ecosystem goods provided to key sectors of the economy and their contribution to final goods and services, incomes, expenditures, employment and trade. Such an extended treatment would support policy analysis and decision making, including analysis of alternative scenarios concerning the dynamic impacts of changes in demography, technology, market prices, climate and other factors.

The main types of models currently used to assess and project changes in the state and performance of the macroeconomy are:

1. **Computable General Equilibrium (CGE) Models** have a theoretical framework that draws on a combination of general equilibrium theory as this relates to the operation of market demand, supply and prices, and neoclassical notions of microeconomic optimisation and the rational behaviour of economic agents.
2. **Dynamic Stochastic General Equilibrium (DSGE) Models** are a group of applied General Equilibrium Models that have a dynamic component that assesses how the economy evolves over time and a stochastic component that assesses the effects of random shocks on the economy, such as fluctuations in oil prices.
3. **Econometric Input-Output models** draw on two traditions: that of econometric macromodelling, where economic processes and trends are modelled using relationships observed in empirical data, and that of input-output analysis, where an economy is treated as a matrix of interrelated sectors.
4. **The Systems Dynamics Approach** identifies key components of a particular phenomenon such as the macroeconomy and the dynamic interactive linkages between these components. Performance is assessed in terms of achievement of system objectives. System dynamics models, typically involving coupled predefined equations describing relationships between economic variables over time, are designed to help understand complex interactive systems.

The modelling methods listed above make use of different economic theories and assumptions, and have their particular shortcomings and limitations. For example, CGE models are criticized for their restrictive assumptions of rationality of economic agents, perfect competition, and because they tend to produce unstable and multiple solutions. They are also criticised because they give limited attention to the longer term, including possible effects of changes in relative prices. Some of these temporal aspects have been addressed by DSGE modelling, but calibration and validation of the models has proved difficult (Barker, 2004). For their part, econometric input-output models have been criticised for their reliance on past data and relationships when forecasting future changes in economic indicators. Systems analysis has been criticised because of the restrictions imposed by predefined assumptions on components, interactions and system boundaries.

It remains to be seen how effectively and pragmatically these macroeconomic modelling approaches can be extended to incorporate ecosystem services while generating consistent and valid results. There is a risk that differences between models in their assessment of the interaction of ecosystem services and the macroeconomy mainly reflect differences in the theories, assumptions and methods pertaining to macroeconomic modelling, rather than the specific treatment of ecosystem services themselves. Therefore it may be appropriate to use more than one macroeconomic modelling method and explain the differences in macroeconomic theory and assumptions when assessing the impacts of ecosystem service change and management on the macroeconomy.

There is also scope to complement existing macroeconomic models with methods that do not specifically deal with macroeconomic indicators but could be useful for building links between ecosystem services and macroeconomy or for comparing policies to manage ecosystem services. Some of these methods are:

1. **Cost-Benefit Analysis (CBA)** involves calculating and comparing costs and benefits of an action or project.
2. **Econometric modelling** determines the functional form of a relationship or a set of relationships that exist between two or more variables. The two main types of datasets used for econometric analysis are: cross-sectional, where data are collected by observing many subjects at the same point in time, and time series where data are collected from the same subjects over a period of time. Although econometric models are reasonably good at explaining past trends, they often

fail to predict non-linear emergent change, which is more adequately captured by non-linear dynamics models.

3. **Input-Output analysis** is an established method to explain the cross-sectoral effects of policies in a country. It links final demand, total output, and intermediate consumption and is often static (considering one year, for example). **Multi-Regional Input-Output (MRIO)** analysis extends the application to more than one region. The method has been used, for example, to track greenhouse gas emissions embedded in trade, and could be expanded to study the flows of goods provided by final ecosystem services through an economy and internationally.
4. **Material Flows Analysis (MFA)** accounts for the mass of resources that are being extracted domestically, are imported then accumulated, processed or recycled in the national economy, and then emitted into nature in the form of gaseous, liquid or solid residues, or exported. It can be used to present a balance of physical inputs and outputs in the national economy. The UK Satellite Environmental Accounts currently include material flows of biomass, minerals and fossil fuels and are annually reported in the Blue Book (ONS, 2013b, Ch. 13). MFA could help to estimate the physical magnitude of flows, for instance, of biomass or water that can be valued and linked to macroeconomic analysis.
5. **Optimisation** involves a large array of methods and decision support tools and addresses one of the central problems of economics: how to best to allocate limited resources over a period of time. The main principle is minimization or maximisation of an 'objective function' subject to constraints imposed by limiting resources or other conditions that must be met, such as meeting minimum targets for environmental outcomes.
6. **Multi-criteria decision aid (MCDA)** involves identification of a set of alternatives or courses of action, establishing criteria to assess the relative performance of these.

2.S.4 Ecosystem services contribution to the macroeconomy in the literature

Comprehensive analysis of the linkages between ecosystem services and the macroeconomy is largely an unexplored area. This is mainly because the ecosystem service approach is a relatively recent and developing area of research, and because of the complexity of these interactions (MA, 2005; UK NEA, 2011b; CICES, 2013). Where they exist, studies have focussed on selected services, for example food or clean water provision and pollination, and their contributions to the macroeconomy, but often without using the term 'ecosystem service'. Some evidence is available on the macroeconomic role of UK agriculture as an important strategic land-based sector of the UK economy that is heavily dependent on natural processes/ecosystem services. There are very few examples in the literature that cover more than one ecosystem service and more than one economic sector. In their preliminary CGE analysis Bosello *et al.* (2011) focus on the macroeconomic effects of climate change associated with changes in the provisioning and regulating (mainly carbon sequestration) services provided by European forest, cropland and grassland ecosystems. Ukidwe and Bakshi (2004) explore the ecosystems contribution to energy flows in 91 sectors of the US economy, but do not include impacts on macroeconomic indicators. No study was identified that attempted to quantify the contribution of all major ecosystem services to the macroeconomy. The following presents some examples from the literature, grouped by their focus on type of service, namely provisioning, regulating, cultural and supporting services. Thereafter reference is made to sources that consider environmental goods and services generally.

2.S.4.1 Provisioning ecosystem services

The economic sectors that are directly dependent on provisioning ecosystem services are generally well studied even if there is no explicit mention of ecosystem services. In the UK, the environmental effects of agriculture, forestry and fishing have been a focus of study. These studies have informed the compilation of partial environmental accounts that feed into are amongst the most studied

economic sectors and are also covered by national accounting. However, for the majority of studies, formal macroeconomic analysis has not been a major focus. The underlying data sets and methodologies, however, indicate a capability to support macroeconomic analysis.
While agriculture (that is farming) in the UK accounts for only 0.7% of national GDP and 1.5% of employment (Appendix 2.3), it occupies about 70% of the land area. At £96 billion annually, the total agri-food chain, including processing, distribution and retailing, is equivalent to 7.4% of national Gross Value Added (GVA) and 14% of total employment (Defra, 2013c). It is important, therefore, to trace the value of food products through the entire food chain. It is noted that UK agriculture itself is a major player in this, contributing over 65% of total raw food into the domestic food chain (Defra, 2010a). The macro importance of the agricultural production is also apparent in international assessments. For example, in 2009 in California (University of California, 2012), the combined direct and indirect effects of the entire food chain accounted for 6.7% of employment and 1.3% of the state's gross product. However, these numbers do not separate the contribution of final ecosystem goods from other inputs.

The forestry sector provides formal and informal employment for an estimated 40-60 million people in the world (GRIDA, 2008). Although timber is commonly the most important forest product (by weight), forests also provide a range of harvested fruits, herbs, honey and wild animals for food. Although forestry directly contributes only 0.03% of GDP and 0.06% employment in the UK (2011 data), the sector contributes to more than 8% to GDP in some developing countries such as Central African Republic, Liberia and Solomon Islands (FAO, 2008). In 2005 all forestry related industries directly employed a total of 167,000 jobs and generated £7.2 billion worth of gross value added, or 0.7 per cent of the UK economy (Cebr, 2006).

Water is a fundamental element necessary for human survival, which is used for drinking, washing, agriculture, food processing, recreation and other purposes. About 22 billion m^3 of water are abstracted in the UK each year (Environment Agency, 2009d; SEPA, 2004). The water supply and treatment industry contributes to about 0.75% of the total UK GVA. A conservative estimate of the economic market and non-market value of a range of ecosystem services provided by inland and coastal wetlands in the UK (*e.g.* water quality, flood control, recreation, tourism and amenity) is between £0.7 billion and £1.1 billion per year, and possibly as much as between £2.5 billion and £5.7 billion (Morris and Camino, 2011), but implications for GDP, incomes and employment are unknown.

2.S.4.2 Cultural ecosystem services

Cultural ecosystem services comprise the environmental settings and wild species diversity that support aesthetic, educational, recreational, spiritual values and other benefits (UK NEA, 2011a). With respect to the UK, the tourism sector in 2012 generated £36.9bn (2.4%) of the UK GDP and 3.1% to total employment. If the entire supply chain is taken into account then these numbers are 6.8% and 7.6% respectively (WTTC, 2013). The macroeconomic impacts national parks that offer access cultural ecosystem services have been quantified for England (Cumulus and ICF, 2013). In 2012 England's National Parks provided around 141,000 jobs (0.6% of total employment in England) and generated £4.1 to 6.3bn of GVA (0.4% to 0.6% of GVA in England). Within this sector, biodiversity and environmental settings support a substantial sub-sector of predominantly rural-based tourism activity, however the contribution of cultural ecosystem services to the macroeconomy is yet to be quantified.

2.S.4.3 Regulating ecosystem services

Regulating ecosystem services comprise, among other things, climate and hazard regulation, detoxification of air, water and land, disease and pest regulation, and noise regulation. These services support the functioning of the economy and are not included directly in macroeconomic indicators, although perversely, expenditures on substitution or remedial measures, if there is a failure of these services, are. A failure of these services has uncertain effects on the macroeconomy. It can either decrease economic activity leading to losses, or increase economic activity if there is a need to repair or clean-up damages that require employing additional people and increased consumption of outputs from other economic sectors.

Flooding has become more problematic in the UK in the last 30 years (Pitt, 2008), whether associated with rivers, coastal water or storm water surcharge within urban areas. The annual damage cost of flooding in the UK is about £1.4bn. A further £1bn per year is spent on flood risk management (Environment Agency, 2009a, b). The greatest share of total annual flood costs is borne by urban households and businesses, evident in the profile of the 2007 floods in England that resulted in estimated economic costs of £3.2billion (Chatterton *et al.,* 2010). Such damage costs feed through to conventional national accounts but possibly with perverse effects. Damage repair, replacement and recovery costs are registered as additional economic activity in national accounting. Large areas of enclosed farmland in floodplains in England and Wales benefit from managed hydrological regulation. Currently, artificial flood defence reduces expected agricultural annual damage costs from river flooding by about £5.2 million, and from coastal flooding by £117.7 million (Roca *et al.* 2010).

It is estimated that the failure of carbon sequestration in the EU would imply 3% lower accumulated, discounted GDP in the world from 2001 to 2050, ranging from US$ 27 to 85 bn (Bosello *et al.* 2011). Dunne *et al.* (2013) showed that climate warming can cause heat stress resulting in reduced labour productivity. How much of this relates to ecosystems capacity to regulate climate and how this translates to economic impacts are yet to be studied.

Ecosystems receive and process the residues of economic activity. Increased levels of consumption and inadequacy of recycling and waste management systems have severely threatened the carrying capacity of ecosystems. However, the linkages to the macroeconomy are rarely developed. There are numerous studies on the health impacts of air pollution and air pollution damage to buildings (for example, from acid rain) that could be used to inform macroeconomic indicators, but again these require considerable disaggregation and economic valuation of service flows. Attention has been paid to the macroeconomic aspects of waste management. For example, Cambridge Econometrics (2003) explored the potential role of waste minimization and resource savings in the UK economy, concluding that if manufacturers invest in best-practice waste minimisation techniques they could achieve around £2bn to £2.9bn savings in annual operating costs, approaching 2% of UK manufacturing GVA and about 6% of profits in 2000. However, the macroeconomic effects of waste regulation services provided by ecosystems are yet to be quantified.

2.S.4.4 Supporting ecosystem services

Ecosystems provide a range of supporting services, associated for example with soil formation, the cycling of nutrients and atmospheric gases. Although the majority of these services are intermediate services and the macroeconomic impacts of changes in these services are not assessed, existing studies do provide some data that could be used as basis for disaggregating the impacts of changes in final ecosystem services for the purpose of macroeconomic analysis. For example, Graves *et al.* (2012) using an ecosystem services approach, estimated the total economic costs of soil degradation in England and Wales at between £0.9 billion and £1.4 billion per year, with a central estimate of £1.2 billion. About 45% of these costs were associated with loss of organic content of soils (valued at equivalent carbon prices), 39% with compaction and 13% with erosion. The latter two components were linked mainly to losses in agricultural yields or soil related damage and mitigation costs and were therefore associated with macroeconomic impacts, in total potentially £0.6 billion annually. With respect to trends in pollination in the UK, Breeze *et al.* (2011) found that the importance of insect pollinated crops has increased in UK agriculture and in 2007 accounted for 19% of total farm gate crop value. The economic value of insect pollination services to agriculture has been estimated at £400 million per year in the UK (UK NEA, 2011b).

2.S.4.5 The natural environment and the economy

A number of studies have taken a broad view of environment-economy relationships although they do not consider ecosystem services explicitly. Cambridge Econometrics (2005), focussing on the South-East of England, showed that activities linked to the environment (with both positive and negative environment outcomes) contributed almost 250,000 jobs and nearly £8 billion GVA to the regional economy. Focusing on Scotland, Cambridge Econometrics (2008) showed that, allowing for direct as well as non-direct (induced and indirect) effects, the removal of environment-related activities from the Scottish economy would result in an estimated fall in output of £17.2 billion annually (in 2003£), or 11% of total output in Scotland for 2003. These activities supported some 242,000 jobs, that is around 11% of all full-time jobs in Scotland.

A recent review of evidence of links between the natural environment and the macroeconomy in Wales (Reveill *et al.* 2012) showed that the natural environment related activities contribute 9% of the country's GDP, one in six jobs and 10% of all wage and salaried incomes. It maintains the country's leisure and tourism, agriculture, forestry, water resources and waste management sectors. Employment and output multipliers of 1.44 and 1.45 respectively were derived for environmental related economic activities (Bilsborough and Hill, 2003): thus every full time job and every £100 of output in 2000 generated another 0.44 jobs and £45 output elsewhere in Wales respectively. Anson (2013) estimated the GVA of the sectors dependent on the marine environment in 2011 and found it to be £49.4bn (about 4% of the UK GVA).

2.S.4.6 Trade effects

International trade plays an increasingly important role in stimulating economic development. However, it can also facilitate cross-boundary changes in ecosystem services. Production, associated with resource use and emissions in one part of the world is often driven by consumer demand in other parts of the world (for example see, Lenzen *et al.* 2012; Wiebe *et al.* 2012 and Peters *et al.* 2011). For example, Lenzen *et al.* (2012) found that approximately 30% of species on the IUCN red list of threatened species are affected by international trade. They linked biodiversity impacts for 25,000 species to more than 15,000 commodities produced in 187 countries. USA, Japan, Germany, France, UK, Italy, Spain, South Korea, Canada were found to be the top 'net importers' of biodiversity. These studies on physical flows could be used for future assessments of how one country's consumption degrades another country of natural capital and associated ecosystem services, and the consequences for macroeconomic performance.

2.S.5 Future research

Given the complexity of covering all ecosystem services and economic sectors at the same time and gaps in data it seems reasonable to start with the sectors for which data and methods of analysis are most developed: namely agriculture, forestry, fishing, energy, and water. In order to progress from conceptualising to operationalising the interactions between ecosystems services and the macroeconomy, the following steps could be taken:

- identification of the main ecosystem goods used as inputs by particular economic sectors and mapping them by using, for example, Bayesian belief networks;
- accounting for and evaluation (quantities, qualities, monetary values) of the main ecosystem goods used as inputs by particular economic sectors;
- quantification of macroeconomic performance of key sectors as a result of quantities and qualities of final ecosystem goods that the economic sector use as inputs. This in turn would build on quantification of intermediate ecosystem goods. This kind of assessment could make use of data collected for impact assessments at the micro/case study level and fundamental understanding of the role of ecosystem services in production and consumption systems and could benefit from existing microeconomic assessments (for example, UK NEA, 2011b, Ch. 22);
- quantification of changes in macroeconomic sectors as a result of changes in ecosystem services;
- quantification of the indirect and induced effects through inter-sectoral linkages;
- quantification of the economy-wide effects including the impacts on investment and trade (and pressures on ecosystem services elsewhere); and
- explicit consideration of ecosystem stock–flow relationships and how changes in these affect macroeconomic performance over time, especially associated with degradation of ecosystems that affect the flow of services such as agricultural yields or fish landings.

Selecting key sectors has the advantage of focussing effort on important interactions for which, to varying degrees, data and methods exist and can be further developed. The disadvantage is that that some of the feedbacks between other economic sectors and ecosystem services will be missed. However, progress on selected sectors that are known to have important ecosystem-macroeconomy interactions will provide a valuable learning experience and help develop data and methods that can be rolled out to other sectors subsequently.

A major conclusion here, that shapes the direction of future research, is that 'greening' the accepted and relatively tried and tested macroeconomic accounting and modelling frameworks and methods by extending them to include ecosystems accounting is probably the best way forward. This integrated approach is challenging but essential to support policy analysis and decision making in pursuit of resource efficiency and sustainable development.

2.1 Introduction

Governments and the scientific community are increasingly concerned about the condition of the natural environment and the use of natural resources as this determines the sustainability of economic development and social progress (see, for example, NEWP, 2011; UK NEA, 2011a). Economic prosperity of a country depends on the availability of resources and on the way these are used. There are four broad types of resources (capital): natural capital (land, water air and living systems), manufactured/manmade capital (buildings, machines and infrastructure), human capital (people and their education, skills and creativity) and social capital (the links between people and communities in terms of cooperation, trust and rule of law) (Ekins, 2003; TEEB, 2013). A range of indicators are used to assess the performance of national economies (for example see the UK Office of National Statistics Blue Book 2012 - ONS, 2013b). These macroeconomic indicators include the value of goods and services produced in the economy (the best known and most widely used measure here is Gross Domestic Product - GDP), investment, employment/unemployment, and international trade indicators such as values of imports and exports.

Economic development and growth relies, among other things, on the extraction of natural resources and leads often to the depletion of natural capital (e.g. deforestation or overfishing) or the replacement of natural capital with other forms of capital (e.g. artificial fertilisers to substitute for soil quality). The System of National Accounting and macroeconomic frameworks have been developed over the last hundred years or more and are relatively well established. National Accounting uses high level aggregates that do not in themselves provide a full account of the prosperity and well-being of nations, nor was this their original intention. For this reason a number of steps have been taken to extend their scope to provide more complete estimates of national welfare. These include the System of Integrated Environmental and Economic Accounting (SEEA) that closely follows the UN System of National Accounts (SNA), IBRD's Adjusted Green Accounts (IBRD, 2011), and 'Satellite' environment accounts produced for the UK by the Office of National Statistics (ONS, 2013b).

The connections between ecosystems, natural capital and the national economy are, however, inadequately reflected in conventional macroeconomic indicators. The importance of development within the limits of the planetary resources from the environment, where the goods[2] from ecosystem services belong, has been highlighted by Boulding in his paper 'The Economics of the Coming Spaceship Earth' as early as in 1966 (Boulding, 1966). The classifications of ecosystem services as well as conceptual frameworks and methodologies for assessing the state of these services are being currently developed (for example, see UK NEAFO, 2013; Haines-Young and Potschin, 2013; UK NEA, 2011b; MA, 2005) and these are in much earlier stages of development than macroeconomics and national accounting conventions.

The integration of environmental (rather than ecosystems) accounting and national accounting has been carried out for some sectors in the UK, notably for agriculture (Jacobs *et al.* 2008), and in the 'satellite' environmental accounts (ONS, 2013b) that facilitate analysis of the wider impact of economic change. These measure the environmental impacts of economic activity (due, for example, to pollution) and how the environment contributes to the economy (for example, through the supply and use of raw materials and associated resource efficiency), using the accounting framework and concepts of the national accounts.

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[2] The term good(s) includes all use and non-use, material and non-material outputs of ecosystems that have value for people.

In addition to the recent rapid development of the ecosystem services approach, the global financial crisis triggered discussion on the possibility of Green Growth and Green Economy that could shift developing and developed countries to a new sustainable growth path (OECD, 2011; UNEP, 2011). Ecosystem services are at the centre of these debates, as is evident from the definition of green growth given by The Organisation for Economic Cooperation and Development:

> 'Green growth means fostering economic growth and development while ensuring that natural assets continue to provide the resources and environmental services on which our well-being relies. To do this it must catalyse investment and innovation which will underpin sustained growth and give rise to new economic opportunities.' OECD, 2011

The Millennium Ecosystem Assessment (MA, 2005) defines an ecosystem as '*a dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit*'.

The UK National Ecosystem Assessment (UK NEA, 2011b) has identified many instances where human activity has been changing ecosystems in the UK and how economic values (market and non-market) change due to changes in ecosystems while impacts of other ecosystem services were qualitatively assessed. However, the contribution of ecosystem services to the national economy (human activities that result in goods and services consumed by people) as a whole is still to be identified. These links between ecosystems and the economy are multi-faceted and complex.

In this context, the aim of this report is to provide a scoping review and research agenda for understanding and accounting for the macroeconomic implications of ecosystem services change and management in the UK. The exploratory study set out to address the following objectives, presented here in the form of research questions:

- What is a suitable framework for guiding the assessment of impacts on the macroeconomy of policies concerned with the management of ecosystem services?
- What and where are the key interactions between ecosystem services and the macroeconomy?
- What literature, data, methods and models are available to enable the macroeconomic impacts of changes in ecosystem services to be assessed?
- Given current capabilities and needs, what are the priorities for research in order to develop a coherent framework to assess the impacts on the macroeconomy of policies concerned with the management of ecosystem services?

This study involved exploring general frameworks for assessing ecosystem and macroeconomy interactions (Section 2.2), a systematic review of existing methodology (Section 2.3) and literature (Section 2.4) to assess the current state of knowledge, and establishing a research agenda for immediate future research (Section 2.5). **Figure 2.1** presents a flow diagram of the steps involved in this study.

