Global socio-economic impacts of future changes in biodiversity and ecosystem services: State of play and approaches for new modelling

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Executive summary

Ecosystems and the biodiversity that underpin them are our life support systems. But the impact of declining trends in biodiversity and ecosystem services (BES) on economies and society is not well known outside the context of one-off local case studies. There is an urgent need to better understand and, importantly, to effectively communicate the importance of BES as foundational to the economic prosperity and wellbeing of current and future generations, the benefits of restoring and enhancing ecosystems, and the consequences of a business-as-usual approach which will render sustainable development as embodied in the UN Sustainable Development Goals (SDGs) elusive.

WWF has initiated a new project to help tackle this challenge. Its goal is to generate new evidence on the potential global socio-economic impacts of future changes in BES. This ambitious initiative can provide critical inputs to the wider policy- and decision-making audiences during the discussions leading to 2020. This is a crucial year, as targets under the Convention on Biological Diversity (CBD) and United Nations Framework Convention on Climate Change (UNFCCC) will be reviewed and progress toward the SDGs reported on. The project will also contribute to the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES). While the IPBES work programme considers socio-economic drivers of conditions and trends in BES, the focus of this initiative is on modelling the interactions of social and economic development trends on BES, and in turn how future changes in BES impact socio-economic outcomes, wealth and wellbeing.

Phase 1 of the new WWF project aims to scope the current state-of-the-art in BES-economy modelling and research, and to identify what new modelling and analyses should be prioritised to fill key knowledge gaps and deliver critical evidence at key points in time.

This report presents results of the Phase 1 scoping study, the objectives of which were to:

1. Identify, based on the project's theory of change, the anticipated informational needs/demands of relevant international initiatives to protect and enhance global BES (including the current IPBES work programme and the CBD, UNFCCC and SDGs leading to 2020) related to the potential global socio-economic impacts of future changes in BES. <u>(Analytical) approach: a review of the relevant literature, key reports and strategies, a stakeholder survey and discussions with key informants were used to complete the needs analysis.</u>
2. Identify the extent to which existing datasets, models and modelling initiatives could be utilised to meet the needs of the relevant international initiatives to protect and enhance BES as identified under Objective 1, and identify key gaps in the existing evidence base and approaches. <u>Approach: a review of key BES models and data, biodiversity scenarios, ecosystem service valuation databases, and integrated environment economy-wide modelling approaches was used to complete the gap analysis</u>.
3. Develop a set of recommendations on further modelling/analysis that could be undertaken in Phase 2, to help address the key gaps identified under Objective 2 and provide an assessment of the socio-economic impacts of BES loss, protection and restoration. <u>Approach: project team expertise and consultation with other key experts was used to draft preliminary recommendations for further modelling and analysis, which were circulated prior to an expert workshop.</u>
4. Organise, participate in and facilitate an expert workshop to discuss the findings of work under Objectives 1 to 3, focusing on finalising recommendations for Phase 2. <u>Approach: a two-day expert workshop was convened in Amsterdam on 6-7 June 2017 involving 17 international multidisciplinary experts which included the project team and WWF.</u>
5. Provide a final publishable report setting out the overall study results and recommendations for Phase 2, including feedback from the expert workshop. <u>Approach: the report elaborated here is the output for this objective.</u>

Key findings of the needs analysis

A structured survey was designed to identify the key information needs on the socio-economic impacts of future changes in BES that could support international initiatives to protect and enhance BES. Approximately 60 key BES experts from a mix of academia, multilaterals, government and NGOs were invited to complete the survey. A review of reports and strategies relevant to the international initiatives identified new information and analysis needed to support improved understanding and quantification of how future changes in BES could impact economies and society. The key information needs that emerged from the survey and literature are summarised in Table E.1.

Table E.1. Major information needs of international initiatives to protect and enhance BES

Major need	Details
New models and scenarios	• Models that are integrated and can assess the interplay between natural resources and social wellbeing. • Models that assess consequences of degrading BES to the economy and/or to human wellbeing. • Scenarios that show the impact of policy intervention and/or target achievement, such as reaching new global biodiversity targets and/or the UN SDGs. • Business-as-usual scenarios to demonstrate the impacts of current trajectories of BES declines. • Models and methods that comply with the UN System of Environmental-Economic Accounting (SEEA) so linkages can be made to national accounts.
IPBES needs	• Models and data describing the impacts on ordinary people from continued biodiversity decline. • Information that explains why biodiversity loss matters (i.e. because it's critical to economies and societies) and pathways to reverse current trends. The avenue is through the IPBES Global Assessment which will provide the foundation for the CBD's next Global Biodiversity Outlook #5. • Information on changes to BES and impacts on society and the economy to create a buzz and support targeting of key media outlets and opinion-shapers in line with the release of the four regional assessments and land degradation assessment in 2018-19. • IPBES stakeholders are most interested in engaging with IPBES through efforts that value biodiversity and nature's benefits to people.
WWF needs	• New information on socio-economic impacts of future changes to BES for the 2018 Living Planet Report, which will underpin WWF activities leading to 2020. • New information channelled through regular coordination meetings and linked to critical moments between now and 2020 (e.g. briefing notes/reports before CBD COP 14 & 15).
Urgency	Information on the socio-economic impacts of future changes to BES is needed urgently. The time frames are: • Mid-2018 to inform the CBD COP 14. • Mid-2019 to inform the UN SDG reporting (via the UN High-Level Policy Forum).
Modelled timeframe	The time horizon of most relevance to international initiatives for protecting and enhancing biodiversity are through to 2030 and 2050.
Indicators	The key indicators that would be most useful are: • Relevant indicators used to report against the UN SDGs (could include health, food/energy/water security, migration, demographic change). • Costs and benefits of conservation. • Macroeconomic impacts of changes to biodiversity (GDP, productivity, wealth, poverty and inequality, and employment). • Supply and economic value of ecosystem services.
Data and modelled outputs	• Visual products (maps) and qualitative narratives and storylines, at the national to global scale, and across all biomes (terrestrial and marine). • Focus could be on where future environmental change is likely to present particularly significant economic risks, such as water scarcity, degradation of river catchments, loss of coral reefs etc. • Greatest priority at national scale to attract attention of national policy-makers. • Quantitative information on impacts at national and global scales. • Wide range of ecosystem services should be covered in the analysis. A more aggregated approach would be better at capturing possible trade-offs between ecosystem services.