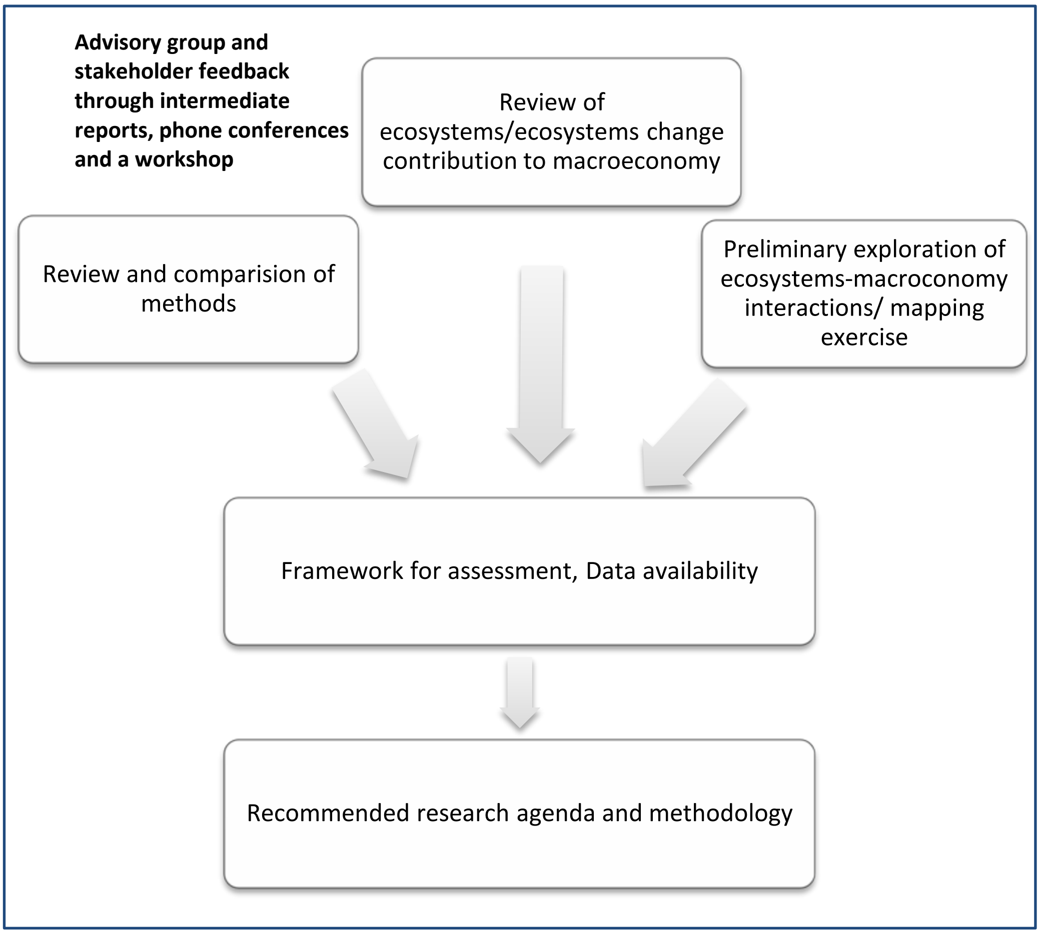


Figure 2.1. Structure of work in WP2.

The study was supported by an advisory panel, a stakeholder and expert panel (see Acknowledgements) providing guidance and comments on interim drafts, as well as attending a workshop held on 28th February and 1st March 2013 at Madingley Hall, Cambridge.

2.2 Conceptual framework

People have close interactions with ecosystems and ecosystems are essential for human existence. The economic system comprising the processes by which humans transform inputs to outputs and facilitate exchange to meet human needs, however, is an outcome of human activity. Hence everything that ecosystems provide in terms of supporting human life supports the economy either directly or indirectly. For example, take the ecosystem service 'photosynthesis' that ensures the majority of the primary production on the earth and imagine an unlikely scenario where there is a disturbance that stops this process from happening. This event would stop oxygen and primary biomass production and everything that depends on these processes would cease. The same would apply for water availability.

In simple terms there would be no life and no economic output on this planet and hence it is possible to say that ecosystems contribute to 100% of the macroeconomy. Hence these services are essential for human existence. However, one might argue that fresh water can be substituted with processed sea water and oxygen can be chemically produced up to a certain extent, but these artificial processes are not likely to be sustainable or sufficient to support life.

2.2.1 The Interface between ecosystem services and macroeconomics

In order to understand how ecosystem services influence the macroeconomy, there is a need to define the interface between ecosystems and the economic system. UK NEA (2011b, Ch.2 p. 13) established a general conceptual framework that links ecosystem services with human well-being in the UK. Macroeconomics, that is the main focus of this report, is concerned with the economy as a whole including valuation of final goods and services produced in various sectors of the economy, the provision of investments, goods and labour that support but are not directly used up in production systems and trade effects. Given this, the UK NEA framework can be expanded to include the macroeconomy that surrounds and interacts with human well-being with economic, health and shared values (**Figure 2.2**).

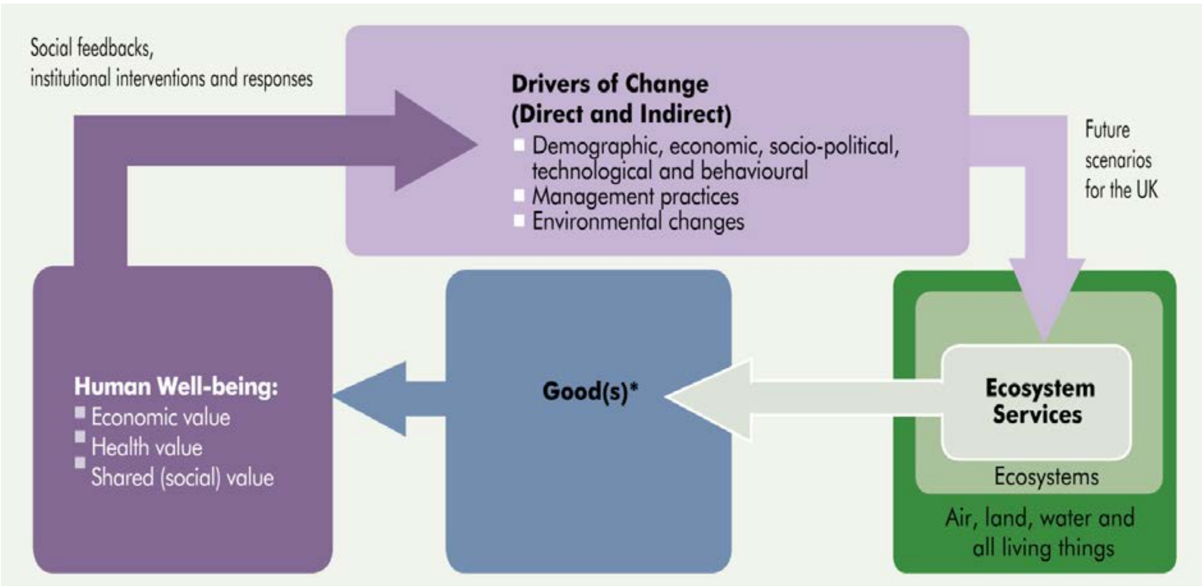


Figure 2.2. Overall Conceptual Framework for the UK NEA with macroeconomy.

One of the first general frameworks for the analysis of economy-environment interactions was formulated by Herman Daly (Daly, 1968) in a paper, where he proposed to use input-output analysis to consider 'ecological commodities' and 'economic commodities' and their interdependence. Although since then a number of general conceptual frameworks have been developed to link changes in the natural environment and the macroeconomy (see for example, Ekins (2000) and Shmelev (2012)), these do not explicitly consider the likely impact on the macroeconomy of changes in the diverse range of ecosystem assets and services as defined in the UK NEA (2011b). Such general frameworks have been in existence for almost five decades but have yet to be made fully operational using valuation and accounting methods and decision techniques. These frameworks link the environment and economy by considering the flow of services that emanate from the existing stock of natural capital as an input in the `production process', which results in the creation of aggregate final goods (one can think of this as GDP) which can be consumed, and in some frameworks generate satisfaction (`utility' in economic terms).

This simplified approach to thinking about the environment/economy interaction allows for a tentative integration of the role of the environment in macroeconomic analyses. In this way it is possible to define a relationship that reflects the technically feasible combinations of inputs that can be used to produce a particular level of output. This set of possibilities is expanded by technological change over time, either as a result of experience or as a consequence of purposeful activities of research and development. These combinations of efficient alternative inputs define a route from these inputs into output that is often conveniently (and somewhat restrictively) formalised as a `production function'. Making the production function operational requires aggregation of capitals and mapping, then a combination of inputs into a quantity of final product - `output' or GDP. Ekins and Max-Neef (1992) suggest a model of the macroeconomy where flows of services emanating from four different capital stocks contribute to the production of the final output ('goods and bads'), and the generation of welfare (see **Figure 2.3**).

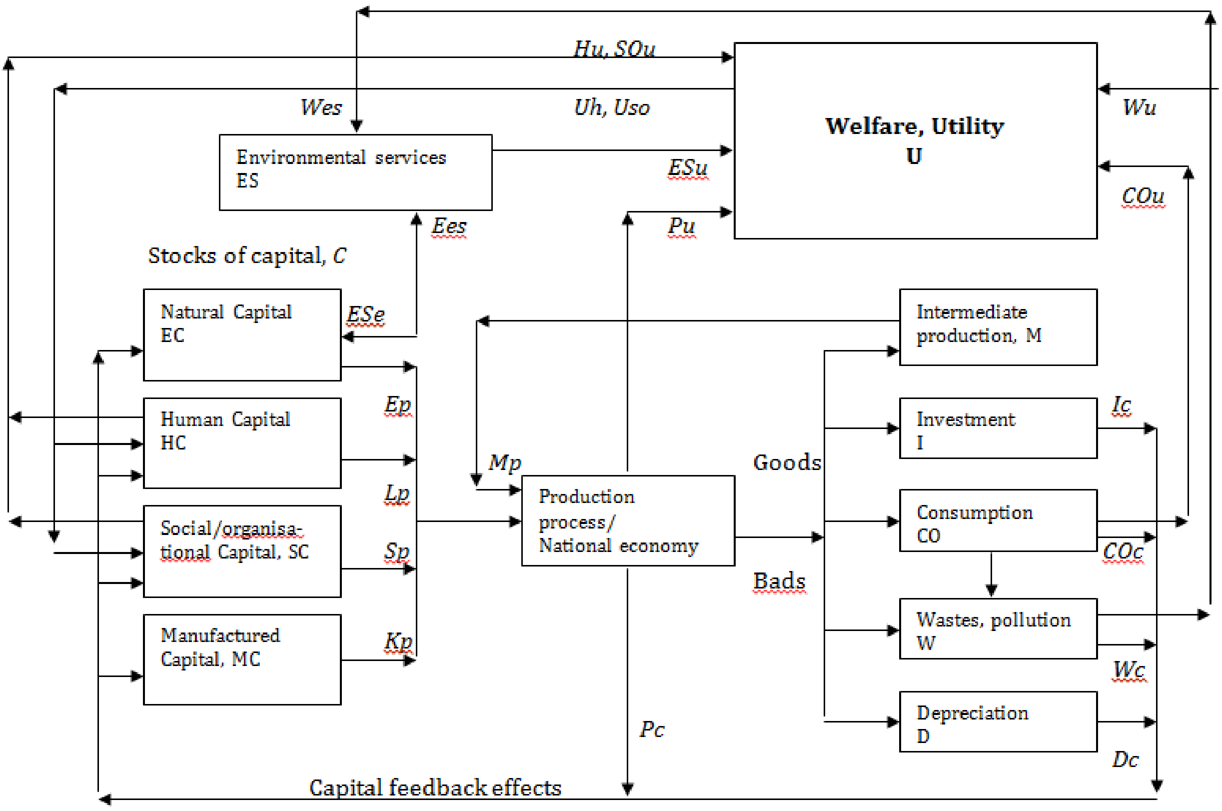


Figure 2.3. A Four-Capital Model of Wealth Creation through a Process of Production. Source: Ekins and Max-Neef (1992).

The four types of capital they consider are manufactured capital, human capital, social/organizational capital and natural capital. To understand the relative importance of any of these types of capital, it is crucial to understand the degree to which any of them can be substituted by the others in the production of the final goods. The possibility of substitution is measured by assessing how the relative use of two inputs changes, when their relative (marginal) productivity changes – known as `elasticity of substitution'. The larger the elasticity of substitution, the easier it is to do without one of the factors of production, without incurring output losses. Conversely, a low elasticity of substitution - for example, between natural capital and other forms of capital - signifies that a reduction in one input implies a substantial, possibly catastrophic reduction in the level of output, and ultimately of social well-being. It is important to understand, however, that statements regarding the elasticity of substitution are conditional upon the current state of technology and the plausible expectation of technology in the near future. For example, it is at least conceivable that developments in geo-engineering would increase the elasticity of substitution between natural and manufactured capital by reducing our reliance on natural climate regulation mechanisms. As a consequence, the role of investment in new technology is crucial when discussing the importance of ecosystem services in the macroeconomic context, especially in relation to long-run sustainability. The natural capital that performs essential functions that cannot be substituted by other forms of capital performing the same functions (such as manmade capital or other natural capital) is called 'critical natural capital' (Ekins *et al.*, 2003). Furthermore, ecosystem assets and services and their value are often spatially specific, such as the hydrological services provided by forests in a particular catchment, and not easily transferable between locations. The identification of critical natural capital in terms of critical ecosystem services that support the economic system is important. These critical services may exhibit thresholds and crossing these may impose cross-sectional systemic risks to the economy that may result in collapse of the entire system.

Theoretically, the framework in **Figure 2.3** can be expanded by linking several of these frameworks together to represent flows between countries and regions to explore the impacts of natural capital embedded in trade.

Despite of the simplicity of the existing general frameworks like the one presented above there are problems with understanding the inputs of natural capital into the economy (SEEA, 2013), aggregating capital (SEEA, 2013; Felipe and McCombie, 2013) and using aggregated production functions (Felipe and McCombie, 2013). Therefore, a good starting point is developing an understanding of how ecosystem services contribute to economic sectors (total effect) and thereafter, the impacts of changes in ecosystem services could be identified (marginal effects). The integration of environmental (rather than ecosystems) accounting and national accounting has been carried out for some sectors in the UK, notably for agriculture (Defra, 2010a; Jacobs *et al.* 2008), and somewhat in the 'satellite' environmental accounts (ONS, 2013b; SEEA, 2013) that facilitate analysis of the wider impact of economic change. These measure the environmental impacts of economic activity (due, for example, to pollution) and how the environment contributes to the economy (for example, through the supply and use of raw materials and associated resource efficiency), using the accounting framework and concepts of the national accounts.

The complex linkages between ecosystem services and economic processes need to be made explicit in order to track the effects of changes in one on another. The greatest interactions are where ecosystem services provide direct inputs to production (for example, water for public water supply or for the beverage industry) and/or influence the production process itself either in a negative or positive way (for example, reduced productivity due to increased outside temperatures). Hence the macroeconomics of ecosystems concerns mainly the final ecosystem services (see, UK NEA, 2011b, Chapter 2) and changes in goods provided by these. It is not concerned with changes in ecosystem processes/intermediate services as these eventually result in changes in final services. However, if the changes in intermediate services (such as soil formation) that cause changes in final services (such as tonnes of lettuce grown) are known then it is possible to follow the changes through from intermediate services to final ecosystem services to the macroeconomy. The focus on final goods avoids the problem of double counting. The UK NEA (2011b) classification lists 12 'final' provisioning, regulating, and cultural ecosystem services (**Figure 2.4**).

Table 2.2 Ecosystem services in the UK NEA classified according to both ecosystem service type (provisioning, regulating, cultural and supporting) and whether or not they are final ecosystem services or intermediate services and/or processes. For each final ecosystem service an example of the good(s) it delivers is provided in italics.

Ecosystem processes/intermediate services		Final ecosystem services (*example of goods*)	
Supporting services	• Primary production • Soil formation • Nutrient cycling • Water cycling	**Provisioning services**	• Crops, livestock, fish (*food*) • Trees, standing vegetation, peat (*fibre, energy, carbon sequestration*) • Water supply (*domestic and industrial water*) • Wild species diversity (*bioprospecting, medicinal plants*)
• Decomposition • Weathering • Climate regulation • Pollination • Disease and pest regulation • Ecological interactions • Evolutionary processes • Wild species diversity		**Cultural services**	• Wild species diversity (*recreation*) • Environmental settings (*recreation, tourism, spiritual/religious*)
		Regulating services	• Climate regulation (*equable climate*) • Pollination • Detoxification and purification in soils, air and water (*pollution control*) • Hazard regulation (*erosion control, flood control*) • Noise regulation (*noise control*) • Disease and pest regulation (*disease and pest control*)

Figure 2.4. Classification of ecosystem services as in UK NEA. Source: UK NEA (2011b, Chapter 2, p. 17).

The economic value of some final ecosystem services, such as the expenditure on countryside recreation and the harvesting of natural foods for sale, already feature in national accounts and macroeconomic indicators. Many final ecosystem services, such as climate regulation, however, are intermediate services in a macroeconomic accounting sense. They provide inputs of natural capital that are combined with other inputs, such as human, social and physical capital within the production systems of economic sectors (**Figure 2.5**).

Figure 2.5. Links between ecosystem services and economic sectors.

The extent to which changes in ecosystem services impact the macroeconomy requires an understanding of which ecosystem services impinge upon which economic sectors. Some ecosystem services are absolutely vital for the survival of life i.e. photosynthesis and water provision, and in the case of their total disruption and given the current and foreseeable state of technology the world's GDP will be reduced to zero. Critical thresholds are important here, overstepping of which may cause irreversible change in the stocks of ecosystems and their flows of services. There is a need for in-depth research into thresholds especially given the complexity of linkages and feedback loops between various ecosystem services (Groffman *et al.* 2006).

The review of literature (Section 2.4) indicates that although there is much interest in assessments of the contribution of ecosystem services to the macroeconomy and some selected applications to date, there is no comprehensive treatment of this issue. In other words, we do not know, for example, the total or marginal contribution of ecosystem assets and services to GDP. There are, however, studies on macroeconomic effects for selected economic sectors such as agriculture and fishing that are mainly directly dependent on goods provided by provisioning ecosystem services and that are also covered by national accounting. The primary aim of many of these studies was not a quantification of the macroeconomic impacts and the ecosystems services framework/approach is not present in these assessments. However, some of them contain quantifications of changes in the values or quantities of goods provided by ecosystem services and/or in related employment that are macroeconomic in nature or could be used as an input for macroeconomic assessments. The lack of macroeconomic assessments of ecosystem service change is partly attributed to the absence of well-established conceptual frameworks and the relative novelty of the ecosystems services approach. National/macroeconomic accounting follows accepted international conventions that have been developed since the 1940s and are designed to provide selected indicators of economic activity, performance and status. They use high level aggregates that do not in themselves provide a full account of the prosperity and well-being of nations, nor was this their original intention. For this reason a number of steps have been taken to extend their scope to provide more complete estimates of national welfare. These include the System of Integrated Environmental and Economic Accounting (SEEA, 2013) that closely follows the UN System of National Accounts (SNA, 2013), IBRD's Adjusted Green Accounts (IBRD, 2011) , and 'Satellite' environment accounts produced for the UK by the Office of National Statistics (ONS, 2013b). However, experience with integrating ecosystem services into national accounting systems is still very limited (Edens and Hein, 2013; SEEA, 2013).

Although the focus in national accounts tends to be on flows of income and expenditure, with allowance for changes in net capital investment, the values of the stock and flows of natural capital has particular importance in ecosystem accounting. Declining stocks of natural capital, associated for example with habitat loss, biodiversity loss, soil degradation and decline in water quality for example, require particular attention in ecosystem-macroeconomy accounting, especially where minimum threshold values are required to secure future service flows. There is considerable debate whether the stock values of renewable resources (such as forests) should be based on remaining value (based on some estimate of the present value of future service flows) or on estimates of restoration cost.

The SEEA (2013) Experimental Ecosystem Accounting focuses on valuations that permit comparison with and augmentation of valuations in national accounting. The SEEA report covers different valuation techniques for ecosystem accounting in detail, sets an agenda for physical and monetary ecosystem accounting, but only briefly touches upon incorporating these in national accounting. Therefore the discussion here will not cover ecosystem accounting and valuation methods and techniques but aims to advance the thinking about ecosystems links with the macroeconomy and especially the way these can be reflected in national accounting.

2.2.2 Ecosystem services links with GDP

GDP is the indicator most widely used to measure the performance of national economies, but at the same time it is also heavily criticized for its limitations as a measure of well-being and sustainability (see for example Costanza *et al.* 2009). The following aims to discuss how ecosystem services are and can be reflected in this popular indicator of national output.

Developed in 1930s and 1940s, GDP was never meant to be a measure of well-being, but rather a high level estimate of the status of economic activity over a period of time, based on a practical and manageable system of monitoring of actual transactions between the various agents in the economy (Marcuss and Kane, 2007).

However, not all valuable outcomes have or should have a market 'exchange' price (though it makes it easier if they do, this being, from an economist's perspective, a key practical determinant of value). There are goods that are not attributable to human activities, but which are of value and these are not and should not be in GDP (e.g. a beautiful landscape). However, when human activity erodes the things that it uses to support this activity, then this should be included in the GDP (see below). Over the past twenty years there emerged many sustainability and progress assessment methodologies complementing GDP. Among them are the Index of Sustainable Economic Welfare (Daly and Cobb, 1989) and the Genuine Savings Indicator calculated by the World Bank (Pearce and Atkinson, 1993). Most of these measures adopt a principle of weighted addition and subtraction of positive and negative impacts from GDP or its derivatives. In other words negative environmental effects are assessed in monetary terms and subtracted from the national income or GDP aggregate.

It is possible to distinguish between five different types of final ecosystem goods in relation to GDP:

- There are **goods of value** as flows (e.g. food, fibre) and these have market price and therefore **are in GDP**.
- Some natural assets are of value as stocks. They may matter in terms of a flow of future ecosystem services, in addition to their effect on attributable outcomes (value added) today, and so they have implications that **should not be in GDP, but should** ideally **be measured and/or valued** where possible and reported in national accounts. Examples include eroding asset stocks (*e.g.* soils), climate, water and ice-caps.
- Some goods are of value as flows (appreciating beautiful landscapes from window), but are not attributable to human activity and therefore **should not be in GDP**.
- Some goods are of value as flows, but are relevant as factor inputs into production (as in the case of the landscape, where appreciation of a beautiful landscape can result in increase of labour productivity). In this case, **the effect on GDP is being picked up,** but its attribution to ecosystems is not being measured correctly, but **should be measured** where possible.
- Many things are of value as flows and are attributable to human activity, so **should be in GDP (either as inputs or final output) but are too difficult to measure**. The impact of a depreciated ecosystem (as per above) or changed climate is attributable to human activity and therefore should be added as a negative value. But by missing the negative input effect, measured GDP may go up rather than down, as we work harder to adapt to a hostile climate or build parks to make up for lost countryside, or start using hand-pollination to offset diminished natural pollination. Earthquakes boost GDP due to reconstruction (but reduce valuable outcomes) and greater heating and cooling costs in a more hostile climate help to boost GDP. Adapting to climate change may increases GDP in some cases, unless the attributable cost is included.
- Some ecosystem services are of value that **should not be measured** and **should not be included in GDP**. For example ecosystems and their services which are independent of human existence (rights, freedoms, opportunities also belong to this group).