Key findings of the gap analysis

The gap analysis aimed to provide a comprehensive assessment of the state-of-the-art in global BES-economy modelling by investigating the extent to which existing modelling initiatives, models and datasets could be used to evaluate the socio-economic impacts of future changes in global BES. Figure E.1 shows the workflow needed to model the socio-economic impacts of future changes to BES, and how changes to BES in turn affect society and economies.

The figure also highlights that, to date, most effort has been on understanding changes to BES under alternative scenarios of economic and population growth, with less emphasis on estimating the subsequent impacts to society and the economy from changes in BES. This is itself a key gap. A further gap is the feedbacks that one round of changes to BES would have on the economy and society and in turn, how this 'new state' of the economy and society would impact BES. The gap analysis focussed on key aspects of each box in Figure E.1, aiming to assess:

1. The suitability of existing BES models to undertake new modelling/analysis of the global social and economic impacts of future changes in BES.
2. The suitability of existing economy-wide and integrated environment-economy models to undertake new modelling of the socio-economic impacts of future changes in BES.
3. The availability of existing data that could be used to support new modelling of socio-economic impacts of future changes in BES.
4. The suitability of current scenarios used in global BES modelling for modelling socio-economic impacts.

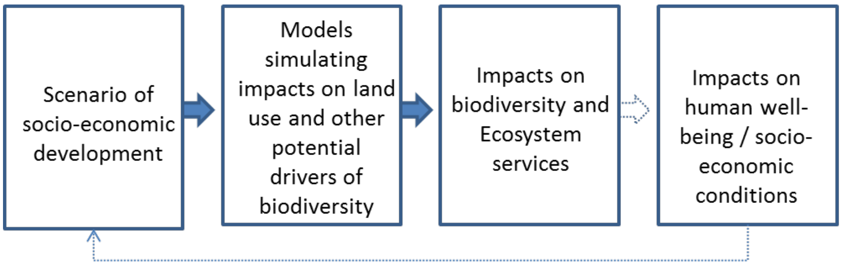

Figure E.1. Workflow for modelling the impacts to society and the economy from changes in global BES. Solid arrows show where most effort has been focussed. Dashed arrows have received relatively less effort.

<u>Suitability of existing BES models for assessment of the socio-economic impacts of BES changes</u>

- There is no current BES model that estimates socio-economic outcomes (or macroeconomic impacts) under future scenarios of economic and demographic change. All models assessed could explore the impact of future scenarios (some combination of climate, and economic and human development) on biodiversity, and in some cases, ecosystem services. However, no model explicitly assesses the impacts to society and the economy from the changes in biodiversity they forecast.
- Some models (e.g. GLOBIOM) estimate the change in monetary value of some ecosystem services under future scenarios. These could be used to assess the benefits of conservation scenarios, but currently used global scenarios (e.g. SSPs) are not configured in this way.
- The BES models assessed have varying degrees of pedigree, credibility and currency. A few models stand out (e.g. Madingley, GLOBIOM, GLOBIO, CLUMondo, Ecopath, InVEST) as examples that are well published (and/or used) and supported by large research groups.
- The scale of analysis of the global BES models reviewed is variable but some model at relatively fine scale. This is important for BES modelling, particularly if the BES models are linked to economy-wide models such as GTAP.
- BES models are an essential component of the integrated environment-economy models needed to assess socio-economic impacts of changes to BES.

<u>Suitability of integrated environment-economy models and modelling approaches for assessment of the potential global socio-economic impacts of BES changes</u>

- A group of models used to directly consider socio-economic impacts of a changing environment are the system dynamics models (e.g. International Futures simulator; GUMBO/MIMES; Threshold 21). However, these models typically have coarse spatial resolution and are constrained in their ability to represent the multisector global economy and prices and trade.
- A nascent approach to modelling socio-economic impacts is the linking of economy-wide Computable General Equilibrium (CGE) models with BES models.

- Integrating provisioning and non-provisioning ecosystem service data into an economy-wide model requires that ecosystem service data be consistent with the data structure of a CGE model. This implies consistency with the System of National Accounts (SNA) which is the primary data source for calibrating a CGE model.
- Only a handful of examples exist (at national scale) where dynamic CGE and BES models are linked (e.g. Inter-American Development Bank's IEEM + ESM), but this approach is what is needed to robustly quantify the socio-economic impacts of changes to BES. The approach draws on the strengths of whole-of-economy approaches with the inherently spatially explicit exercise of ecosystem service modelling. It enables the consideration of expectations of future economic development trajectories, how a specific trajectory affects BES in a given year, and consequently how this change in BES may reorient that economic development trajectory.

Suitability of existing data and databases to support assessment of the potential global socio-economic impacts of future BES changes

- Economy-wide models and the underpinning data and databases that enable scenario simulations and quantify economic and welfare impacts are rare, especially for non-provisioning ecosystem services and biodiversity. They are confined to a very small sample of national-scale cases and largely absent at global scales.
- Data on the economic value of ecosystem services is more prevalent. Many studies have used selections of this data to estimate value functions, which may be useful for transferring and scaling up existing value information to measure impacts of future global changes in BES.
- There is a distinction between value functions estimated for specific types of ecosystem (land-use class) vs. specific ecosystem services. This is important for making the link to the results of biophysical models of land-use change and ecosystem service provision. Some biophysical models produce results primarily in terms of changes in land use whereas others generate estimates of changes in ecosystem service provision.
- A key question is how to link mapped biophysical data on ecosystem service provision with ecosystem service values. It is arguably more straightforward to make the link when values are defined in units of area since this is a directly observable quantity from a map.
- Using value transfer methods is one of the few (perhaps the only) viable means of estimating ecosystem service values at a global scale but it is important to note the limitations and potential inaccuracies involved.
- The structure and basis of measurement (exchange value) of the System of Environment-Economy Accounting (SEEA) Central Framework, and the Experimental Ecosystem Accounts (EEA) extension, is consistent and compatible with the SNA. This is advantageous for economy-wide modelling of impacts from changing BES, as it is also compatible with the underlying data structure of CGE models.
- In the SEEA EAA, biodiversity is captured in the measurement of the condition of ecosystem assets, and therefore accounted for in the ecosystem condition accounts.