The problem of what should and what shouldn't be in GDP is not new nor confined to environmental impacts. National accounting is riddled with activities that should be in GDP but are not (e.g. such as the work of house-wives/husbands). To sum up, the questions to ask are:

- Which ecosystem assets and services should be reflected in GDP (and in other aggregated macroeconomic indicators) and how?
- Which ecosystem services are not and should not be in GDP, but are still important to well-being and should be accounted for in physical terms and/or valued and reported separately as a part of national accounting?

2.2.3 Ecosystem services – economic sectors mapping

How well economic/industrial sectors perform in terms of output depends on input factors (such as labour, materials, technology) and their performance (such as labour productivity, the quality of materials and material use per unit of output). The availability of goods for the final and intermediate consumer depends on domestic production and the amount of these goods that can be imported to satisfy demand. Some of these products can be substituted by others that can be similar (for example substituting potatoes for rice) or different (substituting travel for watching DVDs). Some of the goods and services only exist because they are needed to complement other products or carry out certain activities (for example production of combine harvesters to harvest grain crops) and if the primary activity ceases then there is no feed for the complementary products either. All these factors need to be taken into account while assessing the impact of ecosystem services on economic sectors.

Tracking the linkages between ecosystem services and economic sectors by indicating which services directly support which sectors would be the first step towards understanding the impacts of ecosystem change and management on economic sectors and the whole economy. This first step should be followed by assigning levels of importance to the services and then by quantification of their inputs where possible. This kind of interactive mapping has not been done previously and fully understanding the links between ecosystems and economic performance could guide decisions that policymakers take to manage or/protect ecosystems. Another issue is how the interactions between ecosystem services should be accounted for in order to avoid double counting or under counting.

The following gives an example of how change in final ecosystem services impacts sectoral economic accounts. Decline in yields in agriculture (decline in the final ecosystem service goods that provide food and feed) or loss in labour productivity due to increased outside temperatures (malfunction of the final regulating service 'climate regulation' that ensures the temperatures that we are adapted to) leads to decreased output in the economic sector 'agriculture'. In other words, macroeconomics is primarily concerned with the ecosystem services that can directly influence the output of an economic sector/economic sectors. However, if the changes in intermediate services (such as soil formation) that cause changes in goods provided by the final ecosystem services (such as tonnes of lettuce grown) are known then it is possible to follow the changes through from intermediate services to final ecosystem services to the macroeconomy.

Where there are reductions in the provision of ecosystem services and subsequent decreases in economic output and consumption, then this can be compensated for by increased imports (or by reduced exports) where possible. Goods, such as food, can be imported from other countries and some of the services can also be substituted by services abroad, for example, recreational activities can be carried out in other countries, to satisfy domestic demand. However, increased imports and holidays abroad do not benefit the national income despite helping to meet the demand. Instead, the money paid for imported goods and services benefits the economies abroad that provide these goods and services. Another issue is the pressure that increased imports put on ecosystems abroad and the possible degradation that can occur due to intensified production elsewhere. Another option would be to substitute natural capital with other forms of capital in the production process, for example, to use fertilisers to compensate for decline in food provision.

Consumers are more dependent on the output of some industries than others. The industries that support life by providing necessity goods (goods that are necessary for surviving) may not amount to a major share in the national economy in terms of value. For example, in the UK agriculture accounted for about 0.7% of GDP, 0.6% of GVA and 1.2% of employment in 2011 (see Appendix 2.3). If food/feed production stopped in the UK then the economy would need to switch to importing these products which endangers the security of food supply (for explanation of these concepts, see

Defra, 2006). The same applies to water supply, for example and other goods that are critical for national security.

Since the sectors in an economy are linked to each other by using each other's outputs as inputs (intermediate demand) then changes in the output of one industry impacts outputs of all other industries that use their output as input for their production processes (indirect impacts). For example, in 2010 the produce of the agricultural sector was used as input by 41 other sectors including agriculture itself in the UK (ONS, 2013b). Furthermore, changes in demand for the final goods provided by ecosystem services due to alterations in income (induced effects) must also be assessed. In this way the contribution of ecosystem services to estimates of total value added, trade and employment in the economy can be ascertained, as well as the implications of change. **Figure 2.6** brings the discussion above together and gives a simplified representation of the total effect of ecosystem service changes on the performance of a sector in the economy.

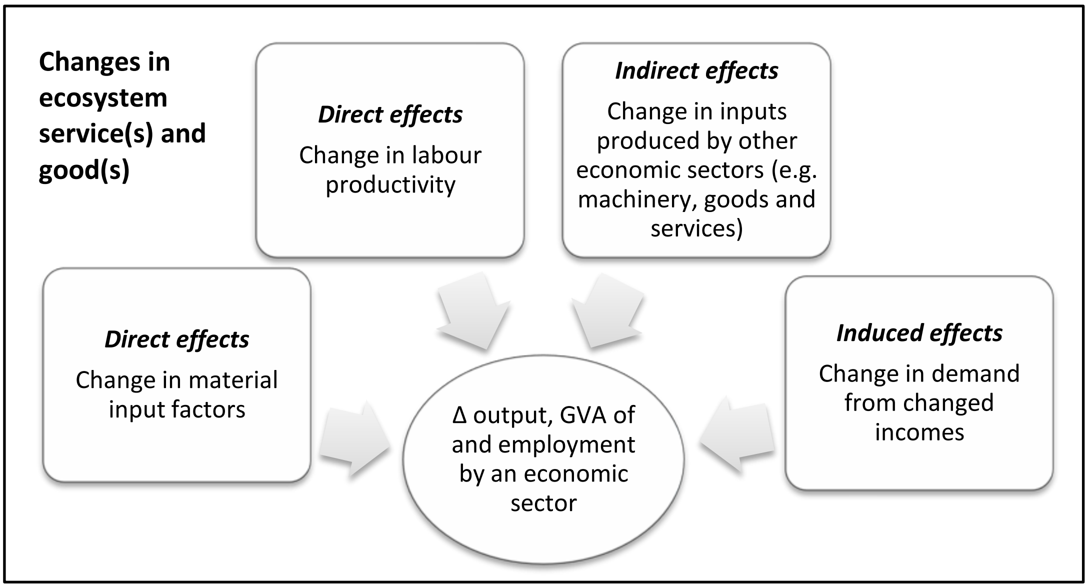


Figure 2.6. A simplified representation of ecosystem service change and management impacts on an economic sector.

The changes in ecosystem services can be positive (for example brought about by investments) or negative (for example from degradation of resources or damages). Once the effects on separate economic sectors are quantified, the results could be added up to derive economy wide effects. Given the complexity of ecosystems and the economic system and that the stocks and flows of natural capital are still largely unknown, a reasonable first step would be identifying the links between final ecosystem services and economic sectors. This could be done by constructing a matrix with ecosystems services (rows) and economic sectors (columns) in order to map the potential inputs from ecosystem services to economic sectors.

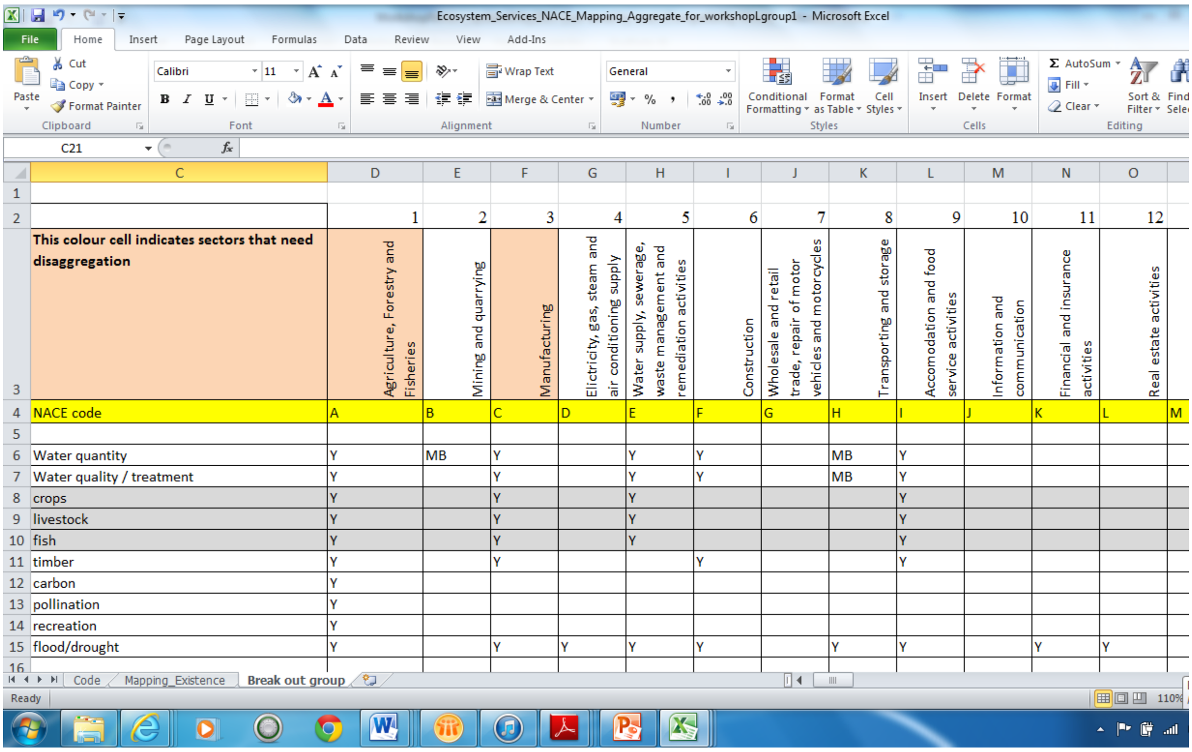
The NACE (2006) classification system includes a large number of economic sectors (in 21 sections with 615 classes) and similarly, a number of UK NEA final ecosystem services have been defined (12 broad final ecosystem services that provide a variety of goods and can be broken down into many more subcategories) therefore the mapping exercise requires in-depth expertise and involvement of industry experts. It should be followed by quantification of the direct contribution of the final ecosystem goods to the economic sectors. Once this is known, the UK input-output tables (industries' intermediate consumption tables) can be used for mapping indirect and induced impacts through sectoral interdependencies. In addition, qualitative descriptions based on the literature and expert opinions can be used for mapping non-market value ecosystem service goods to economic sectors.

The high number of interactions between the NACE sectors and final ecosystem services will make the mapping exercise very complex and therefore it would be justified to begin by focusing on a group of selected economic sectors and final ecosystem services. By doing this, the majority of interactions between the impacts of ecosystem services are necessarily ignored, but partial mapping would be a useful exercise in order to understand the magnitude and complexity of the full mapping exercise.

It is reasonable to start with the sectors for which data and methods of analysis are most developed: namely agriculture, forestry, fishing, energy and water sectors. These economic sectors could be linked with ecosystem services associated with the provision of:

- food (crops, livestock, fish);
- water (quality, quantity, flood/drought hazard);
- forest products (timber, recreation, energy, carbon sequestration).

There is a clear understanding of how these three provide predominantly physical inputs to economic sectors and how the goods are transformed in the production process, as a result of combination with other inputs such as labour and other forms of capital, into final goods (and services) provided by economic sectors. Changes in the quantity and quality of ecosystem goods can modify the transformation process and the output of the economic sectors concerned. It might be most practicable to begin by simply identifying whether there is a link or not (marked by 'yes' or 'no') (see **Figure 2.7** as an example). Ideally the process should follow the standards outlined in SEEA (2012), collection of data on physical flows (where possible), consulting with experts, and, after the links are established, building probabilistic directed acyclic graphical models (Bayesian belief networks) based on best estimates.



	1	2	3	4	5	6	7	8	9	10	11	12	
This colour cell indicates sectors that need disaggregation	Agriculture, Forestry and Fisheries	Mining and quarrying	Manufacturing	Elcricity, gas, steam and air conditioning supply	Water supply, sewerage, waste management and remediation activities	Construction	Wholesale and retail trade, repair of motor vehicles and motorcycles	Transporting and storage	Accomodation and food service activities	Information and communication	Financial and insurance activities	Real estate activities	
NACE code	A	B	C	D	E	F	G	H	I	J	K	L	M
Water quantity	Y	MB	Y		Y	Y		MB	Y				
Water quality / treatment	Y		Y		Y	Y		MB	Y				
crops	Y		Y		Y				Y				
livestock	Y		Y		Y				Y				
fish	Y		Y		Y				Y				
timber	Y		Y			Y			Y				
carbon	Y												
pollination	Y												
recreation	Y												
flood/drought	Y		Y	Y	Y	Y		Y	Y		Y	Y	

Figure 2.7. An example of mapping of Ecosystem Services onto NACE 2 Economic Sector Classification: 'Y' – yes, 'N' – no and 'MB'- maybe.

While mapping economic sectors with their respective ecosystem services the degree of disaggregation of NACE (2007) sectors is required. For example, when considering the interaction between the final ecosystem good 'food' and the performance of the sector 'Agriculture, Forestry and Fishing' (NACE and SIC (ONS, 2007) section A)' the sector needs to be disaggregated to smaller units than the division of 'Agriculture', 'Forestry' and 'Fishing' (NACE and SIC divisions 01,02,03). For example, Agriculture (NACE division 01) should be disaggregated, if possible, to groups and classes (three and four digit NACE codes) as follows:

- Crop production with subcategories such as
    - crop type
    - perennials and non-perennials
    - plant propagation as a separate activity
- Animal production with subcategories such as
    - dairy/meat
    - mixed farming
    - hunting/game

Fishing (SIC sector 03; NACE division 03) could be disaggregated, for example, as follows:

- fishing, aquaculture and fisheries (marine/freshwater);
- angling, a popular sport, that also provides some minor amounts of food in the UK , but belongs to NACE section R division 18 – 'Other sporting activities'. Recreational fishing is also important for licensing, production of fishing gear and other services.

'Water' as an ecosystem service is complex and has many aspects that should be considered when establishing the connections between 'water' and economic sectors. The characteristics to consider include water quality and water quantity. The questions to ask here are: How to link the economic data with the environmental water quality data? Which industries depend on water quality in addition to water availability? Section E in the NACE and SIC classification is 'Water supply, sewerage, waste management and remediation activities' that includes divisions 36 'Water Collection, Treatment and Supply' and 37 'Sewerage' these sectors' activities depend directly on water availability and quality. And they supply their services to other industries that demand water as an input for their production. However, lower water quality is not likely to reduce the output the 'Water Collection, Treatment and Supply', but increase it as additional water treatment can be charged to consumers and is reflected in increased monetary output of the sector.

There are industries that have their own sources of water supply for which water quality in addition to availability is extremely important. For example section C division 11 'Manufacture of beverages' which includes production of bottled water. For these industries a decline in water quality will increase the treatment costs and can result in decreased output/profits.

Another issue is the quantity of water available. This would link directly onto the dependence on water/water consumption by various industries. For example, coal-fired and nuclear power plants require water for cooling (McMahon and Price, 2011). Pumping water requires energy. Water shortages in some areas (for industries, households and irrigation) could increase the amount of energy required to transfer water spatially and temporally (in the case of reservoirs). But increased energy demand will raise the demand for cooling water while switching to alternative electricity sources, such as wind, could help to reduce the demand for water for this purpose.

Carbon Capture and Storage (CCS) systems, while helping to regulate climate, could increase the amount of water used by power stations by 30%-100% depending on the type of power station (Newmark *et al.* 2010). In addition CCS can impose ground water hazards associated with leakage, and, in the extreme, result in potential mobilization of hazardous inorganic constituents due to increased acidity (*ibid.*).

Water is also associated with water hazard – floods and droughts. The impacts of these are highly location specific and a number of economic sectors can be affected directly or indirectly. There are clear links with the agriculture, forestry, fishing, electricity sector, mining, food and beverage manufacturing sectors as well as with recreation and health services.

It is important to find out how to deal with ecosystem services that impact several economic categories and have the possibility to be either over- or under- counted. The mapping work will benefit from the work done in work packages in the UK NEAFO (2013). For example, the UK NEAFO WP3 case study on saltmarshes could yield quantitative estimates of impacts on fish nurseries and fish stocks that can be related to marine commercial fishing (NACE code 03.11).
There are also other challenges related to the practices of various government agencies. For example, the Environment Agency's recreation benefits are very specific in terms of angling and boating. These would be subsumed amongst a multitude of other things within the broad class of 'other sports activities' (93.19) in Division 93 'Sports activities and amusement and recreation activities' that is Section R 'Arts, Entertainment and Recreation'. So it may be difficult to relate the Environment Agency's water related recreation interests with data for this class. In this case it would, however, be possible to use input-output analysis for exploring the indirect effects for this broad class if all recreation and sports within the broad category have the same level and nature of indirect impacts, which is unlikely. It is likely that some further disaggregation of input-output tables will be required before data could be used as input for macroeconomic assessments.

There are also spatial aspects related to exploring the macroeconomic implications of ecosystem services. For example, mismatches in regional importance, water stressed catchment areas, hydrological catchments and political regions. The benefits and impacts (e.g. for water) are usually spatially specific (e.g. in specific catchments and river basin districts and in particular in terms of specific water stressed catchments). For example, it would be useful to show the significance of water dependent sectors in water stressed catchments in terms of % of total GVA in the region in question.

There is a need for micro-level spatial analyses (e.g. based on GIS) for example of the effect of soil quality on farming yield and outputs in specific regions (e.g. similar to these ones conducted in UK NEAFO WP2) that can support macro work. Indeed, the 'critical geography' of macroeconomic modelling, particularly linked to GIS, is a relatively undeveloped area, but essential for the purposes here. Macroeconomic modelling could be designed to accommodate spatial variation that is often a very critical component of ecosystems as well as regional comparative advantage. This detailed spatial analysis would be only justified if the macroeconomic impacts of changes in changes of ecosystem services are thought to be sufficiently large to make such detailed macroeconomic analysis worthwhile.

A detailed analysis of ecosystem effects on the macroeconomy is data intensive. Data on physical stocks of natural assets and flows of goods provided by ecosystem services and their values are needed. Some of the data still need to be collected, but various data that could be useful for the macroeconomic assessments of ecosystem service change is provided by government departments and agencies already. For example, for UK data collected and estimated by ONS:

- UK Environmental Accounts (Material Flows and Environmental Expenditure);
- Annual Business Survey (ABS): sectoral outputs, investments, employment (see an example below);

- Farm Business Survey (FBS) [3]: annual detailed financial and physical data on agriculture;
- National Accounts (aggregated): Intermediate demand, supply and use tables, Leontief inverse matrices, sectoral outputs.

ONS has also several on-going developments that are likely to be useful for the future assessments:
- Physical Ecosystem Asset and Service Accounts for Woodlands;
- Land Use Accounts;
- EGSS – Environmental Goods and Services.

ABS has some break down of industrial sectors to smaller than a division. For example for section A:
- Division 01 'Agriculture' covers only 01.6 'Support activities to agriculture and post-harvest crop activities and 01.07 'Hunting, trapping and related service activities' groups.
- Division 02 'Forestry and logging' covers groups 02.1 to 02.4.
- Division 03 'Fishing and aquaculture ' covers groups 03.1 'Fishing' 03.2 'Aquaculture' which are divided into classes according to habitat – fresh water or marine.

This ABS dataset includes sectoral output, employment and investment data for agriculture it can be complemented with FBS data. Some data in ABS is supressed for confidentiality reasons. There are no known UK supply and use tables at that level of disaggregation of sectors, although it is possible to calculate these from the data available. Some international multi-regional Input-Output (MRIO) databases, such as for example EXIOBASE that breaks input-output tables for agriculture into 15 sectors based on land-use and Eora MRIO database that is compiled for 511 economic sectors (Lenzen *et al.* 2013). Also it will be useful to combine sector-specific microeconomic models (for example the CSERGE SEER project's land use model at UEA[4]) with macroeconomic assessment models.

To sum it up, the main challenges of building links between ecosystem services and macroeconomy are:
- comprehensive linking between ecosystem services and a particular economic sector, so that all relevant ecosystem services are considered;
- estimation of values of ecosystem goods that contribute to the macroeconomy;
- accounting for changes in quality of ecosystem services;
- making these values compatible with those in national accounting;
- avoiding over or under counting that stems from interactions between ecosystem services;
- aggregation of values of different ecosystem goods (e.g. flood defence and timber);
- data conversion from the spatial coverage of ecosystems (geographical areas) to the political regions of national accounting and vice versa;
- compiling input-output tables that have a detailed disaggregation of economic sectors that are more dependent on ecosystem services.

[3] http://www.farmbusinesssurvey.co.uk/
[4] http://www.cserge.ac.uk/research/current-projects/seer

2.3 Methods and models for assessing the contributions of ecosystem services to the macroeconomy

Analysis of the role ecosystems play for the macroeconomy can be undertaken with a wide range of methods and tools, each of which can address one or several important aspects of the ecosystem-macroeconomy interactions. There are also methods and tools that potentially can be combined in order to analyse the links between ecosystem services and the macroeconomy. Depending on the method and underlying theoretical approach, the required information and the possible conclusions are likely to differ substantially. It should be underlined that existing methods and models are not enough for the in-depth analysis of ecosystems-macroeconomy linkages. Ideally, detailed models need to be developed that link ecosystem processes in all their interdependence with a sectorally-disaggregated macroeconomy (see the discussion in 2.2.3), including feedback loops between the two systems. These models will have to be dynamic, allowing for assessments of the impacts of ecosystem service change and management over time. This way it could be seen when the input of natural capital becomes critical and appropriate policies and measures could be developed. However, static and partial models could offer assessments of relative importance of ecosystem services in the macroeconomy and these could be used for first approximations.

2.3.1 Comparison of the macroeconomic methods and models

As a part of the literature review, a systematic comparison of macroeconomic modelling and other methods that could be combined or produce inputs to macroeconomic modelling was carried out to assess their actual or potential suitability for analysing ecosystem-macroeconomy interactions. A method/model suitable for assessments of the impacts of ecosystem service change and management on macroeconomy should be able to handle key ecosystem flows, have a high level of disaggregation that enables the examination of sectoral differences and interdependences; it should allow for the observation of changes over time (i.e. be dynamic), incorporate international trade impacts and be potentially suitable for impact assessments for the UK.

Table 2.1 outlines different methods' abilities to deal with economic interdependencies and environmental analysis, time and space, and whether they can find optimal solutions.

Table 2.1. Comparison of some main characteristics of the main macroeconomic modelling methodologies.

	Economic interdependencies	Environmental flows	Optimality	Space	Time
Input-output (IO)	X				
Multiregional IO (MRIO)	X			X	
Econometric	X	X		X	X
Econometric IO	X	X		X	X
Econometric MRIO	X	X		X	X
Computable General Equilibrium (CGE)	X		X	X	*
Dynamic Stochastic General Equilibrium (DSGE)	X		X	X	X
Systems dynamics				X	X
Systems dynamics IO	X			X	X
Linear programming (LP)			X	X	X

IO LP	X		X		
Dynamic programming (DP)			X		X
IO DP	X		X		X

* mostly static, some dynamics

Table 2.1 shows that there are variety of methods available to assess changes in the macroeconomy and many of these can also be combined to cover a broader range of interactions simultaneously. It is important that a macroeconomic assessment tool allows for differences in economic sectors and economic regions, is dynamic i.e. allows the exploration of changes over time and forecasts future change. Based on this criterion, econometric multi-regional input-output models and multi-regional and multi-sectoral CGE/DSGE models seem to be the best candidates. However, these two types of models have substantial theoretical differences described in-detail below. It is possible to extend all the methods in the table to include environmental flows including the natural capital flows from ecosystem services even if the basic methodology is not designed to incorporate these directly. For instance, an environmentally-extended econometric input-output model is potentially capable of analysing 'what-if' scenarios in the context of limited provision of food in the economic sector 'agriculture'. Modelling approaches could be used in conjunction with a Multi-Criteria Decision Aid (MCDA), which would help with weighting trade-offs and synergies between the economic system and ecosystems. For partial cases, the application of a combination of the environmentally extended input-output and optimisation techniques could be useful to highlight the consequences of changing a particular ecosystem service, for example water cycling, everything else remaining constant.

It is important to understand the key assumptions made by the different methodologies and models and the consequences for results and interpretation. **Table 2.2** contains some more details of the two main model types: CGE (Computable General Equilibrium) and econometric input-output in terms of their key characteristics.

Table 2.2. Main characteristics of Computable General Equilibrium (CGE) and Econometric Input-Output models. Source: Based on West (1995).

	Computable General Equilibrium	**Econometric Input-Output**
Time	Static (some dynamics)	dynamic
Functions	non-linear	non-linear
Coefficients	fixed	variable
Supply constraints	supply and demand constraints	some, primarily demand driven
Price effects	full price adjustment	some
Equilibrium	general (prices and quantities)	disequilibrium or non-equilibrium
Optimisation	optimisation model	describes economy 'as it is' (non-optimisation)
Purpose	impact (and forecasting if dynamic)	impact and forecasting
Employment	mostly full employment	unemployment permitted
Income	wage and non-wage income	wage and non-wage income
Household expenditure	determined by utility maximization	determined by dynamic consumption function
Intermediate demands	determined by Leontief function	determined by Leontief function
Primary factor demands	determined by Constant Elasticity of Substitution, Cobb-Douglas function (cost minimisation)	determined by econometric functions

In addition to the characteristics listed in **Table 2.2**, CGE models embed theoretical assumptions about the existence of equilibrium, rational agents and perfect information. Lately more advanced CGE models, DSGE models, have been developed to relax one or more of these assumptions. For their part, econometric input-output models have been criticised for their reliance on past data and relationships when forecasting future changes in economic indicators. Systems analysis has been criticised because of the restrictions imposed by predefined assumptions on components, interactions and system boundaries. In any case it would be necessary to carry out additional preparatory work to extend the existing models to include both intermediate and final flows of natural capital from ecosystem services. It might be necessary to create or use a separate biophysical model and link it to a macroeconomic model.

Appendix 2.7.4 gives an overview of some macroeconomic models and shows their ability to capture various properties of environment-economy interactions, changes over time, economic structure and inclusion of the UK economy. Only one input-output database and one macroeconomic model include limited and simplified treatment of the flows from ecosystem services. There is also scope to complement existing macroeconomic models with methods that do not specifically deal with macroeconomic indicators but could be useful for building links between ecosystem services and macroeconomy or for comparing policies to manage ecosystem services (such as Cost-Benefit Analysis (see UK NEAFO, 2013, WP10) and Multi-Criteria Decision Aid). The sections below give an overview of the main methods – macroeconomic and other – that could be potentially useful for assessing the impacts of ecosystem service change on macroeconomy.

2.3.2 Material flows analysis

The main principle of material flow analysis (MFA) is that of a balance of physical inputs and outputs in the national economy (**Figure 2.8**).

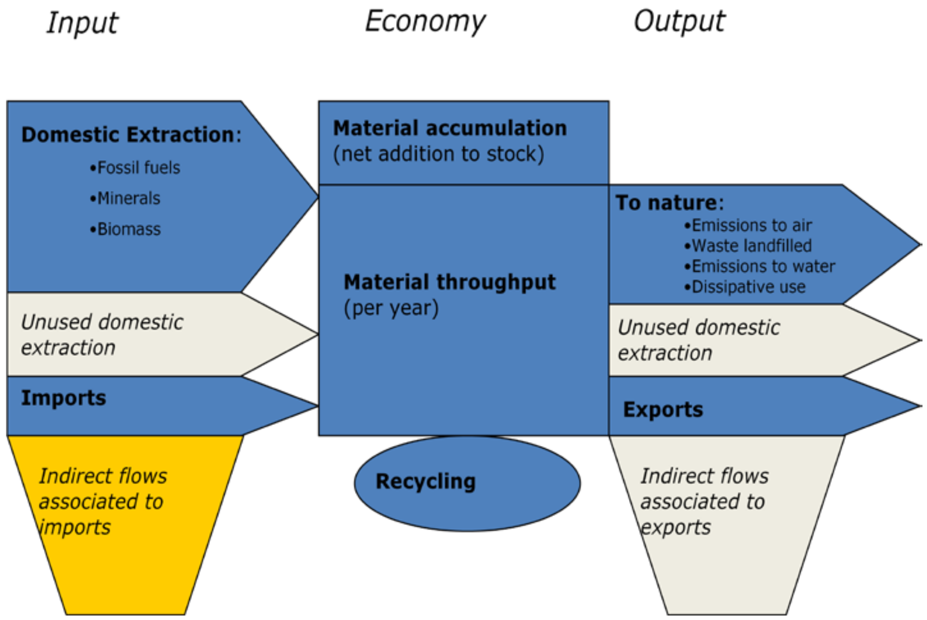


Figure 2.8. Material Flow Analysis. Source: Eurostat (2001).

In other words, MFA accounts for the mass of resources that are being extracted domestically and/or are imported then accumulated, processed or recycled in the national economy, and then emitted into the environment in the form of gaseous, liquid or solid residues or are exported. The additional element of MFA is that it accounts for the unused fraction associated with resource extraction such as the mount of overburden and soil that needs to be transferred to extract a resource.

It is necessary to consider the physical flows of material resources through the economy to understand the magnitude of ecosystem-economy interactions at the macro scale, both directly and indirectly through inter-sectoral linkages (Ayres, 1978; Ayres, 1998; Ayres and Kneese, 1969). Acquiring information on the flows is a necessary first step before any modelling can take place and material flows have been recently included in the international standard of economic-environmental accounting.

The UK Environmental Accounts currently include aggregate indices for several components of biomass, minerals and fossil fuels and are annually reported in the Blue Book (ONS, 2013b, Ch.13). For the analysis of ecosystem services and their role in the macroeconomy MFA could help to establish the physical magnitude of flows goods and services provided by ecosystem services, e.g. flows of biomass or water. To link these flows to macroeconomic analysis they have to be valued.

2.3.3 Input-output analysis

The main aim of input-output analysis is to describe internal processes that happen in the national economy and link the major aggregates – final demand, total output, and intermediary consumption (Miller and Blair, 2009; Leontief, 1936; Raa, 2005). Within the method an economic system is considered to be represented by a range of sectors – homogeneous types of economic activity (agriculture, industries, and service sectors). Each sector is represented by a vector of intermediary inputs – requirements of outputs of other sectors and exogenous resources such as, for example, water, materials and labour. The economic system is therefore represented by a matrix. Input-output analysis is often used for life cycle analysis in industrial ecology. It is a method that helps to explain structural economic change and cross-sectoral effects of policies. It can be used in conjunction with other methods, such as optimization, econometrics, multicriteria decision aid, and material flow analysis.

2.3.3.1 Environmentally extended input-output analysis

The first approaches to analyse economy-environment interactions with an input-output framework were proposed in Daly (1968), Ayres and Kneese (1969) where a formal mathematical framework for tracing residual flows in the economy was offered. Leontief built a conceptual link between the structure of the economy and the interdependent economic sectors and the environmental impacts of economic activity, namely atmospheric emissions (Leontief, 1970; Leontief 1974; Leontief 1977).

2.3.3.2 Multi-regional input-output analysis (MRIO)

Multi-regional input-output analysis is input-output analysis that covers more than one country/region and includes trade matrices (off-diagonal matrices) between all countries considered. The following provides brief descriptions for each main current MRIO database (in alphabetical order) and these summarised in **Table 2.3.**

Table 2.3. Overview of the main MRIO Databases. Source: Based on Tukker and Dietzenbacher (2013).

Database	Regions	Type	Detail (i x p)	Time	Extensions	Approach
EORA	World (around 150)	MR SUT/ IOT	Variable (50-500)	1990-2009	various	Create initial estimate; gather all data in original formats; formulate constraints; detect and judge inconsistencies; let routine calculate global MR SUT/IOT
EXIOBASE	World (43 + RoW)	MR SUT	129x129	1995-2010	30 emissions, 60 IEA energy carriers, water, land, 80 resources	Create SUTs; split use into domestic and imported use; detail and harmonize SUTs; use trade shares to estimate implicit exports; confront with exports in SUT; RAS out differences; add extensions
GTAP-MRIO	World (129)	MR IOT	57×57	1990, 1992, 1995, 1997, 2001, 2004, 2007	5 GHGs, Land use, energy volumes, migration	Harmonize trade; use IOTs to link trade sets; IOT balanced with trade and macroeconomic data
WIOD	World (40 + RoW)	MR SUT	35x59	1995-2009 annually	Detailed socio-economic and environmental satellite accounts	Harmonize SUTs; create bilateral trade database for goods and services; adopt import shares to split use into domestic and imported use; trade information for RoW is used to reconcile bilateral trade shares; add extensions

The University of Sydney develops the Eora database, a global MRIO time series database (Lenzen *et al.* 2012 and 2013). The researchers aim at the maximum possible level of detail with respect to countries, sectors, valuation margins and number of years. The Eora dataset distinguishes approximately 130 countries with about 100 sectors and 40 countries with about 200 (some up to 511) sectors, five types of taxes and distribution margins and includes forty-year time series data. Formats include both Supply and Use as well Symmetric Input-Output Tables; extensions comprise, for example, energy consumption, greenhouse gas (GHG) emissions, land use, ecological footprint, water and human appropriation of net primary productivity (HANPP). The main aims of Eora are timeliness, transparency, low cost, high country and sector detail.

The EU-funded EXIOBASE includes Supply and Use Tables (SUTs) with 130 sectors for 27 EU countries and 16 non-EU countries and a rest of the world region (Tukker *et al.* 2009). As the emphasis is on environmental applications, sectors of agriculture, energy, minerals, mining, etc. have been disaggregated and 309 environmental extensions (on materials, land, water, energy, emissions, external cost values etc.) have been compiled. Physical SUTs for 60 energy carriers have also been developed. The goal of EXIOBASE is to produce a "database for the public domain" (Tukker *et al.* 2009, p.1931).

GTAP 8 is the current version of the Global Analysis Trade Project database, covering 129 regions and 57 sectors (GTAP, 2013). GTAP does not yet include full trade matrices between all countries.

However, it can be converted to a full MRIO table, GTAP-MRIO, without the need for additional balancing (Peters *et al.* 2011) and it is the database with which most environmental MRIO analyses have been carried out so far (Tukker and Dietzenbacher, 2013). The format is SIOT with 57 commodities. Extensions include GHG emissions, energy volumes, land use and others. GTAP's compilation approach relies more on trade data with established reliability to which IO data are matched (rather than matching trade data to IO data as is the case in most other MRIO projects).

The World Input-Output Database project (WIOD) from the University of Groningen (Timmer, 2012) aims at creating a time series of SUTs and SIOTs from 1995 to 2006 for 27 EU countries and 13 other major countries, 35 industries and 59 product sectors. The emphasis is on economic analyses. The satellite accounts include value added generation (compensation for high-skilled, medium-skilled and low skilled labour, ICT (information and communication technologies) capital goods and non-ICT capital goods), but also GHGs, pollutants and energy use). All tables are in line with National Accounts statistics and are based on publicly available, official data.

For the purposes of the analysis of ecosystem services and their interaction with the macroeconomy, environmentally extended input-output analysis is the essential constituent part. The large multi-regional databases could prove beneficial when tracking international impacts associated with trade. The major shortcoming of these stems from the fact that most of them are static, i.e. do not take the inter-temporal connections into account. This could be overcome by building dynamic econometric input-output models, e.g. E3MG (Barker et al. 2012) or CGE models e.g. EXIOMOD (2013) or using the databases for creating new models based on systems dynamics principles. The less costly way forward seems to be to extend the existing models with additional flows or additional modules associated with the performance of ecosystems. Eora database (Lenzen *et al.* 2012 and 2013) seems to be one of the best and most detailed global datasets to help answer important questions on ecosystem-economy interrelationships, and has already been used to demonstrate the threats biodiversity from global consumption (see, for example, Lenzen *et al.* 2012).

2.3.4 Optimization

Optimization or operations research (Taha, 2011) is a large array of tools aimed at helping to solve one the central problems of economics: allocating limited resources under constraints. The main principle of a linear program is minimization or maximisation of a linear function on a set constrained by equations and inequalities. The linear programming has been applied, for example, in economic planning, transport, and production scheduling. Later additional forms emerged, including mixed-integer programming, more suited for real life capacity planning and industrial applications. Multi-criteria programming addresses the situations where several criteria are needed to be taken into account. Dynamic programming addresses the situations where inter-temporal linkages are important and decisions made earlier could affect opportunities or results in the future periods. Optimisation can be combined with other methods, for example with input-output modelling. In relation to the study of ecosystem services and their role for the macroeconomy, linear programming could prove useful in illustrating the role of, for example, water in the economy but could become problematic at a larger scale because of the multiplicity of the ecosystem services (e.g. water, food, biomass, aesthetic values). Linear programming is much more suitable for well-defined industrial or management single-criterion problems. For the complex analysis of ecosystem services in macroeconomic development the apparatus of multi-criteria optimization might be a more suitable approach.

2.3.5 Econometric modelling

The main principle of econometric modelling is in determining the functional form of a relationship or a set or relationships that exist between two or several variables. The two main types of datasets used for econometric analysis are: cross-sectional, where data are collected by observing many subjects at the same point in time, and time series where data are collected from the same subjects over a period of time. Although econometric models are reasonably good at explaining past trends, they often fail to predict non-linear emergent change, which is more adequately captured by non-linear dynamics models. Econometrics is used to test empirically and reformulate economic theories, especially in macroeconomics.

2.3.5.1 Tinbergen model

The first macroeconomic model using econometrics was created by Jan Tinbergen for the Netherlands (Tinbergen, 1936), who later applied this technique in creating a model for the USA and the UK. The original model had 24 equations and was used to perform scenario-based policy modelling in the 1930s at the time of economic crisis (Dhaene and Barten, 1989). One of the conclusions achieved with the help of a Tinbergen model was a 20% devaluation of the Dutch guilder as a remedy for the recession.

2.3.5.2 Econometric Input-Output Modelling

Econometric input-output models represent a combination of the macro-econometric modeling tradition of Tinbergen, where relationships between economic variables over time are modeled empirically, and the input-output structural analysis of Leontief that describes the economy as a matrix of interrelated sectors. Econometric input-output models reject perfect rationality of economic agents and a profit-maximization hypothesis and model the economy on an 'as is' basis. Econometric input-output models are sometimes criticized because the presumption of bounded rationality is considered to lead to modelling assumptions that are ad-hoc. It is argued that there is more generality in the interdependency between volumes and prices presented by an econometric input-output model than in the neoclassical approaches used in CGE models, because it is not necessary to base the analysis on the restrictive assumptions of general equilibrium (Barker, 1996). In econometric input-output models, the rejection of a closed modelling concept is compensated by the emphasis on the empirical data base. Selten (1991) came to the conclusion that it is better to use empirically tested ad-hoc assumptions than unrealistic principles of high generality and elegance. The agents follow empirically-tested routines in the econometric input-output models (Nelson and Winter, 1982). So for example instead of equilibrium prices, a cost based, mark-up hypothesis is used.

It should be clarified that the inability to tackle novelty and emergent effects characteristic of econometric models is inherited by econometric input-output models, which are more suited to projecting past development patterns into the future. Many of these models have already been environmentally extended to include material use, waste, atmospheric emissions and land use. However these developments are still very preliminary and often limited to one or another link between the economic system and environment. Currently econometric input-output models do not include the important economy-environment feedback loops, i.e. such models cannot adequately pick up the impact on the economy from economic growth depleting a natural asset with the subsequent reduction in benefits which that entails.

2.3.5.3 Global Economic Model (Oxford Economics)

The Oxford Economics Macro Model is a 16 sector quarterly international econometric model, which could be used to examine how economies react to a changing economic environment, to perform scenario analysis and produce macroeconomic forecasts with a 25-year horizon (Oxford Economics, 2013). The model includes coverage of 45 countries with varying detail, and has a sectorally disaggregated component, breaking down economic information into 100 sectors. The country models for the G8 economies typically are described in terms of 300 variables, while others have over 100 variables. The model includes detailed coverage of GDP and its determinants: household income and spending; company finances and business investment; trade and the balance of payments; wages, productivity and competitiveness; consumer and producer prices; monetary policy; equity prices and bond markets; the labour market and demographics; and government finances. The linked models for 34 additional countries, assisting in modelling international effects on the main UK macroeconomic model, cover GDP, inflation, exchange rates and the current account. The model lacks the sectoral disaggregation and treatment of resource or environmental flows to support modelling ecosystems services and their importance for the macroeconomy.

2.3.5.4 INFORGE and PANTA RHEI (GWS)

INFORGE is a model of the German economy (GWS, 2013). The model takes into account the input-output structures, income creation and distribution in different sectors, and global interactions (**Figure 2.9**). It describes each sector in terms of inter-industry relations, its role in the macroeconomic process as well as its integration into international trade.

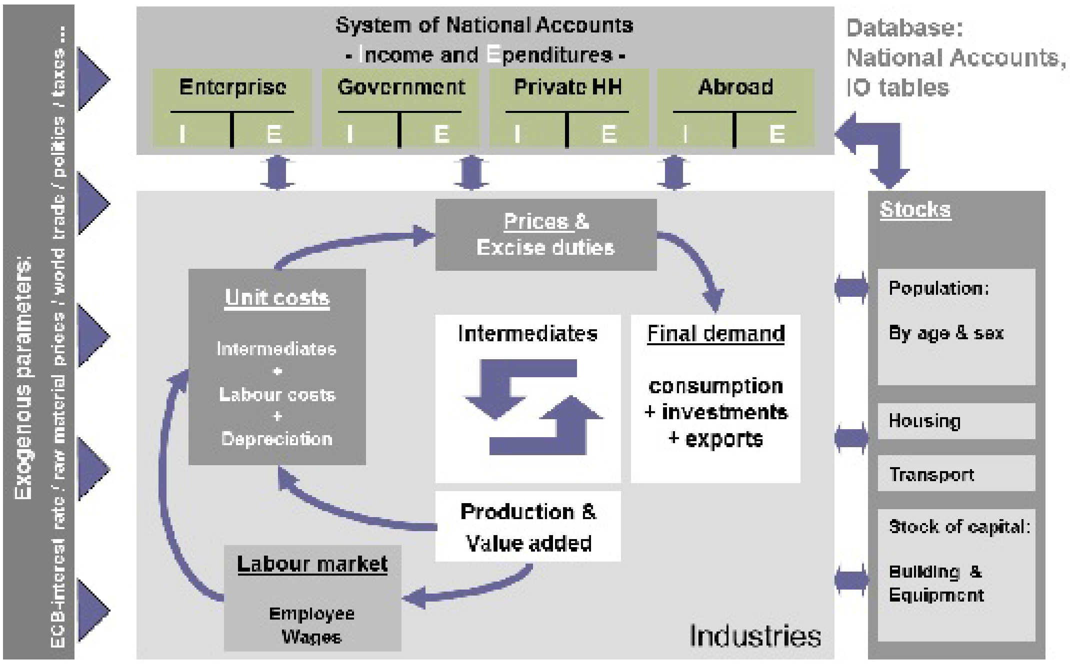


Figure 2.9. The structure of the INFORGE model. Source: GWS (2013).

Over 30,000 equations are used in INFORGE to describe the inter-industry flows between the 59 sectors, their deliveries to personal consumption, government, equipment investment, construction, inventory investment exports as well as prices, wages, output, imports, employment, labour compensation, profits, taxes for each sector as well as for the macroeconomy. In addition the model describes income redistribution in detail. The model frequency is annual and it allows for forecasting up to 2050. The model has a high degree of endogenisation. Exogenously given factors include some tax rates, labour supply and world market variables.

PANTA RHEI (Lutz, 2013) is an environmentally extended version of the macro-econometric simulation and forecasting model INFORGE of the German economy. It is based on official statistics and uses a 59 sector disaggregation, the System of Economic and Environmental Accounts (SEEA) data, energy balances (AG Energiebilanzen) and emission reporting data for UNFCCC. PANTA RHEI is equipped with a disaggregated energy and air pollution model, which distinguishes 29 energy carriers and their inputs in 59 production sectors and households as well as 8 air pollutants and their relations to 29 energy carriers. The current version of PANTA RHEI has been extended to include biotic and abiotic material inputs and land erosion (**Figure 2.10**). Hence, the total direct material requirement of the 59 production sectors and the indirect imported material requirement is described (Bockermann *et al.* 2005).