Suitability of existing scenarios for assessment of the potential global socio-economic impacts of BES changes

- Existing scenarios only describe the future impacts of global change (socio-economic and climate) on biodiversity. To assess impacts of BES changes on society and the economy, new integrated scenarios are needed that account for the feedbacks between global change drivers, BES and socio-economic dynamics.
- Current global biodiversity scenarios rarely relate estimates of biodiversity loss to consequent changes in ecosystem services or explore policy options specifically focused at improved management of biodiversity. They do not account for the feedbacks from changes in BES to society and the economy.
- Most BES models base the development of scenarios on future socio-economic trends to assess the potential impacts on BES (though in some cases biodiversity policies are incorporated into these socio-economic conditions). Indicators of impacts on biodiversity and/or ecosystem services are therefore typically an end-point.
- Impacts on human wellbeing and socio-economic conditions, including feedbacks that affect decision-making and behaviour, are mostly not included in scenarios.
- IPBES is in the early stages of developing new Nature Futures scenarios which will extend the IPCC Shared Socio-economic Pathways (SSPs) scenarios to include goals for both human development and nature stewardship. The ambition of the proposed Nature Futures scenarios is to include socio-ecological feedbacks and multiscale processes. They are expected to be produced in time to support the next IPBES work programme from 2019 onwards.

Overall assessment of how needs are met by existing models, scenarios and data

A complicated picture emerges as to how suitable existing models, data and scenarios are for meeting the needs identified for assessing the socio-economic impacts of future changes in BES. From the needs analysis, there is a clear urgency for this assessment, from IPBES, WWF and many other global policy and advocacy communities. Unfortunately, there is no off-the-shelf product available to assess the socio-economic impacts at global scale. Some leading BES models could relatively quickly produce suitable high-resolution outputs, such as the suite of tools in InVEST, but none of these models are linked to models of the global (or regional) economy. Alternatively, robust, dynamic economy-wide models that include aspects of the environment, such as GTAP, or other integrated economy-environment models, such as Threshold 21, contain or use relatively coarse representations of BES. A model that arguably meets many needs is the IMAGE integrated assessment modelling framework developed by PBL, which contains high-resolution global-scale BES models, and has been linked to a CGE to define future drivers. However, IMAGE itself does not report on future macroeconomic impacts.

Models need data as input, and the models need to be applied within a scenario framework because the problem of socio-economic impacts of future changes in BES contains substantial uncertainty. Unfortunately, current framing and design of scenarios is not sufficient to meet the need because the existing scenarios only tell half the story: they typically only include future changes in BES, and do not extend to the subsequent impacts on society and the economy. While there is much data on BES and economic values, it must use/conform to a framework that is consistent with whole-economy models; here the SEEA-EEA provides a method which complies with national accounts and with whole-economy models that use national accounts data.

Recommendations for further modelling and analysis

From the gap analysis, there is no existing BES model or modelling approach that sufficiently links or integrates with established models of the global economy. Although there are examples of integrated approaches and models that link with a CGE model (e.g. IMAGE and ENV-Linkages), none, as far as we are aware, integrate with the highly regarded GTAP model. For the modelling of BES, the InVEST modelling toolbox is arguably the gold standard – it has a substantial developer and user community, strong model pedigree, and offers the flexibility to choose and apply ecosystem service models of greatest relevance and priority in the study area.

The GTAP model of the economy is the gold standard in economy-wide modelling and is supported by many countries' statistical and economic agencies, as well as being used by large international organisations such as the World Bank. GTAP is a well-established and well-respected model of the global economy and trading patterns, which has been used to model numerous issues and questions, generating outputs in standard economic terms such as GDP, jobs, income, production, trade and so on. Despite the potential, its application to environmental economics issues to date has been limited.

Here we briefly outline a phased approach to integrating BES and macroeconomy modelling, following on from the current scoping phase (Phase 1).

Phase 2:

This would involve a synthesis of the existing (currently fairly limited and specific to individual countries and ecosystem services) information and data on the impact of BES changes on socio-economic outcomes. This would be used to inform the development of a set of plausible future scenarios of changes in BES to be used in the model (ideally aligned with those emerging from modelling work being undertaken within the IPBES work programme), and a set of proposed 'impact pathways' (based on qualitative assessment of the various ways these scenarios would be expected to affect relevant socio-economic indicators).

Phase 2 would then undertake preliminary quantitative modelling using the GTAP model (or equivalent), informed by the scenarios and impact pathways, to assess the potential global socio-economic impacts of BES changes (under scenarios developed above). As a first of its kind, the work would be expected to involve a relatively simple modelling approach at this stage (e.g. relatively simple scenarios and assessment of impacts based on a limited set of specific BES changes), the basis for which would then be further developed and enhanced in Phase 3.

A report would be produced including results at both global and country level (e.g. assessing how BES changes would affect national production, trading patterns and income). A workshop would also be undertaken with experts to discuss the findings, and best way forward.

Phase 3:

This would involve linking the GTAP model (or equivalent) to a number of BES models such as InVEST, to better model the interlinkages between BES and economic outcomes, including models of land-use change. At this stage the aim would be to incorporate feedback loops into the GTAP + BES model framework, in order to take better account of how socio-economic outcomes generated by changes in BES would affect the next iteration of the scenarios to be modelled, in an iterative process. Given the data requirements, this would likely only be possible by focusing on particular countries and/or regions in the first instance. A report would be produced and a workshop held to discuss the findings, decide how to refine the model, and agree on the best way forward.