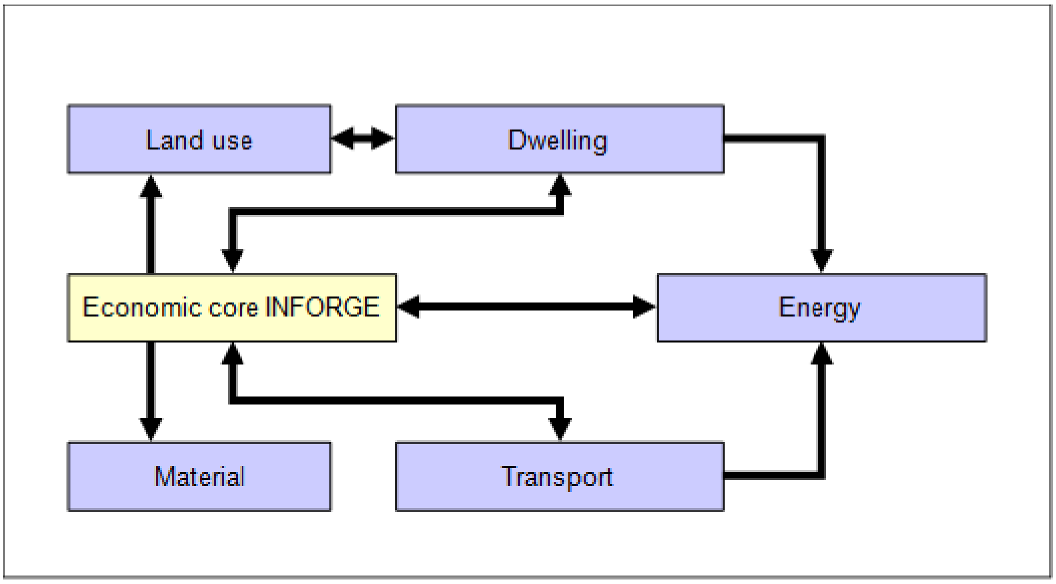


Figure 2.10. The structure of the PANTA RHEI model. Source: Lutz (2013). © Inderscience Publishers

Besides the comprehensive economic modelling, energy and related air emissions, transport, dwelling, material and land use are depicted in detail. All parts are consistently linked via volumes and prices. The model is solved fully interdependently as a single block, i.e. effects of a measure on all model parameters are depicted simultaneously and the model runs annually up to 2050. PANTA RHEI provides a useful reference point for modelling of macroeconomic and selected environmental interactions at the national scale. However, it has mainly to date focussed on abiotic relationships concerning material and energy flows and associated emissions. It not as yet been extended to incorporate ecosystem services.

2.3.5.5 GINFORS (GWS)

The GINFORS model (Lutz *et al.* 2010) has been developed to address questions of global environmental policy, such as climate change and global resource use. GINFORS is an economy–energy–environment model with global coverage, disaggregating 54 countries, including UK, and two world regions (Giljum et al. 2008). GINFORS is based on a time series of international statistical data. Behavioural parameters are derived from econometric estimations assuming bounded rationality of agents adopting myopic foresight. It covers 26 commodities and 48 economic sectors (**Figure 2.11**). It incorporates material input models in physical (mass) units. For this task, the first global database on the domestic extraction of natural resources was compiled, covering 188 countries and comprises over 400 types of materials including fossil fuels, metals and biomass, which presents a good starting point for modelling economy-environment interactions.

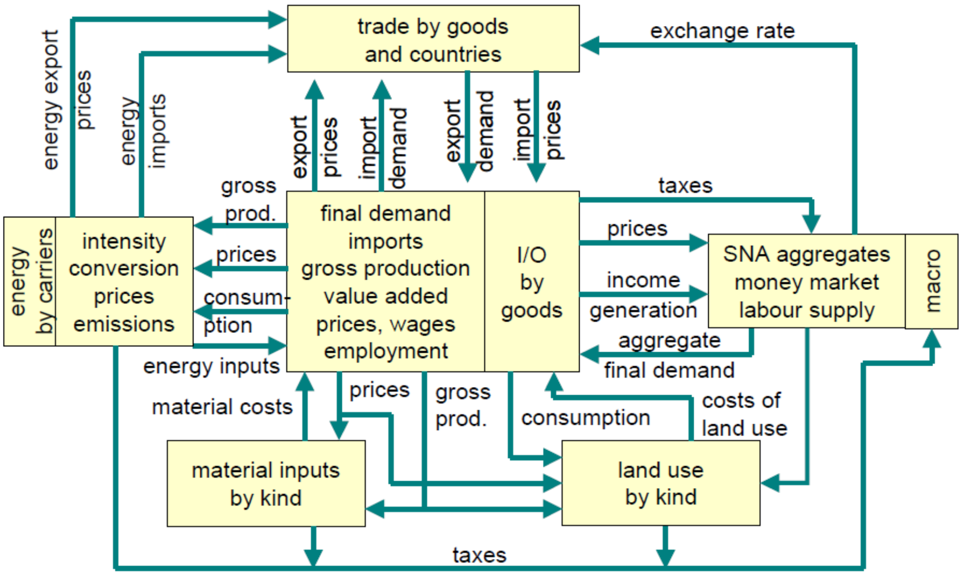


Figure 2.11. The internal structure of the GINFORS country models. Source: Lutz *et al.* (2010).

The GINFORS model has been applied to model scenarios for sustainable resource use in Europe (Giljum *et al.* 2008) and mitigating risks for biodiversity (Spangenberg *et al.* 2012; Stocker *et al.* 2012), which signifies its advantages and additional experience in detailed modelling of resource flows and biodiversity impacts. For the purposes of the analysis of ecosystem services and the macroeconomy, this model might be a good candidate. However, the model lacks sufficient sectoral disaggregation, the biophysical ecosystems module is insufficiently developed to conduct some non-linear forward looking scenario analysis.

2.3.5.6 MDM-E3 (Cambridge Econometrics)

In the UK, the largest and most influential macroeconomic model historically was that of the Cambridge Growth Project. This model later evolved into the Cambridge Multisectoral Dynamic Model of the British Economy, MDM (Barker and Peterson, 1987; Stone, 1984). MDM combines the analysis of input-output structural relationships with the econometric analysis of dynamic economic trends. The current environmentally extended version of the model MDM-E3 is capable of assessing the amount of CO_2 emissions produced by the UK sectors. There is a substantial degree of disaggregation in the model with the specification of 86 economic sectors, 11 fuel types, 25 fuel users (including Agriculture), and 14 types of air emissions (including the six greenhouse gases). The model has been used in a variety of applications, e.g. in the analysis of the Green Fiscal Reform scenarios for the UK (GFC, 2009). The MDM E3 would need to be extended to include environmental resources and ecosystem service goods. Additionally, the weakness of the existing econometric models comes from the fact that they are reasonably good at explaining past trends, but often fail to predict non-linear emergent change, which is more effectively captured by non-linear dynamics models.

2.3.5.7 E3MG (Cambridge Econometrics)

E3MG (Barker *et al.* 2012) is a similar model to MDM-E3 operating at the global level. E3MG produces annual forecasts to the year 2050 and includes a set of fully endogenous technology progress indicators. E3MG provides a highly disaggregated breakdown of economic activity and energy use, based around the following model classifications:

- 21 world regions, including explicit treatment of the US, Japan, India, China, Mexico, Brazil, Russia, Indonesia and the four largest EU economies including the UK;
- 43 industrial sectors based on the NACE classification, including 16 service sectors and disaggregation of the energy sectors;
- 28 consumer spending categories;
- 12 different fuel types; and
- 22 separate fuel user groups;
- 14 atmospheric emissions.

E3MG has less detailed coverage of the UK economy, but allows more detailed analysis of interactions between the UK and its main trade partners. This and the MDM-E3 model have the potential to support ecosystems- macroeconomy interactions with particular reference to energy provision and use, and associated environmental effects, but also could be linked with sector-specific models, because of their high level of sectoral disaggregation.

2.3.6 Multi-Criteria Decision Aid

The method of Multi-Criteria Decision Aid (MCDA) emerged in response to the need to deal with many criteria when justifying expenditure on large infrastructure projects and management consultancy tasks (Roy and Vincke, 1981; Roy, 1985; Roy, 1991; Roy, 1996). At the macro scale the MCDA techniques have been employed to assess macroeconomic sustainability trends and illustrate trade-offs between economic, social and ecological dimensions (e.g. Shmelev and Rodriguez-Labajos, 2009). MCDA is used to compare the alternatives courses of actions (scenarios). A set of criteria are used to assess the performance of and prioritise these actions. Currently there are dozens of MCDA methods available in the form of standalone software packages or libraries of tools. For the subject of ecosystem services and their role in the macroeconomy MCDA could be useful given the multiple dimensions (ecological, economic and social) of ecosystems and the multiplicity of ecosystem services (Shmelev 2012, Chapter 9).

2.3.7 Computable general equilibrium models

Computable General Equilibrium (CGE) models form currently the largest and most widely used group of macroeconomic assessment models. The CGE theoretical framework draws on a combination of Walrasian general equilibrium theory, neo-classical micro-economic optimisation behaviour of rational economic agents, and some macroeconomic elements that attempt to explain economic, and more recently, social and environmental phenomena (Grassini, 2005; Scrieciu, 2005). Such models are used by international organizations (such as IMF, World Bank) and national governments to make decisions on macroeconomic policy. Lately more advanced CGE models, Dynamic Stochastic General Equilibrium (DSGE) models, have been developed to relax one or more of these assumptions. DSGE models are a group of applied General Equilibrium Models that have a dynamic component that assesses how the economy evolves over time and a stochastic component that assesses the effects of random shocks on the economy, such as fluctuations in oil prices.

The critique of CGE approaches and the general equilibrium idea can be summarized by the following major points (Ackerman, 2004) :

- ***Rationality of economic agents***. It has been argued that that the rational maximization hypothesis on which these models are based is not an adequate description of reality. It is argued that bounded rationality provides a better explanation of how humans think and make decisions (Tversky and Kahneman, 1974; Tversky and Kahneman, 1981). Furthermore Vatn (2012) showed that humans often act collaboratively to enhance their joint welfare, especially in the context of resource use, and lead to successful outcomes.

- ***Perfect competition***. CGE is built on classical general equilibrium assumptions that perfect competition prevails in markets, that resources are fully employed and factors of production are fully mobile, that there is complete information about all prices now and in the future, and that economic agents implicitly have unlimited computational abilities (Scrieciu, 2005).
- ***Unstable and multiple solutions***. General equilibrium theory mathematically yields unstable and multiple solutions (Barker, 2004). Stable solutions are observed only under very restrictive assumptions about aggregation (Ackerman, 2002).
- ***Time dimension***. Treatment of time in CGE models is extremely limited, they are essentially 'atemporal' (Barker, 2004). Barker (2004) points out the difficulties in selecting the base year for calibrating CGE models (the year with the most stable economic structure in the absence of shocks or the most recent year), and the interpretation of their long-term solution (to be attained in two years or ten years time).
- ***Model calibration***. The CGE modeling approach does not require estimation of functional forms; but simply model calibration by picking up parameter-values from data banks which in turn are made up with information collected from the economic literature (Grassini, 2005). Calibration procedures and the optimisation postulate force the CGE modeller to deduce, for example, the demand functions from the analytical form of the utility functions. This implies that with the same data and with the same set of parameters different functional forms can produce different predicted policy outcomes (McKitrick, 1998).
- ***Treatment of long-term adjustment processes***. CGE modellers usually ignore time series data available for the world economy, resource use and energy consumption often using data for one year only for long-term projections (Grassini, 2005).
- ***Treatment of disequilibrium***. CGE models are not capable of modelling a transition to sustainability, which is essentially a dynamic disequilibrium process of transitional change (Barker, 2004). In other words, CGE models do not consider what happens outside the equilibrium (Grassini, 2005).
- ***Unfalsifiability***. The practice of constructing benchmark data for CGE models means that no testing against data is possible, because inconvenient observations, e.g. high supernormal profits suggesting lack of competition are simply redefined to fit the theory (Grassini, 2003). Many CGE models cannot therefore be falsified, because they are forced to fit the data perfectly.
- ***Relative prices***. In the general equilibrium framework (Grassini, 2005), there is a unit, named numeraire, used to express all the other unit values in the model. The presence of a numeraire implies that in CGE only relative, rather than absolute, prices matter. However, relative prices are not observable.

There are a number of existing CGE models, some of which are discussed below.

2.3.7.1 Global Trade Analysis Project (GTAP)–CGE (Purdue University)

The standard GTAP-CGE Model (Hertel et al. 2007) is a multiregion, multisector, computable general equilibrium (CGE) model, with perfect competition and constant returns to scale. The UK is represented in the model by a 54 sector input-output table based on Eurostat data. CO_2-emissions are built into the model database (currently v.8). Innovative aspects of this model include: the treatment of private household preferences; the explicit treatment of international trade and transport margins; a global banking sector which links global savings and consumption. Based on neoclassical economic theory, Cobb-Douglas production functions, utility functions and an assumption that markets are in equilibrium, the GTAP-CGE model includes several accounting relationships covering for example: distribution of sales to regional markets; sources of purchases by households and firms, regional incomes and major global sectors. It also includes equations covering the behaviour of firms and households, factor mobility, investment and capital formation and global transportation.

The GTAP-CGE Model gives users a wide range of target options, including unemployment, tax revenue replacement and fixed trade balance closures, and a selection of partial equilibrium options. For the purposes of the ecosystem services analysis in relation to the macroeconomy, the GTAP-CGE presents a useful database of trade (GTAP) with almost global coverage, however the general criticisms of CGE modelling referred to earlier applies in this case.

2.3.7.2 Global Income Distribution Dynamics (GIDD) Model (World Bank}

The World Bank Development Economics Department (DEC) has developed the Global Income Distribution Dynamics (GIDD) Model (Bussolo *et al.* 2010). This is a one-sector global CGE-microsimulation model aiming to measure the effects of economic policies on poverty and on the distribution of welfare among individuals and households. The GIDD model takes into account the macro nature of growth and of economic policies and adds a microeconomic—that is, a household and individual—dimension to it.

The GIDD includes within- and between-country distributional data on economic activity for 121 countries including the UK and covers 90 percent of the world population. It can be used to assess growth and distribution effects of global policies such as multilateral trade liberalization, policies dealing with international migration and climate change. The GIDD also allows the analysis of the impacts on global income distribution from different global growth scenarios and distinguishes changes due to shifts in average income between countries from changes attributable to widening disparities within countries. For the purposes of modelling the ecosystem services interaction with the macroeconomy this CGE approach seems to be insufficiently disaggregated to enable the integration of ecosystem services and the effects of policies on the macroeconomy.

2.3.7.3 Global LINKAGE Model (World Bank)

The LINKAGE model (World Bank, 2011) is a global dynamic computable general equilibrium (CGE) model maintained by the World Bank to support global trade policy analysis, for example in the current context of the multilateral trade negotiations under the auspices of the Doha Development Agenda (WTO, 2013). It is based on global social accounting matrix (SAM) composed of 87 regions/countries (of which 69 are individual countries including the UK) and 57 economic sectors. Bilateral trade is fully accounted for and includes estimates of export taxes/subsidies, international trade and transport margins, and bilateral import tariffs that incorporate preferences. It features three main production archetypes—crops, livestock, and 'other', and a full range of tax instruments, price mark-ups, multiple labour skills, vintage capital, and energy as an input combined with capital. The database is a product of the Global Trade Analysis Project (GTAP, 2013). The model captures population and labour dynamics, the role of savings and investment on capital accumulation and productivity. The model has been used in the World Bank's Global Economic Prospects reports, World Bank policy papers and external publications (*e.g.* van der Mensbrugghe, 2006; *Anderson et al.* 2009). It has been criticized by (Taylor and von Arnim, 2006) for making implausible assumptions about a range of market and production elasticities.

2.3.7.4 ENVISAGE (World Bank)

The World Bank's Environmental Impact and Sustainability Applied General Equilibrium (ENVISAGE) Model (van der Mensbrugghe 2008) is designed to analyse a variety of issues related to the economics of climate change:

- baseline emissions of CO_2 and other greenhouse gases;
- impacts of climate change on the economy;
- adaptation by economic agents to climate change;
- greenhouse gas mitigation policies—taxes, caps and trade;
- the role of land use in future emissions and mitigation;
- the distributional consequences of climate change impacts, adaptation and mitigation—at both the national and household level.

ENVISAGE is intended to be flexible in use. The core data, that includes energy volumes and CO_2 emissions, are from the GTAP (2013) database. The latter divides the world into 113 countries and regions (including the UK), of which 95 are countries and the others region-based aggregations. The database divides global production into 57 sectors—with extensive details for agriculture and food and energy disaggregated into coal mining, crude oil production, natural gas production, refined oil, electricity, and distributed natural gas.

2.3.7.5 GEM (IMF)

The Global Economic Model (GEM) is an example of a large international dynamic, stochastic, general equilibrium (DSGE) model built using recent economic research. It is a quarterly model that runs over 10-year time horizon and is based on an explicit microeconomic framework in which consumers maximize utility and producers maximise profits (Pesenti, 2008; Bayoumi and International Monetary Fund, 2004). In particular, the integration of domestic supply, demand, trade, and international asset markets in a single theoretical structure allows transmission mechanisms to be fully articulated. The model comprises firms that produce goods, households that consume and provide labour and capital to firms, and a government that taxes and spends (Laxton and Pesenti, 2003). The microeconomic structure of GEM uses functional forms that allow firms and consumers to be aggregated as if they were a single entity. GEM aims to provide an optimising inter-temporal framework capable of addressing basic policy questions involving international transmission of policy and structural shocks, while reproducing key elements of macroeconomic interdependence among countries and regional blocs. Like other recent DSGE models, the design of GEM combines the long-run properties of real business cycle models with short-run ''Keynesian'' dynamics. It attempts to incorporate realistic dynamics, recognising long run effects and consumption and production do not immediately jump to a new long-term equilibrium.
Similar models to GEM have been developed by the US Federal Reserve Board (Erceg *et al*. 2003), and are areas of active research in several other institutions (such as the central banks of Canada, Finland, Italy, Norway, Spain, and the United Kingdom). They are being considered in some emerging market countries, such as by the central banks in Brazil, Chile, and the Czech Republic. The European Central Bank (ECB) has developed a single-country model (New Area-Wide Model, NAWM), (ECB, 2008) and is developing a multi-country extension (Euro Area and Global Economy, EAGLE model.

2.3.7.6 EXIOMOD (TNO)

EXIOMOD is an environmentally extended dynamic CGE model developed by TNO (EXIOMOD, 2013). The model incorporates the representation of 43 main countries of the world, including EU27 countries and candidate member states as well as the largest emitters such as US, Japan, Russia, Brazil, India and China. The EXIOMOD model is a dynamic, recursive over time, model, involving dynamics of capital accumulation and technology progress, stock and flow relationships and adaptive expectations. It is a synthetic approach in a way that all behavioural equations are econometrically estimated. EXIOMOD combines economic, environmental and social domains in an efficient and flexible way:

1. Social effects: includes the representation of three education levels, ten occupation types and households grouped into five income classes. One can trace the effects of specific policy on income redistribution and unemployment.
2. Economic effects: the model captures both direct and indirect (wide-economic and rebound) effects of policy measures. EXIOMOD allows for calculation of detailed sectoral impacts at the level of 129 economic sectors.
3. Environmental effects: the model includes representation of 28 types GHG and non-GHG emissions, different types of waste, land use (15 types) and use of material resources (171 types).

However, EXOMOD does not incorporate a detailed physical model of flows from ecosystems, but could be extended for this purpose.

2.3.8 Systems dynamics

A systems dynamics approach is designed to help understand dynamic systems over time (Forrester, 1999). The method rests on creating temporal relationships between variables to simulate the dynamics of interaction of several subsystems, based on feedback loops. The main strengths of the method are that it allows non-linearity, tipping points, bifurcation, and chaos to be dealt with. It is helpful in understanding the behaviour of complex adaptive systems, especially the interaction between ecosystems and the economy. Systems dynamics methodology was the main philosophy of the Limits to Growth project at MIT (Meadows, D. and Club of Rome, 1972). In the project the importance of three factors has been acknowledged: population change, availability of resources and environmental pollution. Failure to control for all these three dimensions of the global system leads to a global collapse.

Systems dynamics has been one of the main analytical tools in ecological models such as the 'Daisyworld' model (Lovelock, 1992), where biological diversity is identified as a key explanatory factor for stable climatic conditions on the planet. For the purposes of ecosystem-economy analysis, systems dynamics could prove very useful in assessing potential future development alternatives and its ability to capture non-linear emergent behaviours such as regime changes, chaotic fluctuations and shifts.

2.3.8.1 Threshold 21 (Millennium Institute)

The Threshold 21 model (Millennium Institute, 2013) represents the systems dynamic thinking underpinning the UNEP Green Economy report. The model links economic, environmental and social elements by means of feed-back loops. The economy is represented by three sectors (agriculture, industry and services) characterised by Cobb-Douglas production functions with inputs of labour, resources, capital and technology. A Social Accounting Matrix (SAM) is used to balance supply and demand in each sector. Relative prices are calculated to provide the basis for allocating investment. The social sphere in the model is represented by detailed population dynamics coupled with education and health challenges. The environment module tracks non-renewable and renewable resources, and assesses air and water pollution, GHG emissions, soil erosion, water degradation and forest depletion. This seems to be a promising way forward although lack of detailed sectoral disaggregation, not enough detail in the macroeconomic core and a limiting treatment of dynamics of production with a Cobb-Douglas function (see, for example, Felipe and McCombie, 2013 for criticism) are clearly major shortcomings.

2.4 Ecosystem services contribution to the macroeconomy in the literature

A systematic literature review was conducted by using a multi-stage procedure to identify and select articles, reports and books for review and inclusion in a database. The principle criterion was the coverage of the interaction of the environment (including ecosystems) with economic systems and sectors. Information sources were also screened for the use of methods for modelling and analysis, such as, for example, input-output analysis and material flows analysis. Over three hundred articles, books and reports were collected and examined, and papers with a macroeconomic focus and that could potentially inform future assessments of macroeconomic impacts of ecosystem service change or management are summarised below. These papers are presented using the UK NEA (2011b, Ch.2) classification of goods that are provided by final ecosystem services and the classification of intermediate services where appropriate. The search was carried out mainly using the SCOPUS database using a combined search with keywords (see Appendix 2.3) referring to different ecosystems services, analytical methods, and themes such as valuation, assessment, and impact. The grey literature (literature other than peer-reviewed articles in academic journals, such as consultancy reports, reviews) was covered through targeted search for publications produced by or for UNEP, IUCN, Defra, WRI, EEA, JRC or similar organizations, including international NGOs and agencies and also provided by stakeholders.

2.4.1 Provisioning ecosystem services

2.4.1.1 Crops, livestock, fish

The final ecosystem service ‘crops, livestock, fish’ provides ecosystem goods such as food and animal feed. Food is fundamental for human survival and is created and administered by a whole range of economic sectors, from agriculture to food processing, wholesale and retail sector to hotels, restaurants and social services. It is important therefore to understand how this ecosystem service is used by the economic system and transformed through the chain of sectoral linkages. Agriculture employs over 1.3 billion people throughout the world, or close to 40% of the global workforce (FAO, 2013). In recent years, there has been growing concern about the pressures on the global food system associated with population growth, economic development, changing lifestyles and diets, environmental degradation and climate change and the consequences for sustainability and equity (Foresight, 2011; IAASTD, 2009).

While agriculture (that is farming) in the UK accounted in 2011 for only 0.7% of national GDP and 1.2% of employment, it occupies about 70% of the land area. According to ONS (2013a), the gross value of UK agriculture in 2012 was £24 billion (35% crops, 56% livestock, 9% other) and gross value added at £8.6 billion. A further £3.2 billion per year is committed to agri-environment schemes and income support to farms that also require maintenance of land and environmental assets.

The strategic importance of the sector, and the extent to which it receives support from Government, warrants a special annual report on the sector (ONS, 2013a) that, amongst other things, reviews the contribution of agriculture and related industries to the national economy. Agriculture in the UK is also monitored in a sample annual census of farms covering land use (Defra, 2013a), annual farm business surveys (FBS, 2012), and specific surveys that monitor the implementation of agri-environment schemes (Natural England, 2009). From an ecosystems perspective, agriculture in the UK was considered in the UK NEA under the category of ‘enclosed farmland’ (UK NEA, 2011b).

Of particular interest here, a set of Environmental Accounts for Agriculture (Defra, 2010a; Jacobs *et al.* 2008), gives some, albeit incomplete, estimates of the positive and negative environmental externalities associated with agricultural land use (**Table 2.4**). In 2007, the environmental accounts for UK agriculture estimated a net cost of about £830 million per year (equivalent to £14 per head of population and about 15% of agriculture's GVA at the time). Gross annual environmental benefits were about £1.74 billion (about £29 per head), mainly associated with agriculturally managed landscapes and habitats. This probably underestimates the real value of managed landscapes, especially for tourism and recreation. The impact of the travel restrictions on tourism and the rural economy due to the 2001 Foot and Mouth epidemic, for example, was estimated at £5 billion (NAO, 2002). Thus, there is a relatively rich data resource that, together with considerable experience in land use farming systems research (as discussed below), could support mapping and modelling of key ecosystem and macroeconomy interrelationships.

Table 2.4. Summary of environmental accounts for UK agriculture in 2007. Source: Jacobs *et al.* (2008).

	Externality	**Annual flow (£ million)**
Benefits	Landscape	616
	Biodiversity	1,088
	Waste services	37
	Total	**1,741**
Costs excluding emissions to air	Flooding	244
	Fresh water	144
	Drinking water	160
	Soil erosion	11
	Waste	7
	Sub-total	**566**
	Net benefits excluding emissions to air	***1,175***
Costs from emissions to air	Climate change	1,371
	Air quality	634
	Total emissions to air	**2,005**
	Total benefits less costs	*-829*

As previously noted, the contribution to the UK economy of the agri-food sector is considerably greater than that of farming alone. At £96 billion annually, the total agri-food chain, including processing, distribution and retailing, is equivalent to 7.4% of national Gross Value Added (GVA) and 14% of total employment (Defra, 2013c). It is important, therefore, to trace the value of food products through the entire food chain. Food manufacturing, retailing and non-residential catering each account for about 25% of total agricultural GVA (**Figure 2.12**). It is important, therefore, to trace the value of food products through the entire food chain. It is noted that UK agriculture itself is a major player, contributing over 65% of total raw food into the food chain (Defra, 2010b).

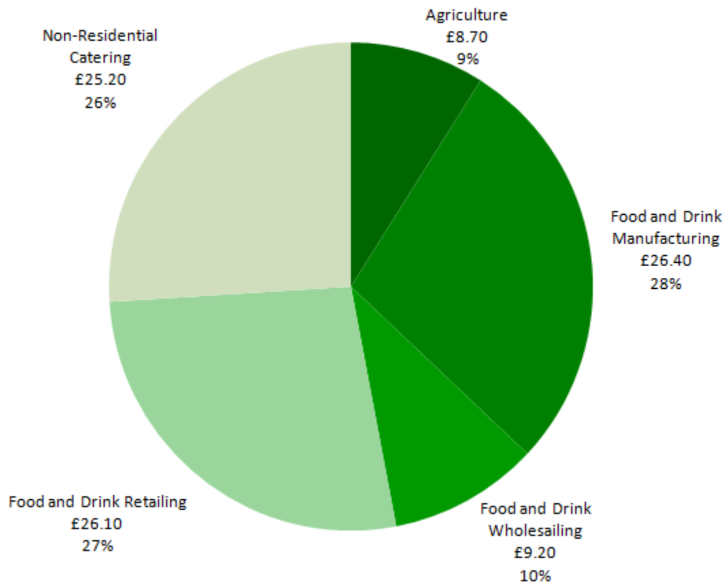


Figure 2.12. The Contribution of the agri-food sector to the UK economy in 2011 (£ billion). Source: Defra (2013d, Figure 14.1).

Given the dominant place of agriculture in the landscape and its importance in rural economies, numerous attempts, using a range of modelling and scenario methods, have been made to assess the impact on land use, farming livelihoods, and the environment of changes in markets, policies, technology and climate (Hanley *et al.* 2012; Harrison *et al.* 2012; Reed *et al.* 2009; Eickhout *et al.* 2007; Busch, 2006; Miejl *et al.,* 2006; Verburg *et al.* 2006; Ewert *et al.,* 2005; Holman *et al.,* 2005; Morris *et al.* 2005.; Rounsevell *et al.* 2005). Most studies operate either at the farm, agricultural sector or regional scales with an emphasis on the agricultural economy, employment, incomes and in some cases international trade. For the most part, formal macroeconomic analysis has not been a major focus. The underlying data sets and methodologies, however, indicate a capability to support this.

The macro importance of the agricultural production is also apparent in international assessments. For example, in 2009 in California (University of California, 2012), the combined direct and indirect effects of the entire food chain accounted for 6.7% of employment and 1.3% of the state's gross product. However, these numbers do not separate the contribution of final ecosystem goods from other inputs.

The UK NEA reviewed the importance of 'enclosed farmland' for food production, 'the provision of landscape, recreation and other cultural benefits'. In parallel with UK NEA, an integrated spatially disaggregated dynamic model has been developed to consider the impact of changes in markets, policies and climate on agricultural land use, agricultural production and incomes, and other ecosystem services for the UK (UK NEA, 2011b, Ch. 22). The approach has the potential to support modelling of the marginal effects on key macroeconomic indicators, namely GVA, employment and incomes, associated with policies to promote particular agricultural or ecosystem outcomes.

The relationship between farming, food and environment has been studied using Life Cycle Assessment techniques, often modelling scenarios to estimate agricultural production, employment and trade effects (Audsley *et al.* 2009; Williams *et al.* 2010). Williams *et al.* (2010), for example, reviewed the environmental burdens of major agricultural commodities and considered options for alternative sourcing, whether domestic or international. The livestock sector was given particular attention due to complex environment-economy relationships. Graves *et al.* (2011) considered possible future environmental and economic outcomes (production, incomes and employment) associated with changes in livestock numbers and types in response to environmental regulation or changes in diets. Removal of the livestock sector and substitution by arable farming where possible led to a net decrease in the value of production and employment, an overall net reduction in costs associated with regulation services (for example, GHG emissions) but a fall in cultural service benefits associated with a managed pastoral landscape. However, substitution by imports transfers some environmental costs elsewhere.

Kytzia *et al.* (2004) considered the effects of a change in food consumption in Switzerland, using an array of metrics: primary energy demand, land value and material costs and imported fraction. The macroeconomic turnover of the agricultural sector decreases significantly with a complete switch to a full vegetarian diet (-55%), with a reduction of sales volumes in related sectors of 40% (processing) and 25% (retailing). Turnover increases in the organic agriculture scenario (+20%).
Although data and methods are available to model on-farm and some food sector level effects of changes in farming systems, there are limited data to support the analysis of off-farm supply chain consequences that is needed for comprehensive macroeconomic assessment.

2.4.1.2 Water supply

Water is a fundamental element necessary for human survival, which is used for drinking, washing, agriculture, food processing, recreation and other purposes. About 22 billion m^3 of water are abstracted in the UK each year (Environment Agency, 2009d; SEPA, 2004), 52% from rivers and lakes, 11% from groundwater and about 37% from tidal waters (mainly used for cooling). Of the 13 billion m^3/year extracted from freshwater non tidal sources in England and Wales, about half is used for public water supply. A further third is used for electricity power generation. Industry takes about 10% and aquaculture and amenity about 9%. Spray irrigation accounts for less than 1% of total abstraction but this is concentrated in the relatively dry Anglian region in summer. Total reported abstraction quantities have remained more or less constant over the last 15 years (Environment Agency, 2009d), although this partly reflects recent deregulation of small abstractions. The water supply and treatment industry contributes to about 0.75% of the total UK GVA (Appendix 2.3). A conservative estimate of the annual value of a range of ecosystem services provided by inland and coastal wetlands in the UK (e.g. water quality, flood control, recreation, tourism and amenity) is between £0.7 billion and £1.1billion, and possibly as much as between £2.5 billion and £5.7 billion (Morris and Camino, 2011).

It is difficult to derive values that represent the contribution of natural water to the economy because of the diversity of water demand and supply, the degree of spatial and temporal variation and the extent to which water is an essential, non-substitutable input. The value of water varies considerably between uses. The Scottish Government provides estimates of water values that are broadly indicative of the UK as a whole (SEPA, 2004; Moran and Dann, 2008). The average cost of supplying household treated water, indicative of resource costs, ranges from £0.50/m^3 to £1.20/m^3, with as much again for sewage and treatment. For raw water, the average value of irrigation water in 'areas of irrigation need' is between about £0.8/m3 to over £1.5/m3 on high value crops such as potatoes in the drier parts of eastern England, justifying investments in reservoirs to secure supply (Knox *et al.* 1999; Morris *et al.* 2004 and Weatherhead *et al.* 2013). Marginal values for raw water vary considerably according to industrial processes, highest where high water quality is required for chemicals and whisky manufacturing. The energy sector shows relatively low marginal values for water for cooling but for large quantities. The value of water for hydropower is particularly sensitive to assumptions about the economic price of energy and the cost of alternative sources.

Another perspective on freshwater quality is given by the estimated annual equivalent expenditure of £1.1 billion per year (in 2008 prices) to meet the Water Framework Directive quality targets over the next 43 years through to 2052 (Environment Agency, 2011). Reflecting pressures and vulnerabilities, most of this expense is associated with supporting water abstraction and discharges (£889 million/year), habitat and fisheries (£160 million/year), urban drainage and reservoir safety (£91 million/year) and agricultural pollution (£57 million).

A number of studies have explored the potential links between water used and the macroeconomy, usually in the context of sustainable water resource management. The link between water use and production and consumption of goods and services has been examined using the concepts of virtual water (Allan, 1998) and water footprints (Hoekstra and Hung, 2002; Hoekstra *et al*. 2011). There remain many methodological challenges not least concerning consistent indicators to measure water use and efficiency (Berger and Finkbeiner, 2011; Hess, 2010; Yu *et al.* 2010). To date, there have been relatively few comprehensive applications of water footprinting to water resources planning in the government or business sectors (McKinsey, 2009), although the strategic implications of water availability and use for international trade have received attention (for example, Li *et al.* 2012 for China). The variation in approaches used has led to calls for a consistent framework for water footprinting (Postle *et al.* 2011). There is scope to combine aspects of LCA, input-output analysis and water footprinting to support macroeconomic assessment of water policy interventions, especially regarding improvements in water resource efficiency.

2.4.1.3 Trees, standing vegetation, peat

Approximately 240 million of the world's poor that live in forested areas of developing countries depend on forests for their livelihoods. Forests and their products provide cash income, jobs, and consumption goods for poor families. Forestry provides formal and informal employment for an estimated 40-60 million people in the world (GRIDA, 2008). Although forestry contributes only 0.03% of GDP and 0.06% employment in the UK (2011 data), the sector contributes to more than 8% to GDP in some developing countries such as Central African Republic, Liberia and Solomon Islands (FAO, 2008). Timber may be the most important forest product (by weight), but forests are also harvested for fruits, herbs and honey as well as for wild animals.

In the UK material flows analysis covers four types of flows from environment to the economy: biomass, fossil fuels, metals and other (ONS, 2013b). The first one, biomass that includes timber, is of particular relevance and is reported annually.

In 2005 all forestry related industries directly employed a total of 167,000 jobs and generated £7.2 billion worth of GVA, or 0.7 per cent of the UK economy (Cebr, 2006). The forest industries supported 2.5% of the UK economy in 2005 through their direct and indirect operations, a total of 727,000 FTE UK jobs were supported and £26.4 billion worth of GVA was generated. A developed biomass industry could help the forest industries to support an additional 59,000 UK jobs. Edwards *et al.* (2008) estimated the total employment (i.e. direct, indirect and induced) in the Scottish forestry sector associated with the use of Scottish timber to be 13,200 FTE jobs (10,300 FTEs for direct employment, 1,500 FTEs for indirect employment, and 1,400 FTEs for induced employment) for the year 2007. In 2004 the total GVA (direct, indirect and induced) associated with Scottish timber was around £460 million at 2007/08 prices (£304 million for direct GVA, £86 million for indirect GVA and £69 million for induced GVA), or 0.5% of the total GVA for the Scottish economy. These estimates exclude GVA associated with the use of timber not grown in Scotland. In addition, the GVA of first-round (direct) visitor spending attributable to woodland visits, where woodland was the primary reason for the visit, was estimated to be £209 million at 2007/08 prices. GVA and employment associated with non-timber forest product harvesting and the game sector in Scotland are deemed to be difficult to assess (CJC Consulting, 2013; Edwards *et al.* 2008). However, none of the studies considers ecosystem services explicitly.

In 2009, the value of peat extracted was around £9.4 million. However, this resulted in the release of about 400,000 tonnes of CO_2, which is has an external cost of around £20 million using a carbon price in 2009 of £50/tonne (UK NEA, 2011b).

2.4.2 Regulating ecosystem services

Regulating ecosystem services comprise, among other things, climate and hazard regulation, detoxification of air, water and land, disease and pest regulation, and noise regulation. These services support the functioning of the economy and are not included directly in macroeconomic indicators, although perversely, expenditures on substitution or remedial measures, if there is a failure of these services, are. A failure of these services has uncertain effects on the macroeconomy. It can either decrease economic activity leading to losses, or increase economic activity if there is a need to repair or clean-up damages that require employing additional people and increased consumption of outputs from other economic sectors.

2.4.2.1 Climate regulation

The development of the field of industrial ecology and the activities of the Intergovernmental Panel on Climate Change (IPCC) have stimulated a lot of interest in climate change and the determinants of CO_2 emissions.

The value of EU forest, grassland and cropland carbon sequestration services is assessed by estimating the environmental damages that the world as a whole avoids because of the benefits from those services. The failure of carbon sequestration in the EU would imply 3% lower accumulated, discounted GDP in the world from 2001 to 2050, ranging from US$ 27 to 85 bn (Bosello *et al.* 2011). Bosello *et al.* (2011) found in Northern Europe, Canada, Japan and New Zealand the carbon sequestration service that reduces climate change to be welfare decreasing.

Dunne *et al.* (2013) showed that climate warming can cause heat stress resulting in reduced labour productivity. How much of this relates to ecosystems capacity to regulate climate and how this translates to economic impacts are yet to be studied.

There are many studies on embedded carbon emissions that could useful for future macroeconomic assessments. Peters and Hertwich (2006), for example, found that in Norway CO_2 emissions embodied in imports amounted to 67% of Norway's domestic emissions. Around a half of this embodied pollution originated in developing countries, yet they represent only 10% of the value of Norwegian imports. Wiedmann *et al.* (2010) considered UK CO_2 emissions from production and consumption (production + trade related) between 1994 and 2004 and concluded that CO_2 consumer emissions were typically 20% higher than estimated producer emissions and 34% higher than the national total reported to the United Nations Framework Convention on Climate Change (UNFCCC). Additionally, the authors concluded that CO_2 emissions embedded in imports (EEI) are higher than emissions embedded in exports (EEE) for all years. Both increased over time but EEI rose much faster (by 60% between 1992 and 2004) than EEE (by 28%).

2.4.2.2 Hazard regulation

Flooding, another manifestation of water stress, has become more problematic in the UK in the last 30 years (Pitt, 2008), whether associated with rivers, coastal water or storm water surcharge within urban areas. The annual cost of flooding in the UK is about £1.4bn. A further £1bn per year is spent on flood risk management (Environment Agency, 2009a,b). In the UK as a whole, probably over 5 million properties are exposed to moderate to low probability of flooding (less than 0.5% to 1.3% chance of flooding each year). Climate change, however, could increase their exposure to higher levels of flood risk (Environment Agency, 2009c).

There is comprehensive guidance on the estimation of flood damage costs, covering residential, business, infrastructural and agricultural impacts (Penning-Rowsell *et al.* 2013). The greatest share of total annual flood costs is borne by urban households and businesses, evident in the profile of the 2007 floods in England (**Figure 2.13**) that resulted in estimated economic costs of £3.2billion (Chatterton *et al.* 2010).

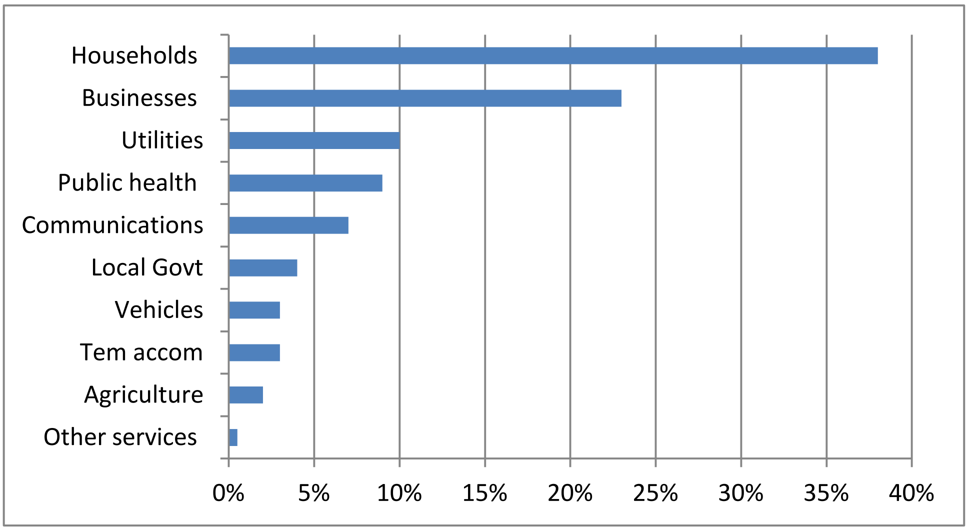


Figure 2.13. Cost profile of the 2007 Summer Floods in England (% of total economic costs*).
Source: Chatterton *et al*. (2010). * total economic cost £3.2 billion

There is much concern about future flooding associated with climate change. Looking forward to 2080, the Foresight Future Flooding Project (Foresight, 2004) identified a possible *increase* in annual damage costs to property of £14-£19 billion (in 2004 prices) due to river and coastal flood flooding under future consumption-oriented scenarios in the absence of additional measures to control flood risk (**Table 2.5**). By comparison, incremental flood damage costs were estimated at £0.5 to £3.8 billion for 2080 under sustainability oriented scenarios, reflecting a combination of reduced flood probability and event damage costs. Such damage costs would feed through to conventional national accounts but possibly with perverse effects; damage repair, replacement and recovery costs are registered as additional economic activity.

Table 2.5. Estimated Annual economic flood damage to residential and commercial properties for the UK under current (2000) and future (2080) scenarios. Source: Foresight (2004).

2004 prices	**Current flooding: Year 2000**	**Consumption oriented scenarios***	**Sustainability oriented scenarios****
Flood source	£ million	£ million	£ million
River and coastal	1,088	15,175-20,600	1,508-4,820
Within- Urban	270	5,100-7,900	740-1,870
Total	1,358	20,275-28,500	2,248-6,690

*National Enterprise and World Market Scenarios ** Local Stewardship and Global Sustainability Scenarios.

Large areas of enclosed farmland in floodplains in England and Wales benefit from managed hydrological regulation. There are about 1,336,000 ha of agricultural land at risk of flooding. About 421,500 ha currently benefit from flood defences, and 424,000 ha benefit from coastal defences. About 1,280,000 ha also benefit from pumped drainage to avoid either flooding or waterlogging, over 90% of which is used for agriculture, a third of it in the Anglian region.

An assessment of land use, estimated flood damage costs, and flood return period in years for defended and undefended areas in England and Wales (**Table 2.6**) shows that flood defence reduces expected annual damage costs from river flooding by about £5.2 million, and from coastal flooding by £117.7 million (Roca *et al.* 2010).

Table 2.6. Expected annual damages of flooding on agricultural land in protected and unprotected areas in England and Wales. Source: Roca *et al.* (2010).

	Expected Annual Damage <u>with</u> defences (£ million)		**Expected Annual Damage <u>without</u> defences (£ million)**	
	River	Coastal	River	Coastal
England	4.25	6.47	9.26	117.3
Wales	0.87	1.27	1.08	8.25

Changing water management regimes would have diverse effects for agriculture, environment and the rural economy (Maltby *et al.* 2013; Morris *et al.* 2010; Rouquette *et al.* 2011).

2.4.2.3 Detoxification and purification in air, soils and water

Ecosystems act as recipients and processors of the residues of economic activity. The increased levels of consumption and lack of strong recycling systems emulating the natural ecological processes has severely threatened the carrying capacity of ecosystems, especially associated with untreated discharges to water, solid waste deposited in landfill sites, and international trafficking of wastes with associated environmental and human risks. For example, Nowak *et al*. (2006) estimated the effect of the USA urban forests in 55 major US cities in reducing the effects of atmosphere pollution (O_3, PM_{10}, NO_2, SO_2, CO) at 711,000 metric tons - of which 305,100 tons of O_3, 214,900 tons of PM_{10}, 97,800 tons of NO_2 and 70,900 tons of SO_2. Macroeconomic, employment or trade effects of these services are yet to be studied, but there are studies on the health impacts of air pollution and air pollution damages of buildings (for example, acid rain) that could be used as starting point.