Phase 4:

This would involve further refinement of the linked GTAP + BES modelling approach, based on learning in the previous two phases and benefiting from additional data that is becoming available. The aim would be to scale up the work to a more sophisticated analysis to generate results at the global level. Potential timing of the various phases is summarised below.

Phase	Duration	Scope/focus
2) Development of scenarios and preliminary simple modelling	~ 6 months	Synthesis of existing global- and national-level information/data to inform development of scenarios, and model calibration. Calibration of model, preliminary modelling using GTAP and expert workshop.
3) Full model development and detailed modelling at the regional level	~12 months	Refinement of scenarios and link GTAP model with BES models, and detailed modelling of a broader range of scenarios for key countries/regions.
4) Full model development and detailed modelling at the global level	12+ months	Further additional modelling and analysis, to enhance global coverage and strengthen consideration of environment-economy linkages and feedbacks.

1 Introduction

Ecosystems and the biodiversity they contain provide many benefits to people. These services may be valued in monetary and non-monetary terms to quantify their contribution to society and economic prosperity. The continued degradation of ecosystems and loss of biodiversity compromises the flow of ecosystem services, which has a detrimental impact on society and the economy. Halting degradation and restoring ecosystems is therefore critical to the wellbeing of current and future generations.

International commitments, such as those under the Convention on Biological Diversity (CBD), United Nations Framework Convention on Climate Change (UNFCCC), and the Sustainable Development Goals (SDGs), aim to tackle the declines in BES. The 17 SDGs, agreed to in 2015, are an integrated set of goals that traverse the environment, society and the economy, with the biosphere as the basis on which all SDGs sit (Figure 1). The SDGs clearly recognise that the biosphere, and the ecosystems and biodiversity it contains, cannot be managed separately from the economy or society. Ecosystem services provide the direct link between the biosphere, economy and society.

Figure 1. Integration of 17 SDGs across the biosphere, society and the economy. Source: Stockholm Resilience Centre.

The year 2020 is particularly important because the CBD, UNFCCC and SDGs will come under scrutiny. In July 2020, the High-Level Political Forum on the UN SDGs will meet to review the first five years of progress toward achieving the SDG targets, providing an opportunity to renew sustainability commitments and targets. Also in 2020, the CBD will set a new framework and targets to follow the Aichi Biodiversity Targets, and implementation of the UNFCCC Paris Agreement will begin. Both events provide an opportunity to strengthen commitments to halting biodiversity loss.

Considerable effort by the global research and policy community over the last few years has focussed on understanding the current condition and future trends of BES. Examples include efforts through the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), The Economics of Ecosystems and Biodiversity (TEEB), Rio Conventions and non-governmental organisations (NGOs).

However, the impact of BES trends on economies and societies has been less well studied and documented outside the context of specific local and thematic case studies (Banerjee, Alavalapati & Lima 2016; Bassi, Gallagher & Helsingen 2016). There is an urgent need to better understand and communicate the importance of BES to economic prosperity and human wellbeing at national to global levels, the potential impacts of maintaining and restoring ecosystems, and potential consequences of business as usual.

While IPBES includes socio-economic aspects in its assessments of the current status and potential future trends in BES, the focus is mostly on modelling the impacts of socio-economic development scenarios on BES. What is missing is assessment of how the modelled BES changes (under various trends/scenarios) could impact the economy (e.g. changes to GDP, productivity, growth or employment) and society (e.g. changes to health, employment, demographic change).

This type of assessment requires different modelling approaches than those found in the ecosystem service valuation literature, which typically estimate the consumer welfare value (or costs/benefits) of changes in BES. BES are central to economic growth prospects, but the methods and tools for assessing impacts of changes to biodiversity at the macroeconomic and societal level are less mature and have not communicated well the interdependence of the environment and economy.

WWF has initiated a new project to help tackle this issue. Its overall aim is to help strengthen the evidence base on the potential global socio-economic impacts of future changes in BES. The ambition is to generate new evidence that can be widely shared with policy and business audiences during the evolution of the IPBES work programme and the discussions leading to 2020 (when the CBD and UNFCCC will be reviewed). Phase 1 of the new WWF project aims to scope the current state of play in environment-economy modelling and research at global scales, and to identify what new modelling and/or analyses should be prioritised to fill key gaps.

Phase 1 has five objectives:

1. Based on the project's theory of change, identify the anticipated 'needs' of relevant international initiatives to protect global biodiversity (i.e. the current IPBES work programme and the CBD, UNFCC and SDGs leading to 2020), in terms of what information on the potential global socio-economic impacts of future changes in BES would help them to achieve their goals/objectives.
2. To identify the extent to which existing datasets, models and modelling initiatives could be utilised to meet the needs of the relevant international initiatives to protect global biodiversity (as identified under Objective 1), and identify key gaps in the existing knowledge base and approaches.
3. To develop a set of recommendations on further modelling/analysis that could be undertaken in Phase 2, to help address the key gaps (as identified under Objective 2) and provide an assessment of the socio-economic impacts of BES loss, protection and restoration.
4. To organise, attend and help to facilitate an expert workshop to discuss the findings of work under Objectives 1 to 3 (particularly recommendations for Phase 2).
5. To provide a final publishable report setting out the overall study results and recommendations for Phase 2, including feedback from the expert workshop.

This report presents the results of the Phase 1 study.

1.1 Overarching theory of change

The theory of change for a project clarifies what it is aiming to achieve (aims) and how (methods). It should also set out the main context, underlying philosophy and assumptions. This section presents the high-level theory of change for this project.

<u>Aims:</u>

- Undertake new modelling to generate robust and credible evidence on the potential global economic and social impact of potential future changes in BES.
- Clearly communicate the evidence to a wide set of policy decision-makers and other stakeholders at global level (e.g. IPBES, CBD, WWF, UN, World Bank, OECD).

- Influence policy decision-making processes in the lead up to 2020 when the CBD, UNFCCC and SDGs will be under scrutiny.

Achieving the aims will:

- Show policy-makers how BES changes may affect the socio-economic indictors they care about (e.g. GDP, productivity, trade, investment, jobs etc.).
- Raise public awareness of declines in BES, and how this will affect their own prosperity and wellbeing, leading to more pressure on governments to address this decline.
- Lead to key decision-makers taking steps to halt and reverse declines in BES.
- Improve decisions, because the socio-economic impacts of declines in BES are better understood and decision-makers held accountable.

So that ultimately:

- Governments increase commitments to policy action and investments so that the state of biodiversity and nature's life-support systems demonstrably improve, generating better outcomes for both people and nature.

Key assumptions:

- Key decision-makers, and the public they are accountable to, care more about the socio-economic consequences of environmental change.
- Key decision-makers can plan beyond immediate, short-term timeframes.
- There exists, or could exist if new modelling is completed, enough information to demonstrate to decision-makers the problem and the case for tackling it.
- The current lack of this kind of evidence is a key barrier to action.

1.2 Who are the key target audiences for this project?

The ambition is to reach policy decision-makers and other stakeholders that are concerned with the socio-economic consequences of declines in BES, and are able to effect change. These audiences include:

- Governments, ultimately heads of state, and especially key ministries that exert a strong influence over economic drivers of environmental change (ministries of finance, economics, development and planning)
- Multilateral agencies (e.g. UN, World Bank)
- Private sector (e.g. global businesses, financial institutions, investors, industrial strategists)
- Political-economy fora (e.g. World Economic Forum, G20, G7, Natural Capital Coalition)
- Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES)
- NGOs (including WWF and others that will be actively engaging in 2020 policy discussions).

2 Needs analysis

2.1 Aims of the needs analysis

The aim of the needs analysis is to assess what new information on the potential socio-economic impacts of future changes in BES would be most useful to support policy decision-makers and other stakeholders (key target audiences) in the lead up to 2020.

2.2 Methods

We used two methods to achieve the aims of the needs analysis. We reviewed key reports and strategy documents, and we conducted an online survey of stakeholders.

2.2.1 Review of key reports and strategies

The scope of the review includes IPBES reports and work programmes, WWF material including Living Planet Reports and 2020 Super Year Strategy, and material from OECD and UNEP. Also reviewed were the existing knowledge and needs of other international conventions and initiatives at the intersection of biodiversity and the economy, such as CBD, UNFCCC, UN Convention to Combat Desertification (UNCCD) and the SDGs.

We consulted the following documents and initiatives to assess the extent to which they identify the impacts of BES changes on social and economic systems as important information and/or issues.

Global policy frameworks/processes:

- CBD Global Biodiversity Outlook 2, 3, 4 (2006, 2010, 2014)
- OECD reports relevant to environmental change and socio-economic impacts
- UNEP Green Economy reports
- UN SDGs, UNFCCC, UNCCD

For WWF:

- WWF Living Planet Reports for 2000, 2002, 2004, 2006, 2008, 2010, 2012, 2014, 2016
- WWF 2020 Super Year Strategy

For IPBES:

- IPBES communications and stakeholder strategy, and stakeholder analysis survey results
- IPBES methodological assessment report on Scenarios and Models of Biodiversity and Ecosystem Services (2016)

2.2.2 Survey of key stakeholders

In total, around 50 key stakeholders (listed in Appendix 1) were approached to elicit their understanding of the importance of information on the impacts to society and the economy from changes in BES. About 60% of those listed in Appendix 1 are 'end-use' stakeholders.

Given the large number of participants, we designed and implemented an online questionnaire to capture the views of stakeholders more efficiently than structured verbal interviews with each stakeholder. The draft questionnaire was developed by the project team and circulated to WWF for refinement. The questions were deliberately selected and designed to capture the information needs of end-users involved in some way in policy and strategy development for improving BES. The final questionnaire (Appendix 1) included 17 questions, consisting mostly of open text responses, selecting from a finite set of options, and ranking of alternatives. Basic information about each respondent and their employment was also collected. The survey was designed and implemented using the online SurveyMonkey tool. The key stakeholders listed in Appendix 1 were invited via email to complete the survey within about 10 days of the invitation. The invitation also asked them to share the survey link with other relevant experts in their networks or organisations.

As per the theory of change (Section 1.1), the target stakeholders for completing the survey included:

- Policy-focused experts, to advise on the needs of policy decision-makers related to the broader post-2020 agenda (i.e. related to CBD, UNFCCC and SDGs);
- Experts with understanding of the needs, priorities and processes of IPBES, as well as representatives from the modelling/research organisations currently engaging with and/or supporting IPBES (including associated technical support units of the global/thematic/regional assessments and the scenarios and modelling group);
- Key people in WWF and in the IPBES Secretariat;
- Other organisations/individuals with an interest in engaging in activities leading up to 2020 (e.g. NGOs, academia, and within the wider environment-economy modelling/research community); and
- Experts in global modelling and assessment of BES and/or global modelling of economy-environment relationships.

2.3 Results

2.3.1 Document analysis

2.3.1.1 WWF Documents – Living Planet Reports

WWF's focus on valuing nature has increased over the last two decades. This is illustrated by the growing prominence of natural capital and ecosystem services in the Living Planet Reports (LPR) (see Table 1). The value of nature to people is increasingly used in the LPR to justify why people should care about the health of the planet and why action is needed. Before 2010, the LPR only gave cursory reference to natural capital, ecosystem services and the value of nature, with the primary focus on changes in biodiversity. Since 2010 the LPR has increasingly focused on ecosystem services and natural capital and the benefits of protecting and restoring them.

Table 1. Summary of how natural capital and ecosystem service concepts are included in the WWF Living Planet Reports. Source: Emily McKenzie, WWF, unpublished.

Living Planet Report #	How are links made between nature/biodiversity, ecosystem services, and economy and society, and how important is this information?
2000	Cursory reference
2002	Cursory reference
2004	Cursory reference
2006	Cursory reference
2008	Definitions & categorisation of ecosystem services
2010	• Ecosystem services are 'impacts' in driver-pressure-state-impact-response framework. • Global maps indicate current provision of terrestrial carbon storage and surface water run-off, and highlight overlaps with biodiversity. • Recommendations for action framed around green economy, investing in natural capital, and valuing ecosystem services.
2012	• Ecosystem services used to justify why people should care about the LPR findings. • Definitions of ecosystem services and natural capital. • Specific mention of initiatives to measure and quantify ecosystem services. • References scientific analyses that explore links between ecosystem services and biodiversity, focusing on carbon storage, wood fuel, rivers and oceans.