There are studies that look at the macroeconomic impacts of waste management. For example, Cambridge Econometrics (2003) explored the potential role of waste minimization and resource savings in the UK economy, concluding that:

- if manufacturers invested in best-practice waste minimisation techniques they could achieve around £2-2.9bn savings in annual operating costs, approaching 2% of UK manufacturing GVA and about 6% of profits in 2000;
- the implementation of cost-effective measures to promote energy efficiency could save £1.8bn annually in industry and £7.3bn for all sectors of the economy.

2.4.3 Ecosystem processes/intermediate ecosystem services

The focus in macroeconomic assessment is on final rather than intermediate ecosystem goods to avoid the likelihood of double counting and is consistent with the approach adopted in macroeconomic accounting. However, if the changes in intermediate services (such as soil formation) that cause changes in goods provided by the final ecosystem services (such as tonnes of lettuce grown) are known then it is possible to follow the changes through from intermediate services to final ecosystem services to the macroeconomy.

2.4.3.1 Soil formation

Soils are an inherent feature of the natural landscape, and an important component of land as a natural resource. They provide a range of services that support a broad spectrum of human activities and associated benefits. Under Defra sponsorship, and drawing on over 60 years of soil surveys, the Land Information System (LandIS, 2013), the largest data base of its kind in Europe, contains soil and soil-related information for England and Wales including spatial mapping of soils at a variety of scales, as well as corresponding soil property and agro-climatological data. LandIS can be used to assess the suitability of soils for various economic activities, as well as their ability to support a range of ecosystem services. It provides soil related information, for example, for the Natural Perils Directory (Hallett *et al.* 1996) used by the finance and insurance sectors.

Although there are no complete estimates of the economic benefits of soils and how these change according to soil condition, there is increasing recognition of their supporting role (Haygarth and Ritz, 2009; Robinson *et al.* 2013). Furthermore, evidence confirms that the degradation of soils due to their use gives rise to significant costs, not only to immediate users of soils but also society as a whole (Gorlach *et al.* 2004). Defra's Soil Strategy for England (Defra, 2009), for example, estimated the total cost of soil degradation at about £206-£315 million per year, but recognised that this was probably an underestimate. More recently, Graves *et al.* (2012) using an ecosystem services approach, estimated the economic costs of soil degradation in England and Wales at between £0.9bn and £1.4bn per year, with a central estimate of £1.2bn. About 45 % of these costs were associated with loss of organic content of soils, 39% with compaction and 13% with erosion. It was found that 20% of the estimated annual costs of soil degradation are associated with loss of provisioning services linked to agricultural production, both reduced output and increased costs. The remaining 80% of total annual degradation costs are associated with loss of regulating services. Within this category, the main quantified economic costs are linked to GHG emissions (49% of all costs), flood damage and flood risk management (19% of total costs) and water quality related costs (11% of total costs). Over 80% of the costs of degradation occur offsite and as such are of limited concern to those whose actions may be responsible for soil degradation. The degradation of soils due to intensive farming is particularly high on peat soils with consequences for carbon release to the atmosphere (Morris *et al.* 2010; Natural England, 2010). The distribution of the costs of soil degradation indicates priority areas for future policy.

2.4.3.2 Primary production

The global oxygen cycle has been the focus of attention of a number of global studies but few, if any, make the link to economic aspects. Petsch (2003) offered a structured explanation of all major oxygen circulation processes on earth, including photosynthesis. It appears that $14 * 10^{15}$ mol yr^{-1} O_2 is produced from terrestrial primary production and $12 * 10^{15}$ mol yr^{-1} O_2 from marine primary production, which is balanced by respiration both at sea and on land. Photosynthesis is the most important process of oxygen production on earth, complemented by photolysis of water in the high atmosphere. Oxygen is consumed through a range of processes, which include: aerobic cellular respiration, photorespiration, C1 metabolism, inorganic metabolism, volcanic gases, mineral oxidation, hydrothermal vents, iron and sulphur oxidation and abiotic organic matter oxidation.

Vitousek *et al.* (1986) proposed a concept of Human Appropriation of Net Primary Production (HANNP) describing the proportion of biomass that is grown on the planet and consumed by humans. The original paper gave a global HANPP estimate at nearly 40%. The papers in this area make an important step in identifying the share of human appropriation of net primary production but the aggregate macroeconomic effects are yet to be considered.

2.4.3.3 Pollination

Although many of the highest volume crops (e.g. rice, wheat and oilseed rape) are wind-pollinated (Ghazoul, 2005), a large proportion of vegetables and fruit crops (e.g. apple, melon and berries) are pollinated by insects, mainly bees, and are potentially vulnerable to declines in apiculture and wild pollinator stocks. The production of 84% of crop species cultivated in Europe depends directly on insect pollinators, especially bees (Williams, 1994). In addition, Klein *et al.* (2007) found that 87 crops, that is 70% of the 124 main crops used directly for human consumption in the world, are dependent on pollinators. Pollination is critical for the maintenance of crop genetic diversity.

Breeze *et al.* (2011) studied pollination trends in the UK and found that insect pollinated crops have become increasingly important in UK crop agriculture and, as of 2007, accounted for 20% of UK cropland and 19% of the total farm-gate crop value. A total of 19 crops and crop groups recorded by the Department for Environment Food and Rural Affairs (Defra, 2013b) which benefit from insect pollination were identified. Analysis of honeybee hive numbers indicates that current UK populations are only capable of supplying 34% of pollination service demands even under favourable assumptions, falling from 70% in 1984. Economically, the value of insect pollination services to crop agriculture has been estimated at £400 million per annum within the UK based on the economic value of the crops produced. Analysis of cropland in the UK since 1984 indicates that the insect-pollinated crop area has risen by 58% covering 849,000ha of UK cropland in 2007, growing at an average rate of 21,250 ha per year.

Gallai *et al.* (2009) attempted to estimate the economic value of pollination worldwide and derived a figure of €153 billion, which represented 9.5% of the value of the world agricultural production used for human food in 2005. Complete pollinator loss would translate into a production deficit over current consumption levels of -12% for fruits and -6% for vegetables. Among the most important drivers of pollinators decline are: land-use change with the consequent loss and fragmentation of habitats, increasing pesticide application and environmental pollution, decreased resource diversity, increases in alien species, the spread of pathogens, and climate change. The market value of crop categories that do not depend on insect pollination averaged €151/t while that of those that are pollinator-dependent averaged €761/t.

2.4.4 Cultural ecosystem services

Cultural ecosystem services are derived from environmental settings (places where humans interact with each other and with nature) that give rise to cultural goods and benefits and comprise aesthetic, educational, spiritual values (UK NEA, 2011a). These are more difficult to measure and assess in monetary terms than provisioning and regulating services (See WP 5 Report for more information). In the following section we consider mainly the tourism sector as a proxy for the assessment of cultural ecosystem services at the macro scale, which fits the macroeconomic focus of this report (UNEP, 2011). Worldwide, the tourism economy represents 5% of world GDP, while it contributed 6-7% of total employment amounting to 235 million jobs in 2010. International tourism ranks fourth (after fuels, chemicals and automotive products) in global exports, with an industry value of US$1trillion a year, accounting for 30% of the world's exports of commercial services or 6% of total exports. 935 million international tourists were recorded in 2010 and 4 billion domestic arrivals in 2008. In over 150 countries, tourism is one of five top export earners, and in 60 it is the number one export. It is estimated that travel and tourism sector investments reached US$ 1,398 billion in 2009, or 9.4% of global investment. For the EU 27, direct and indirect employment multipliers for environment-related tourism are estimated at between 1.69 and 2.13, which means that 100 jobs in the green tourism sector are capable of creating additional 69 jobs as a result of indirect effects and the figure increases to 113 when induced effects are taken into account (UNEP, 2011).

With respect to the UK, the tourism sector in 2012 generated £36.9bn (2.4%) of the UK GDP and 3.1% to total employment. If the entire supply chain is taken into account then these numbers are 6.8% and 7.6% respectively (WTTC, 2013). Within this sector, biodiversity and environmental settings support a substantial sub-sector of predominantly rural-based tourism activity, however the contribution of cultural ecosystem services to the macroeconomy is yet to be quantified. The macroeconomic impacts national parks that offer access cultural ecosystem services have been quantified for England (Cumulus and ICF, 2013). In 2012 England's National Parks provided around 141,000 jobs (0.6% of total employment in England) and generated £4.1 to 6.3bn of GVA (0.4% to 0.6% of GVA in England).

Biodiversity supports a substantial sub sector of environment-related tourism. The estimated value of wildlife related activities to the Welsh economy, for example, is substantial (Environment Agency, 2007): comprising a total output of £1.9 billion with a direct output value of £1.4 billion, total employment of 31,766 (full-time equivalents, compared with 90,660 in total tourism-related employment in Wales), total Gross Value Added (GVA) of £895 million (compared with £2,118 million in tourism-related GVA in Wales); and total income to labour of £479 million. Thus, wildlife related activities in Wales could be contributing 2.9% of Wales National Output, 3% of Employment, 2.2% of GVA and 2.6% of Incomes in Wales. Much of the output is driven by or linked strongly to wildlife-related public service, hospitality/retail and agriculture related activities with diverse links into other linked sectors.

Molloy *et al.* (2011) found that its wildlife reserves supported 1,872 FTE jobs in the UK in 2009, with the largest impacts coming through direct employment of RSPB staff associated with visitor services, and the effects of expenditures by visitors on local economies. Many of these jobs are located in more remote, disadvantaged rural areas with few alternative employment opportunities. Reserve management can have a significant impact on local economies, especially around the larger reserves that generate significant numbers of visitors. Spending by visitors to reserves occurs throughout the year, helping to extend the tourism season. Combining these estimates, expenditures resulting from visits to RSPB reserves were estimated to total £66 million in 2009, of which £44 came from direct spending by visitors.

Environment related cultural services are particularly important in the urban context where they can be accessed by large number of people. Keskin *et al.* (2011) focusing on the urban economies of Sheffield and Manchester, concluded that every £1 of green infrastructure investment (including investment in street trees, green roofs and climatic experimental plots in Manchester and a footbridge, flood defence works, walkways and planting in Sheffield) leads to an additional £0.94 and £0.86 of income generation in the Yorkshire/Humber Region and North West Region respectively.

Defra (2005) focused on the debate on the role of environmental regulation in constraining competitiveness concluded that there could be a false trade-off between environmental protection and economic development, mainly due to the assumptions that 'top-down' macroeconomic and general equilibrium models make when studying the relationship. Top down models often conclude a negative relationship, incorporating assumptions that firms maximise their profits, subject to technological constraints, and are already on their production possibility frontier. They also give much higher cost estimates than bottom-up models based on econometric and engineering data. The review cites Porter (1990, 1995), who stated that stringent and well-designed regulations can trigger innovation that may partially, fully or more than fully offset the costs of regulatory compliance. Evidence from Wales suggests that the designation of National Park status increased rather than depressed economic activity in otherwise disadvantaged areas (Hyde and Midmore, 2006).

In an international context, a number of studies have assessed the value of tourism to regional and national economies where environmental quality and ecosystems services make an important contribution. Furthermore, the concept of ecotourism has emerged in the last 20 years as a means of simultaneously meeting conservation and economic development objectives. Kweka *et al.* (2001) found that the tourism sector in Tanzania contributed to 5.8% of GDP and 1.6% of the labour force in Tanzania in 1992. Mazdumer *et al.* (2011) assessed the impact of tourism in Malaysia with the help of a 94 sector input-output table for the year 2000. While these studies consider macroeconomic aspects they do not attribute economic benefits to differences in environmental quality and ecosystem services. Steenge and Van De Steeg (2010), focussing on the Island of Aruba in the Caribbean, pointed out the difficulty in addressing tourism from a macroeconomic perspective because of the lack of comprehensive input-output data.

2.4.5 The natural environment and the economy

A number of studies have reviewed the broad links between the natural environment and the macroeconomy. These studies include assessments of agriculture and a range of other rural–based economic activities. Differences in their methods and scope make comparisons of their results difficult.

A study by Cambridge Econometrics and Land Use Consultants Ltd (2002) focused on the Environmental Economy of the South-East of England comprising 1) primary industries directly dependent on environmental resources, such as agriculture, forestry, fishing and mineral extraction; 2) industries that are dependent upon a high quality environment such as tourism, recreation and leisure; 3) conservation organizations, government agencies, and local authorities, which help to create quality of life and attract investment; 4) businesses focusing on environmental technologies (waste management, water purification, sustainable energy). The study showed that:

- in 2000, the Environmental Economy contributed over £7.8 billion GVA to the South East Economy, which was equivalent to just over 6% of the total regional economy;
- the Environmental Economy employed approximately 230,000 people in 2000, representing 5.5% of the region's total workforce;

- the contribution of the Environmental Economy to the regional economy is similar in percentage terms to that of the West Midlands and the South West, but the total number of people employed and GVA are highest in the South East.

A report by Defra (2004) concluded that habitats, most of which have been shaped by centuries of economic activity, natural and semi-natural systems are valuable to people because they:

- support the production of food, timber and other rural produce;
- provide a resource for recreation, leisure and tourism;
- support vital ecosystem services – such as climate regulation, flood management and carbon storage;
- provide habitats for wildlife, which is valued by people both because it adds interest to countryside activities and for its very existence.

Activities within these sectors that are closely and positively connected with the management of the natural environment supported 299,000 full time equivalent (FTE) jobs in England, and contributed £7.6 billion in gross value added. Specifically, the study concluded that:

- There are 8,600 FTE jobs in nature and landscape conservation in England, in a variety of public, voluntary and private sector organisations.
- Around a quarter of forestry employment and output can be attributed to the establishment and management of semi-natural woodlands, and the harvesting and processing of the timber they produce.
- Existing green agricultural systems, including organic systems and land in agri-environment schemes, were estimated to support 41,000 FTE jobs and contribute £840 million in value added.
- The future of commercial fisheries, and fish processing activities, which supported 5,300 and 8,300 FTE jobs respectively in England, depends on achieving sustainable management of the marine environment.
- Around 60% of rural tourism and recreation activity is dependent on landscapes and wildlife, supporting more than 190,000 FTE jobs.
- Nearly 2% of the £120 billion food chain involves the production and marketing of produce linked to a high quality rural environment (i.e. organic food, local food, environment based marketing, assured produce, forestry, commercial fisheries, tourism and recreation, countryside sports).

A study focusing on Scotland (Cambridge Econometrics, 2008) found that using the multipliers from the input-output modelling, which capture the non-direct (indirect and induced) as well as the direct effects, the estimated fall in output in the Scottish economy resulting from the removal of the environment sector is £17.2bn, or 11% of total output in Scotland, defined as total output at basic prices (in 2003£). The environment was estimated to support some 242,000 jobs in the Scottish economy that is around 11% of all full-time jobs.

A recent review in Wales confirmed the important links between the natural environment and macroeconomy (Reveill *et al.* 2012). For example, the natural environment in Wales contributes 9% of the country's GDP, one in six jobs and 10% of all wage and salaried incomes, maintaining the country's leisure and tourism, agriculture, forestry, water resources and waste management sectors. Employment and output multipliers of 1.44 and 1.45 respectively were derived for environmental related economic activity (Bilsborough and Hill, 2003): thus every full time job and every £100 of output in 2000 generated another 0.44 jobs and £45 output elsewhere in Wales respectively. A study of the country's three National Parks (Hyde and Midmore, 2006) showed that the parks generated about 12,000 jobs and £117m of annual income, with multipliers ranging between 1.1 and 1.5. The designation of National Park status was deemed to promote economic activity rather than constrain it as is often perceived to be the case. Wales' coastal and marine environment is associated with

52,400 jobs, producing £4.8 billion of income to businesses and £1.5billion of GDP to the Welsh economy (VEP, 2006).

In 2011 the Joint Research Centre of the European Commission published an extensive report (JRC, 2011), where for the first time the spatial mapping of the key ecosystem services has been done in the EU context. One of the key questions was to analyse the trade-offs between various types of ecosystem services. At the resolution of Nomenclature of Units for Territorial Statistics (NUTS) provinces, the spatial mapping provides the capacity to explore crop trade-offs with all other services. NUTS provinces rich in agro-ecosystems are essentially producing crops and are relatively poor in delivering other ecosystem services. NUTS provinces rich in forests and wetlands provide a wide array of services. The information provided by this report is useful for the future quantification of macroeconomic impacts of changes in the provision of interrelated ecosystem services.

Anson (2013) estimated the GVA of the sectors dependent on the marine environment in 2011 and found it to be £49.4bn (about 4% of the UK GVA). The report emphasises that there are inconsistences in data used and does not distinguish between GVA from ecosystem services and other inputs.

Ukidwe and Bakshi (2004) looked at the ecosystems contribution to the US economy in a 91 sector formulation. The paper presented and illustrated a novel approach for including the contribution of ecosystems to economic sectors. It synthesized available data and methods from multiple disciplines, including studies of the contribution of ecosystems at global or national scales, economic input-output analysis, systems ecology, life cycle assessment, and engineering thermodynamics. The concept of ecological cumulative energy consumption permits the integration of inputs from ecosystems and human resources and the impact of emissions. The authors presented results for economy-related uses of ecosystem services, but did not cover the macroeconomic, employment or international trade-related effects. However a similar way of thinking could be useful while assessing the macroeconomic impacts of ecosystem service change and management.

Bosello *et al.* (2011) focus on the macroeconomic effects of climate change associated with changes in the provisioning and regulating (mainly carbon sequestration) services provided by European forest, cropland and grassland ecosystems. The study proposed a methodology for assessing climate change impacts on ecosystem services using ICES, a recursive dynamic CGE model. Climate change impacts on ecosystem services were physically quantified, translated into changes in market activities and used for impact assessment in ICES. For provisioning services, we show first that agricultural land productivity in the EU is expected to decline up to -6% in the Mediterranean EU in 2050 (temperature increase of 3.1°C) as a result of soil biodiversity loss. Forest timber productivity will decline in the Mediterranean but increase in other EU areas, in particular the north. The Mediterranean EU may experience an NPV GDP (2001-2050) loss ranging from US$ 9.7 to 32.5bn and the Eastern EU a loss ranging from US$ 7.2 to 22bn for the temperature increases from 1.2°C to 3.1°C. Northern European countries may experience an NPV GDP gain ranging from US$ 2 to 5.6 bn. These results can be interpreted as the general equilibrium cost associated with the decreased production of the forest and agricultural systems. The analysis in Bosello *et al.* (2011) has several shortcoming, for example, it does not include climate-change impacts on ecosystem services outside the EU and the thresholds in ecosystem functioning are not considered.

2.4.6 Trade effects

International trade plays an increasingly important role in stimulating economic development, however at the same time it facilitates cross-boundary environmental effects. Production, associated with resource use (including biodiversity impacts) and emissions in one part of the world is often driven by consumer demand in other parts of the world (for example see, Lenzen *et al.* 2012; Wiebe *et al.* 2012; Peters *et al.* 2011; Muñoz and Steininger, 2010; Minx *et al.* 2009). The macroeconomic consequences of these shifts in the location of industries are not quantified, but studies on physical flows could be used for future assessments of how one country's consumption degrades another country's ecosystem services and depletes it's natural capital, and the effect on macroeconomic indicators. For example, Lenzen *et al.* (2012) found that approximately 30% of species on the IUCN red list of threatened species are affected by in some way by international trade.

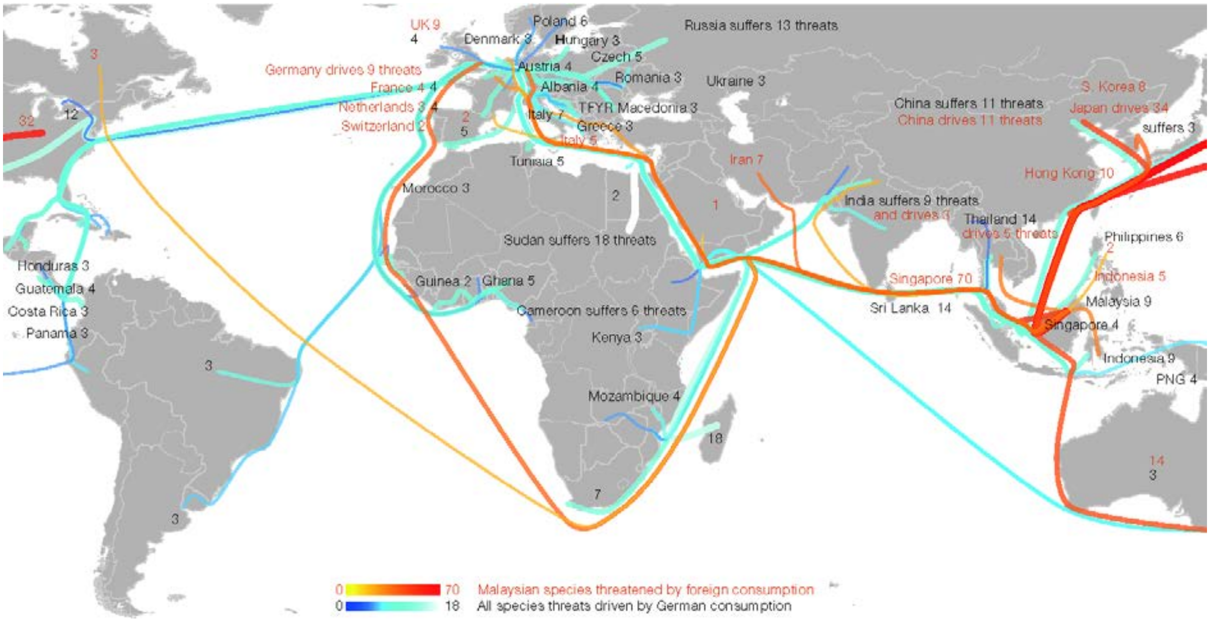


Figure 2.14. Malaysian species threatened by foreign consumption (orange) and all species threatened by German consumption (blue). Source: Reprinted by permission from Macmillan Publishers Ltd: [Nature] Lenzen et al., copyright (2012).

In their research that linked 25000 species to more than 15000 commodities produced in 187 countries and evaluated over 5 bln supply chains from the point of view of their biodiversity impacts, Lenzen *et al.* (2012) found that the USA, Japan, Germany, France, UK, Italy, Spain, South Korea and Canada are the top 'net importers' of biodiversity and Indonesia, Madagascar, Papua New Guinea, Malaysia, Philippines, Sri Lanka, Thailand, Russia, Cambodia, Cameroon are the top 'net exporters'. Such analysis was possible through the links between the threatened species and implicated commodities traded in international markets (**Figure 2.14**).