2014	• Ecosystem services used to justify why people should care about the LPR findings. • Natural capital is a significant part of the Director General's foreword. • Includes relatively sophisticated definitions of ecosystem services and natural capital, and how this information can be used. • Mentions initiatives to measure and quantify ecosystem services.
2016	• Director General highlights the interdependence between social, economic and environmental agendas, acknowledging the importance of the SDGs. • States that protecting natural capital and ecosystem services is in interests of people and nature. • Includes section on ecosystem services with examples of the role of natural capital in contributing to human wellbeing: forests, soil health, water availability, fish stocks. • Notes the challenge in effective measurement of how changes in natural capital affect human wellbeing.

2.3.1.2 Other documents

The key UN, IPBES and OECD material reviewed here all to some degree identified BES as a bridge between the environment and the economy and society. All the material also called for better understanding of the values of natural capital and ecosystem services and how ecosystem services contribute to the macroeconomy. Table 2 summarises the way ecosystem services are represented, and the importance placed on their role in policy decision-making. The key statements summarised from the reports that clearly show a need for better understanding of the impacts to society and the economy from changes to BES are highlighted in bold.

Table 2. Summary of how natural capital and ecosystem service concepts are included in key WWF, IPBES, CBD, OECD, UNEP Green Economy, UN SDGs, UNFCCC and UNCCD documents. Points in bold stand out as particularly relevant to BES and the economy and society.

Document	How are links made between nature/biodiversity, ecosystem services, and economy and society, and the importance of this information in decision-making?
WWF 2020 Super Year Strategy	• Ecosystem goods and services identified as being of critical importance to economies and societies, and provided by nature. • Declines in nature recognised as threatening continued economic development and human prosperity. • **Information on the critical links between nature and economy and society will be a significant piece of the evidence to support the aim of the 2020 Super Year**. • LPR 2018 will be major evidence base for 2020 activities and advocacy. Narratives in LPR 2018 will be very influential.
IPBES Stakeholder Needs Analysis (IPBES/5/INF/16)	• IPBES conducted stakeholder needs analysis in October 2016, with 834 responses. • 43% of organisation responses were from natural sciences, with 21% from social sciences (presumably includes economics). 39% of respondents were from academia/research, and 21% from government sector. • The questionnaire asked broad questions about stakeholder interests in IPBES and reasons for engaging with IPBES. No questions asked about potential use of IPBES products. • **The area of IPBES work of most interest to respondents engaging with IPBES on behalf of institutions/organisations was 'valuation of biodiversity and nature's benefits to people'**, with 222 responses (11%). The next most important was land degradation and restoration, with 184 responses (10%). • 17% of organisation respondents intend to make future contributions to IPBES through offering specialised expertise. This was the highest response, with next highest being the provision of regional knowledge (14%).
IPBES Communications and Outreach Strategy (IPBES/5/9)	• Provides information on logo, visual presentation, branding, website, and use of social and traditional media. • Outlines broad plans for release of four regional assessments and land degradation assessment in 2018-19 – **create a buzz and target key media outlets and opinion-shapers; regularly promote at conferences; support stakeholders to promote the assessments**.

Document	How are links made between nature/biodiversity, ecosystem services, and economy and society, and the importance of this information in decision-making?
	• Identifies need to better understand stakeholders and target under-represented groups of stakeholders. • Identifies global-scale UN organisations and policy initiatives to target for strategic partnerships.
IPBES Methodological Assessment Report on Scenarios and Models of Biodiversity and Ecosystem Services (IPBES 2016)	• Contains chapter on modelling of ecosystem services and nature's benefits to people (Chapter 5). Neville Crossman was lead author. • Focuses on the biophysical ecosystem service models, with little attention to economic models. Models reviewed are discussed in Chapter 3 Gap Analysis of this report. • Report does not discuss linked environmental-economic modelling nor does it discuss how to model the impacts to society and economy from changes to BES.
IPBES Conceptual Framework (Díaz *et al.* 2015)	• The framework guiding all work of IPBES. • **One of the framework's six elements is 'Nature's benefit to people' which explicitly refers to all the benefits that humanity obtains from nature – ecosystem goods and services.** • States that the benefits have monetary and non-monetary values, and that many benefits are jointly produced by nature and anthropogenic assets such as built infrastructure, knowledge, technology and finance. • **Recognises that macroeconomic, fiscal and monetary policy play a significant role in influencing behaviour related to and perception of nature's benefits.**
CBD Global Biodiversity Outlook 2 (2006)	• Draws heavily from the Millennium Ecosystem Assessment to provide examples of the importance and economic value of BES. • Provides example of how ecosystem services contribute to national economies, using example of tourism in Kenya and Galapagos, and harvesting of wild species in Nepal and in Iceland's marine ecosystems.

CBD Global Biodiversity Outlook 3 (2010)	• **The report is replete with information on ecosystem services and their economic values, and makes many strong and compelling arguments to halt biodiversity decline because of the direct importance to humanity of ecosystem services provided by biodiversity.** For example, the report:
	  o Recognises that the provision of food, fibre, medicines and fresh water, pollination of crops, filtration of pollutants, and protection from natural disasters are among those ecosystem services potentially threatened by declines and changes in biodiversity.
	  o States that cultural services such as spiritual and religious values, opportunities for knowledge and education, as well as recreational and aesthetic values, are also declining.
	  o **States that most future scenarios project continuing high levels of extinctions and loss of habitats throughout this century, with associated decline of some ecosystem services important to human wellbeing.**

CBD Global Biodiversity Outlook 4 (2014)	• Provides mid-term assessment of progress toward meeting the 20 Aichi Biodiversity Targets. Identifies the importance of biodiversity in meeting goals of sustainable human development.
	• Identifies need to restore ecosystem services in agricultural landscapes to achieve sustainable farming and food systems.
	• **To hasten achievement of the 2011-2020 goal of mainstreaming biodiversity across government and society, recommends further compilation of environmental statistics and building environmental-economic accounts, including developing and maintaining national accounts of biodiversity-related natural resource stocks (such as forests and water) and where possible, integrating these into national financial accounts**.
	• To hasten achievement of the 2011-2020 goal of enhancing benefits to all from BES, recommends:
	  o **Identifying, at the national level those ecosystems that are particularly important in providing ecosystem services, with attention to ecosystems upon which vulnerable groups are directly dependent for their health, nutrition and general wellbeing and livelihoods, as well as ecosystems that help to reduce risks from disasters.**
	  o Reducing the pressures on and, where necessary, enhancing the protection and restoration of those ecosystems providing essential services.