Wiebe *et al.* (2012) confirm the increasingly important role of international trade for the environmental performance of countries. In particular, they show that the OECD countries have improved their performance partly due to shifts of environmental pressures into other newly industrialising countries (*e.g.* Brazil, Russia, India, China, South Africa and Argentina). This increase is more pronounced for extraction of minerals, production of metals, and manufacturing but is also high for fossil fuel and biomass production. According to the results, China and Russia exhibit the greatest environmental burdens associated with the global relocation of heavy industries.

2.4.7 Main messages from the literature review

Comprehensive analysis of linkages between ecosystem services and the economy remains a largely underexplored area. No study was identified that attempted to quantify the wide and interactive contribution to the macroeconomy of all of ecosystem services simultaneously and the effects on

GDP, investment, employment and trade in a country, regionally or globally. Most studies focus on selected ecosystem services, *e.g.* pollination, or services provided by selected environment-related economic sectors, *e.g.* food and agricultural sector in the UK and USA. Many of the previous assessments of the impacts of ecosystem services' contribution to the economy are conducted at the microeconomic level *i.e.* household/business level. These numbers are sometimes aggregated to provide macroeconomic impact assessments. It is also known how flows of water, energy and carbon embodied in products around the world are transferring across national boundaries which could be a useful starting point for quantifying the macroeconomic impacts of these flows.

The economic sectors where the impacts on sectoral output and employment were considered are mainly the ones directly related to the provisioning ecosystem services, such as agriculture and forestry. Cultural ecosystem services' contributions to national economies were mainly considered via the tourism sector. Many studies on the trade of ecosystem services (for example trade in water) did not attempt to quantify the value of the services traded.

The review carried out in this report point towards the following set of conclusions:

- Comprehensive analysis of linkages between ecosystem services and the economy is still largely an underexplored area. There are studies linking one or more ecosystem services to the macroeconomy, but never a full spectrum. Among the ecosystem services for which their relation to the macroeconomy is relatively better understood are provisioning ecosystem services. The reviewed literature did not contain a study attempting to quantify contribution of all ecosystem services, which interact and influence each other, to GDP and employment in a country or globally.
- For the UK, some knowledge is available on: the macroeconomic role of agriculture and other environment-related economic sectors (larger than previously thought due to related industries), the economic role of tourism in the UK, and it is clear how flows of water and carbon embodied in products from around the world are traversing national boundaries and can be linked with consumption in the UK.
- The present review led to the conclusion that detailed mapping of ecosystem services onto economic sectors should be undertaken to clarify the important connections.

2.5 Conclusions and future research

Taking into account the findings from the sections above it can be concluded that:

- there is a scope for studying the macroeconomic impacts of ecosystems service change and management;
- a number of conceptual frameworks are available to represent environment - macroeconomy interactions. However, they have not as yet been transposed into sufficiently robust and comprehensive methods to measure the interactions between ecosystems and the macroeconomy in practice, nor to support policy appraisal and decision making. This is mainly due to the complexity and uncertainty of these interactions, and limited data availability;
- there have been sectoral studies and studies that are not macroeconomic in their nature but quantify one or another macroeconomic effect of nature related activities such as employment for example. These studies cover mainly the economic sectors that depend on provisioning ecosystem services;
- to date there have been no macroeconomic assessments conducted that include all ecosystem services with their interactions;
- there are models and methodologies available that could be operationalised for assessing the macroeconomic effects of ecosystems service change and management. Currently there are no models that can be applied for this purpose without further modifications.

Given the complexity of covering all ecosystem services and economic sectors at the same time and gaps in data it seems to be reasonable to start exploring the macroeconomic impacts of ecosystem change and management with the most studied economic sectors that directly depend on natural capital. These are agriculture, forestry, fishing, energy and water sectors.

In order to analyse the macroeconomic impacts of ecosystem service change and management the following steps should be taken:

- identification of ecosystem services contribution to and impact up on particular economic sectors. Since macroeconomic accounting is much more advanced than ecosystem accounting then it seems to be reasonable to map ecosystem services to macroeconomic accounting and not the other way around. This could be done by using, for example, Bayesian belief networks;
- accounting for and evaluation (quantities, qualities, monetary values) of the main ecosystem goods used as inputs by particular economic sectors. Ideally the process should follow the standards outlined in SEEA (2012);
- quantification of the macroeconomic performance of a sector as a result of quantities and qualities of inputs provided by ecosystem services (direct effects). This will include assessing the essentialness and potential substitutability of natural capital in production and consumption, and the extent to which macroeconomic performance is sensitive to changes in ecosystem services. Data needs to be collected on impact assessments at the micro/case study level and fundamental understanding of the role of ecosystem services in production and consumption systems. The macroeconomic assessments of ecosystem service change and management are likely benefit from existing microeconomic assessments (for example see, UK NEA, 2011, Ch. 22);
- quantification of the indirect and induced effects through intersectoral linkages;
- quantification of the economy wide effects including the impacts on investment and trade (and pressures on ecosystem services elsewhere);
- quantification over a time horizon to understand how changes in ecosystem services, for example depletion of stocks associated with degradation of ecosystems that affect the flow of services (for example, fish landings), will change the macroeconomic indicators over time. Studies focusing on these sectors could benefit from the work conducted in UK NEAFO WP1 (Natural Capital Asset Check) and WP3 and 4 (economic values of ecosystem services). The

disadvantage of focusing on selected economic sectors and the ecosystem services associated with these is that some of the feedbacks between economic sectors and ecosystem services will be missed. The advantage is that interactions of these sectors with ecosystem services are already intensively explored and there are more data available than for other sectors. The ecosystem service impacts that are not covered by existing studies, such as changes in labour productivity due to increased outside temperatures, could be explored and quantified where possible and the assessment methods developed and tested. The sectoral studies are likely to provide valuable learning experience and prepare the ground for studies with a wider coverage of economic sectors and ecosystem services. Most benefit will probably be gained by developing methods of ecosystems service accounting that can fit within, and eventually extend, existing sector and national accounting conventions and modelling methods used for macroeconomic policy analysis.

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2.8 Appendices

Appendix 2.1 Glossary

Capital is anything which can, either directly or indirectly, yield flows of value to people over time. The different types of capital commonly defined are: natural capital (see below), manufactured capital (for example, machinery and buildings), human capital (for example, knowledge and skills) and social capital (for example, levels of trust and connections amongst people).

Cross-sectional systemic risk is the potential for shocks that hit one part of the system to be transmitted to the rest of the system.

Ecosystem Services are the outcomes from ecosystems that directly lead to good(s) that are valued by people.

Environment-related tourism (ERT) is defined as activities where the natural environment (not the built environment) is responsible for influencing the choice of destination for the tourism activities and includes visits to hills, mountains, coasts, farmland, woods, forests, springs, lakes and wildlife; - activities: fishing (sea, game and coarse), walking, climbing, golfing, skiing, cycling, bathing/swimming, etc. (GHK, 2007).

Natural Capital is a configuration of natural resources and ecological processes, that contributes through its existence and/or in some combination, to human welfare.

Natural Asset is any natural resource (biotic or abiotic) or ecological process that has a value to society due to its function in combination with other assets (includes both ecosystem assets and individual assets).

Macroeconomics is a branch of economics that deals with the economy as a whole. The indicators that are developed in macroeconomics are mainly of interest to international organisations, governments and development agencies that use them to assess the impacts of policies, programmes and projects. These indicators are usually measured by the national statistics offices such as the UK Office of National Statistics (ONS, 2013b), are based on national accounting systems and provide aggregated descriptions of economic activity.

National accounting as it is currently carried out by most national statistical offices is based on accepted classifications of economic/industrial sectors. For the UK case, for example, the ONS collects data from a sample of private and public companies/firms belonging to these sectors. Missing values are usually estimated to retain sample size. Based on the data collected, macroeconomic indicators such as sectoral outputs, GDP, employment, investment, government expenditure, exports and imports, are estimated and reported. In principle these indicators are directly measurable either in monetary terms or in numbers of people employed. However as some of the values are estimated by the ONS and there is uncertainty about the numbers declared to the ONS, there is uncertainty about the indicators reported. This is particularly important to consider while assessing the macroeconomic impacts of relatively small (marginal) changes in ecosystem services that contribute to sectors that make up a very small proportion of the national economy. The current national accounting in the UK (ONS, 2007) is broadly based on the European Systems of Accounts 1995 (ESA, 1995) that is consistent with United Nations System of National Accounts 1993 (SNA, 1993). Both of these systems have been updated and is compatible with the statistical classification of economic activities in the European Communities (NACE, 2006).

Gross Domestic Product (GDP) - market value of all officially produced goods and services in a country within a certain period of time. It can be estimated in three ways, which are theoretically equal.

GDP by production approach (GDP(P)) is the sum of the value of all products within an economy. GDP(P) = output – intermediate consumption + taxes on products – subsidies on products. Output represents total production in monetary terms, whilst intermediate consumption means all the goods and services consumed or transformed in a production process.

GDP by expenditure approach GDP(E) is the sum of all final expenditures within an economy. GDP(E) = household final consumption expenditure (C) + gross capital formation or investment (I) + general government final consumption expenditure (G) + exports – imports (NX). This equation is often presented as Y=C+I+G+NX.

Household final consumption expenditure is the expenditure on goods and services that are used for the direct satisfaction of consumer's individual needs, i.e. food, beverages, clothing, housing, travel, recreation, education etc.

Gross capital formation comprises purchases of fixed capital items by resident producers, government and households minus fixed capital disposals. In economic literature it is referred to as investment (I).

Government final consumption expenditure includes expenditure on goods and services by government and comprises compensation to government employees, road maintenance, health, education, defence and some other collective services.

GDP by income approach (GDP(I)) is the sum of all factor incomes within an economy. In equation form: GDP(I) = compensation of employees + gross operating surplus + mixed income + taxes on production and products – subsidies on production and products.

Compensation of employees is defined as the total remuneration, in cash or in kind, payable by an enterprise to an employee in return for work done by the latter during the accounting period. It represents a total labour costs to an employer.

Gross operating surplus is equivalent to economic rent or value of capital services flows or benefit from the asset.

Mixed income is the surplus or deficit emerging from production by unincorporated enterprises owned by households.

Gross Value Added is defined as output value at basic prices less intermediate consumption valued at purchasers' prices and represents a fraction of GDP without taxes or subsidies taken into account. It is a balancing item of the national accounts' production account. In other words, GVA = compensation of employees + gross operating surplus + mixed income. Alternatively, GVA = GDP – taxes + subsidies. The sum of GVA at basic prices over all industries plus taxes on products minus subsidies on products gives gross domestic product. Gross value added of the total economy usually accounts for more than 90 % of GDP (Eurostat, 2013).

Basic price is the amount receivable by the producer from the purchaser for a unit of a product minus any *tax on the product* plus any *subsidy on the product.*

Environmental accounting accounts for changes in environmental stocks and service flows in a country. Examples of the systems developed for environmental accounting include the United

National System for Environmental-Economic Accounts (SEEA, 2013), and the UK Environmental Accounts recently developed by the Office of National Statistics (ONS, 2013b).

The System of Environmental-Economics Accounts (SEEA) is a multi-purpose conceptual framework designed to assess the stocks and flows of environmental assets.

The UK Environmental Accounts issued by the UK Office for National Statistics (ONS, 2013b) comprise three categories of information: Natural Resource Accounts (oil and gas); Physical Flow Accounts (fossil fuel and energy consumption, atmospheric emissions and material flows) and Monetary Accounts (covering environmental taxes and environmental protection expenditure). Most data are provided in units of physical measurement (mass or volume), although some are in monetary units, where this is the most relevant or the only data available.

Appendix 2.2 Keywords used in the literature search

Water, food, fibre, genetic resources, biochemicals, natural medicines and pharmaceuticals, fuel, wind, hydro, tidal, geothermal, biogeochemical cycles, carbon, phosphorous, nitrogen, climate regulation, soil formation, photosynthesis, primary production, pollination, cultural diversity, social relations, inspiration, knowledge systems, spiritual and religious values, aesthetic values, sense of place, input-output, regression analysis, life cycle analysis, expert systems, multicriteria decision aid, non-linear dynamic analysis, risk analysis, institutional analysis, mathematical programming, material flows analysis, human appropriation of net primary production, natural capital, contingent valuation method, stakeholder analysis, geographical information systems, Delphi method, psycho-physiological research, energy inputs, sector, policies, statistical systems, data, project selection, resource efficiency, technological choice, macroeconomics, recycling, trade, ecosystem services, planning, economic activity, impact, assessment, conservation, conflict resolution, state of ecosystems, biodiversity, ecosystem value, macro sustainability, green economy, green growth, progress.

Appendix 2.3 UK Gross Value Added, Gross output and average employment by sector in 2011

Sector	GVA by sector; £2009m	GVA as % of total	Gross output by sector; £2009m	Gross output as % of total	Average employment by sector; '000s	Average employment as a % of total
1 Crop and animal product.	6815.1	0.55%	17692.0	0.66%	362.9	1.16%
2 Forestry and logging	226.9	0.02%	734.7	0.03%	19.0	0.06%
3 Fishing	512.8	0.04%	1277.9	0.05%	14.0	0.04%
4 Coal	348.9	0.03%	828.0	0.03%	5.2	0.02%
5 Oil extraction	13261.7	1.07%	18760.2	0.70%	11.7	0.04%
6 Gas extraction	5702.2	0.46%	8950.3	0.34%	0.4	0.00%
7 Other mining	2351.6	0.19%	5514.6	0.21%	17.6	0.06%
8 Mining support service	3327.0	0.27%	4715.6	0.18%	24.1	0.08%
9 Food products	19031.6	1.53%	60873.6	2.28%	355.8	1.14%
10 Beverages	5589.4	0.45%	15308.2	0.57%	35.8	0.11%
11 Tobacco	1199.7	0.10%	1925.6	0.07%	3.1	0.01%
12 Textiles	2060.4	0.17%	5218.0	0.20%	68.1	0.22%
13 Wearing apparel	1635.6	0.13%	4047.7	0.15%	42.0	0.13%
14 Leather, etc	435.6	0.04%	930.5	0.03%	9.0	0.03%
15 Wood, etc	1957.4	0.16%	5845.0	0.22%	86.1	0.28%
16 Paper, etc	2449.3	0.20%	8965.2	0.34%	53.0	0.17%
17 Printing and recording	5697.4	0.46%	13388.9	0.50%	147.0	0.47%
18 Coke and petroleum	1505.6	0.12%	23966.0	0.90%	12.0	0.04%
19 Chemicals, etc	12244.5	0.98%	37163.4	1.39%	106.0	0.34%
20 Pharmaceuticals	9684.0	0.78%	16846.3	0.63%	38.0	0.12%
21 Rubber and plastic	4979.6	0.40%	17066.0	0.64%	146.9	0.47%
22 Other non-metallic	4315.8	0.35%	13077.5	0.49%	89.0	0.29%
23 Basic metals	3766.6	0.30%	15872.4	0.60%	73.0	0.23%
24 Metal products	14361.9	1.16%	32575.8	1.22%	287.9	0.92%
25 Computers, etc	7994.8	0.64%	19976.0	0.75%	138.9	0.45%
26 Electrical equipment	4319.8	0.35%	11078.2	0.42%	86.9	0.28%
27 Machinery, etc	12285.5	0.99%	30951.5	1.16%	186.0	0.60%
28 Motor vehicles, etc	6892.7	0.55%	42235.5	1.59%	131.9	0.42%
29 Other trans. Equip	8095.0	0.65%	19139.9	0.72%	129.9	0.42%
30 Furniture	3205.1	0.26%	8388.8	0.31%	75.0	0.24%
31 Other manufacturing	2819.3	0.23%	7275.9	0.27%	92.1	0.30%
32 Repair and installation	3594.8	0.29%	11361.2	0.43%	138.2	0.44%
33 Electricity	15582.6	1.25%	62567.8	2.35%	95.9	0.31%
34 Gas, heat and cooling	3136.2	0.25%	17694.0	0.66%	36.1	0.12%
35 Water	3917.8	0.32%	5250.2	0.20%	30.0	0.10%
36 Sewerage	5380.3	0.43%	7616.2	0.29%	19.0	0.06%
37 Waste disposal	6687.1	0.54%	16831.8	0.63%	134.7	0.43%

38 Waste management	370.9	0.03%	546.9	0.02%	5.3	0.02%
39 Construction	38980.9	3.14%	99605.4	3.74%	636.9	2.04%
40 Civil engineering	18091.8	1.46%	45787.8	1.72%	247.0	0.79%
41 Specialised construct	38264.9	3.08%	92620.4	3.48%	1135.8	3.64%
42 Motor vehicles trade	22371.6	1.80%	42094.7	1.58%	540.0	1.73%
43 Wholesale trade	53454.7	4.30%	109301.8	4.10%	1177.0	3.78%
44 Retail trade	66968.9	5.39%	115757.0	4.34%	2996.9	9.61%
45 Land transport	22653.6	1.82%	48141.4	1.81%	694.9	2.23%
46 Water transport	6856.0	0.55%	16740.2	0.63%	19.0	0.06%
47 Air transport	5719.4	0.46%	17107.8	0.64%	73.0	0.23%
48 Warehousing, etc	16262.4	1.31%	34464.3	1.29%	370.0	1.19%
49 Postal and courier	7581.7	0.61%	13672.2	0.51%	306.0	0.98%
50 Accommodation	12008.8	0.97%	23786.7	0.89%	428.0	1.37%
51 Food and beverage	26195.5	2.11%	53427.1	2.01%	1561.9	5.01%
52 Publishing	9727.2	0.78%	22071.6	0.83%	193.2	0.62%
53 Film and music	4936.6	0.40%	11346.8	0.43%	120.2	0.39%
54 Broadcasting	7183.3	0.58%	11796.3	0.44%	28.0	0.09%
55 Telecommunications	24069.2	1.94%	48258.4	1.81%	229.0	0.73%
56 Computer programming	30403.3	2.45%	52368.0	1.97%	583.4	1.87%
57 Information services	3564.0	0.29%	5721.0	0.21%	60.0	0.19%
58 Financial services	82878.3	6.67%	127857.5	4.80%	562.5	1.80%
59 Insurance and pensions	21384.9	1.72%	56510.8	2.12%	118.1	0.38%
60 Aux. financial serv	16911.2	1.36%	28288.9	1.06%	442.4	1.42%
61 Real estate	34784.1	2.80%	155189.8	5.82%	412.0	1.32%
62 Legal and accounting	33920.4	2.73%	46902.5	1.76%	676.7	2.17%
63 Head offices, etc	16777.2	1.35%	34023.3	1.28%	619.8	1.99%
64 Architect. and related	20205.2	1.63%	41829.1	1.57%	488.7	1.57%
65 Scientific research	4040.8	0.33%	9327.1	0.35%	125.0	0.40%
66 Advertising, etc	12329.3	0.99%	20865.7	0.78%	203.9	0.65%
67 Other professional	8806.2	0.71%	17580.7	0.66%	224.7	0.72%
68 Veterinary	1820.6	0.15%	2641.1	0.10%	54.0	0.17%
69 Rental and leasing	13369.2	1.08%	23588.7	0.89%	139.0	0.45%
70 Employment activities	21437.6	1.72%	37417.2	1.40%	770.0	2.47%
71 Travel agencies, etc	2389.3	0.19%	14954.3	0.56%	106.0	0.34%
72 Security, etc	4619.4	0.37%	7378.6	0.28%	196.0	0.63%
73 Services to buildings	6902.1	0.56%	12797.4	0.48%	834.9	2.68%
74 Office admin.	17200.1	1.38%	34180.1	1.28%	334.0	1.07%
75 Public admin. and def	65695.3	5.28%	136278.1	5.11%	1463.0	4.69%
76 Education	85467.6	6.87%	112110.6	4.21%	2732.9	8.77%
77 Health	75177.6	6.05%	146180.9	5.49%	2266.9	7.27%
78 Residential care	15733.6	1.27%	31983.2	1.20%	687.0	2.20%
79 Social work	15289.6	1.23%	31610.9	1.19%	1061.9	3.41%
80 Arts and entertainment	3280.3	0.26%	8322.8	0.31%	182.6	0.59%

81 Libraries, etc	3671.0	0.30%	5102.1	0.19%	113.2	0.36%
82 Gambling	5121.5	0.41%	10473.7	0.39%	101.2	0.32%
83 Sport and recreation	8594.5	0.69%	20429.5	0.77%	487.9	1.57%
84 Membership organ.	7131.0	0.57%	10386.2	0.39%	272.0	0.87%
85 Repair of goods	3006.9	0.24%	4825.7	0.18%	101.0	0.32%
86 Other personal	12298.5	0.99%	18929.9	0.71%	496.9	1.59%
87 Unallocated	0.0	0.00%	0.0	0.00%	193.0	0.62%
Total	1243279.8	100.00%	2664492.1	100.00%	31175.0	100.00%

Source: MDM-E3 model based on ONS data

Appendix 2.4 Main characteristics of some existing macroeconomic and Input-Output models.

	Model type	Number of economic sectors	Number of regions	Time horizon	Detailed coverage of the UK	Land use	Resource use	Water use	CO_2	CH_4	NO_x	SO_2	Waste	Ecosystem Services
GTAP-CGE	CGE	57	117	2004, 2007	X									
NiGEM	CGE	1	60	1961-2039	X									
GEM (IMF)	DSGE	1	1	10 years										
GIDD (WB)	CGE	2	121	2000-2050										
LINKAGE (WB)	CGE	57	87	2004	X	X	X							
ENVISAGE (WB)	CGE	57	113	2004	X		X		X	X				
MDM-E3 (CE)	EE EIO	86	12†	1970-2100	X	X*			X	X	X	X	X*	
E3MG (CE)	EE EIO	43	21	1970-2100	X	X*			X	X	X	X		
INFORGE (GWS)	EIO	59	1	1991-2050										
PANTHA RHEI (GWS)	EE EIO	59	1	1991-2050		X	X		X					
GINFORS (GWS)	EE EIO	25	56	1980-2050	X	X	X		X					X*
EORA (U. Sydney)	EE-MRIO	50-500	187	1990-2009	X		X	X	X	X				X*
EXIOPOL (FEEM)	EE-MRIO	129	44	2000	X	X	X	X	X		X	X		
EXIOMOD (TNO)	EE-CGE	129	44	2000-2050	X				X	X	X	X		
WIOD (U. Groningen)	EE-MRIO	35	41	1995-2009	X	X	X	X	X		X	X		
GTAP MRIO (CICERO)	EEMRIO	57	129	several	X				X	X	X			

* - limited treatment, †- 12 UK regions