OECD Environmental Outlook 2050	• **Identifies links between biodiversity, ecosystem services, water, climate and human health, and argues that these cross-cutting environmental functions (of nature) must be carefully considered because they have wider social and economic implications.**

Document	How are links made between nature/biodiversity, ecosystem services, and economy and society, and the importance of this information in decision-making?

	• **Argues that estimating the monetary value of the services provided by ecosystems and biodiversity can make their benefits more visible, and can lead to better, more cost-effective decisions.**
	• **Firmly states that there are many areas where economic valuation should be improved, including the benefits of BES.**
	• **Calls for more data and investment in environmental-economic accounting, consistent with the SNA.**
	• Loosely combines a global dynamic CGE model (OECD ENV-Linkages) with the PBL IMAGE suite of environmental models:
	    o Feeds socio-economic trends from ENV-Linkages into IMAGE to project environmental consequences, and feeds these environmental projections back into the ENV-Linkages to assess economic implications
	    o Modelling done for 2050 baseline and various policy scenarios
	    o Coarse model with 24 IMAGE regions and 15 ENV-Linkages regions
	    o No spatially explicit ecosystem services.
	• Models future changes to biodiversity (under various socio-economic scenarios), but does not then assess the socio-economic impacts of the changes in biodiversity.
	• Projects future human health impacts (as premature deaths) of environmental risks (particulate matter, ozone, unsafe water supply and sanitation, indoor air pollution and malaria from climate change).

OECD Working Paper 93: The Economic Feedbacks of Loss of Biodiversity and Ecosystem Services (Markandya 2015)	• Reviews the main findings in the literature and key issues involved in the monetisation of biodiversity and ecosystem services. • Reviews the literature that has valued the loss of biodiversity and ecosystem services due to economic activity. • Discusses analytical frameworks and modelling approaches that have been used in the literature to examine aggregate economic effects of declining BES. • Discusses the main opportunities and obstacles in including BES into a dynamic general equilibrium framework. • **Concludes there is a significant, yet critical, gap in modelling the linkages from the changes in ecosystem services to the functioning of the economy.** • Overall is a relatively light review and discussion.
OECD Employment Implications of Green Growth: Linking jobs, growth and green policies (OECD 2017)	• **Recognises that degradation of the natural resource base affects all sectors of the economy and can impact long-term economic growth.** • States that successful transition to green growth can create new job opportunities; job losses in the 'brown economy' need to be carefully managed by supporting dynamic labour markets. • **Calls for further research to quantify all employment dimensions of green economy, including the interactions with other socio-economic indicators.**
UNEP Green Economy (UNEP 2011; UNEP 2014; UNEP 2015)	• UNEP defines green economy as 'an economy that results in improved human wellbeing and social equity, while significantly reducing environmental risks and ecological scarcities'. • Places the value of ecosystem services at the centre of a green economy. • **Recognises that ecological scarcities are seriously affecting all economic sectors (fisheries, agriculture, freshwater, forestry).** • **Calls for changes in stocks of natural capital to be evaluated in monetary terms and incorporated into national accounts (e.g. via the SEEA of the UN Statistics Division)** • Applies Threshold 21 (T21) system dynamics model to assess impacts on GDP to 2050 of 'business as usual' brown economy against a green economy scenario. Estimates a 14% increase in GDP/capita for the green economy against the BAU.
UN SDGs	• **Two SDGs (SDG 6 Clean Water and Sanitation; SDG 15 Life on Land) contain explicit targets for restoring and maintaining ecosystems.** • The SGD target 15.9 mentions the need to integrate ecosystem values into planning, development processes, and strategies for reducing poverty. • Other SDGs (SDG 2 Zero Hunger; SDG 7 Affordable and Clean Energy; SDG 13 Climate Action; SDG 14 Life Below Water) all have targets where sustainable management and restoration of water, land and ecosystems are critical to achieve targets. Quantifying and valuing ecosystem services are core to sustainable management.

Document	How are links made between nature/biodiversity, ecosystem services, and economy and society, and the importance of this information in decision-making?
UNCCD	• The objective of the UNCCD is to combat desertification and mitigate the effects of drought. • The objective will be achieved through long-term integrated strategies that focus simultaneously on improved productivity of land, and the rehabilitation, conservation and sustainable management of land and water resources, leading to improved living conditions. • **Parties will adopt an integrated approach addressing the physical, biological and socio-economic aspects of the processes of desertification and drought.** • **UNCCD supports approaches that take an ecosystem-based adaptation approach and that protect and restore ecosystem services. The contribution of ecosystem services to the economy and human wellbeing must be understood.**
UNFCCC	• The ultimate objective of the UNFCCC is to stabilise greenhouse gas concentrations 'at a level that would prevent dangerous anthropogenic (human induced) interference with the climate system.' It states that 'such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened, and to enable economic development to proceed in a sustainable manner.' • While preventing or mitigating climate change has always been the primary objective, recent developments of the UNFCCC have placed more focus on adaptation. • **The UNFCCC now recognises a close link between healthy ecosystems and communities' capacity to adapt to climate change, with ecosystem services as the coupling between ecosystems and society.** • **States that ecosystem-based adaptation contributes to reducing greenhouse gas emissions, and offers a form of infrastructure often significantly cheaper than built infrastructure in adapting to climate change impacts.** • Defines ecosystem-based adaptation as the use of BES to adapt to the adverse effects of climate change (see FCCC/SBSTA/2017/3).

2.3.2 Questionnaire findings

The survey was completed by 25 respondents. A further 11 respondents started the survey but did not provide a complete set of answers. About 60% of respondents are from academia/research, with the remaining 40% split about evenly across the public sector and NGOs.

About two-thirds of respondents said they are familiar with the current IPBES work programme and about 60% are familiar with other global frameworks and policies where biodiversity-economy relationships are important (e.g. CBD, UNFCCC, UN SDGs). Only about 25% said they are familiar with WWF's 2020 policy advocacy activities. Respondents familiar with IPBES were involved at senior levels in the IPBES Modelling and Scenarios Assessment or the IPBES Global Assessment. Respondents familiar with the WWF 2020 policy advocacy all worked for WWF and are either directly involved or work closely with the 2020 policy advocacy activities.

When asked to suggest ways new information on socio-economic impacts of future change in BES could be introduced to the IPBES work programme and the WWF 2020 policy activities, respondents gave several valuable insights. Some suggestions were made around models and tools:

- *We need to develop a new generation of scenarios and models.*
- *What would be useful would be evidence/data that shows and supports integrated thinking i.e. the interplay between natural resources and social wellbeing – globally and in different economic contexts – not just in developing countries.*
- *The System of Environmental Economic Accounting – Experimental Ecosystem Accounting can serve as a useful tool for developing [an] information system for ecosystem and biodiversity.*
- *There is a range of existing socio-economic biodiversity and ecosystem measurement initiatives that should be used to form the base of any work in this area by IPBES and WWF. Combining and linking existing efforts would be worthwhile. Unfortunately, for example, attempts to link the potential role of SEEA with the measurement required within IPBES have been unsuccessful to date.*

- *Existing models, at global and regional level, used for scenario analyses do assess impacts of socio-economic changes on biodiversity and ecosystems services, however no model includes the consequences of degrading ecosystem services to the economy or to human wellbeing. New information will help to fill in this feedback gap.*

For IPBES, the following suggestions were made:

- *IPBES needs to collate data that enables an explanation/description of what the impacts on ordinary people will be from continued biodiversity decline. It should be responsible for explaining why biodiversity loss matters and pathways to reverse current trends.*
- *Re the IPBES work programme: main windows of opportunity are via the Regional Assessment chapters dealing with nature's benefits to people (although this window is almost closed given the advanced stage of these assessments) and through relevant chapters of the global assessment, providing the foundation for the CBD's next global biodiversity outlook report (this is the biggest opportunity, with huge potential to influence formulation of global biodiversity strategy/policy for next decade.*
- *According to ongoing tasks related to IPBES deliverable 3c there are workshops (Task 7) and development of long-term research agenda (Task 8) where new information on socio-economic impacts could be introduced. I suggest timely and careful presentation to people involved in these tasks.*

For WWF 2020 policy advocacy activities, the following suggestions were made:

- *It would be good to inform Living Planet Report (LPR) 2018 and/or LPR 2020 since that is a firm basis for our advocacy efforts. If there is something available earlier, even better. But should be in line with top line 2020 advocacy around One Planet Development, zero biodiversity footprint, etc.*
- *It could be introduced as a key part of the narrative in WWF's LPR and associated advocacy, and could be used to inform the network's advocacy on international policy processes and the new Practices that have recently been established. This will need wider buy-in and engagement around the WWF network to help ensure wider uptake.*
- *For WWF, this would be through the regular coordination meetings and link to critical moments along the timeline between now and 2020 (eg briefing notes / reports before CBD COP 14 & 15 etc). The Living Planet Reports (for 2018 & 2020) would provide good platforms for the outputs.*

The specific new information respondents need or identified as important is shown in Figure 2. Nearly 80% of respondents identified information for the UN SDGs as important. A similar number suggested information on the costs and benefits of conservation is needed. Several pieces of information describing the macroeconomic impacts of changes to biodiversity (GDP, economic productivity and employment) were identified as needs by about 60% of respondents; a similar number thought the supply and economic value of ecosystem services was also important or of need. Many of the indicators and measurements used to describe human wellbeing, such as human health, safety and security, social relations, happiness, quality of life and governance, were identified as important or of need by only 30% or less of respondents (Figure 2).

The spatial resolution of information to assess the impacts to the economy and society from future changes in BES favoured by respondents ranges from the sub-national to global scale (Figure 3). National-scale analyses were most favoured (Figure 2), while less than half the respondents thought local-scale information is needed. Respondents did not identify any specific biomes of high need, although 20% did identify coastal areas intensively used by humans as a priority. Over 80% of respondents said they need information on all biomes supporting the favoured national to global scale.

In terms of format, respondents most wanted information of a more visual and qualitative nature. Nearly 90% of respondents identified maps as of greatest need, and about 65% need stories and narratives (Figure 4). About 60% of respondents said they need quantitative data and graphs describing socio-economic impacts of future changes in BES. Peer-reviewed literature is also needed.

Many respondents suggested 2030 and 2050 as the forecasting range of modelling of socio-economic impacts, so that the result could be linked to and inform progress toward achieving the UN SDGs. Almost all respondents identified assessing progress toward the CBD Aichi targets and the UN SDGs as the policy and target framework where the modelled socio-economic impacts of future changes to BES would be of most use. The measurement of generic indicators related to human development, GDP, world health and child rights were suggested as an important policy setting for the socio-economic impacts information.

All respondents expressed a high level of urgency for information on the socio-economic impacts of future BES changes. The end of 2017 is the deadline to feed information into the IPBES Global Assessment, and early-2018 the deadline to feed information into the 2018 WWF Living Planet Report and the next IPBES work programme. Information is also needed through 2018/2019, and in the run up to 2020, to support policy processes, discussions and advocacy activities in relation to SDGs, CBD and UNFCCC.

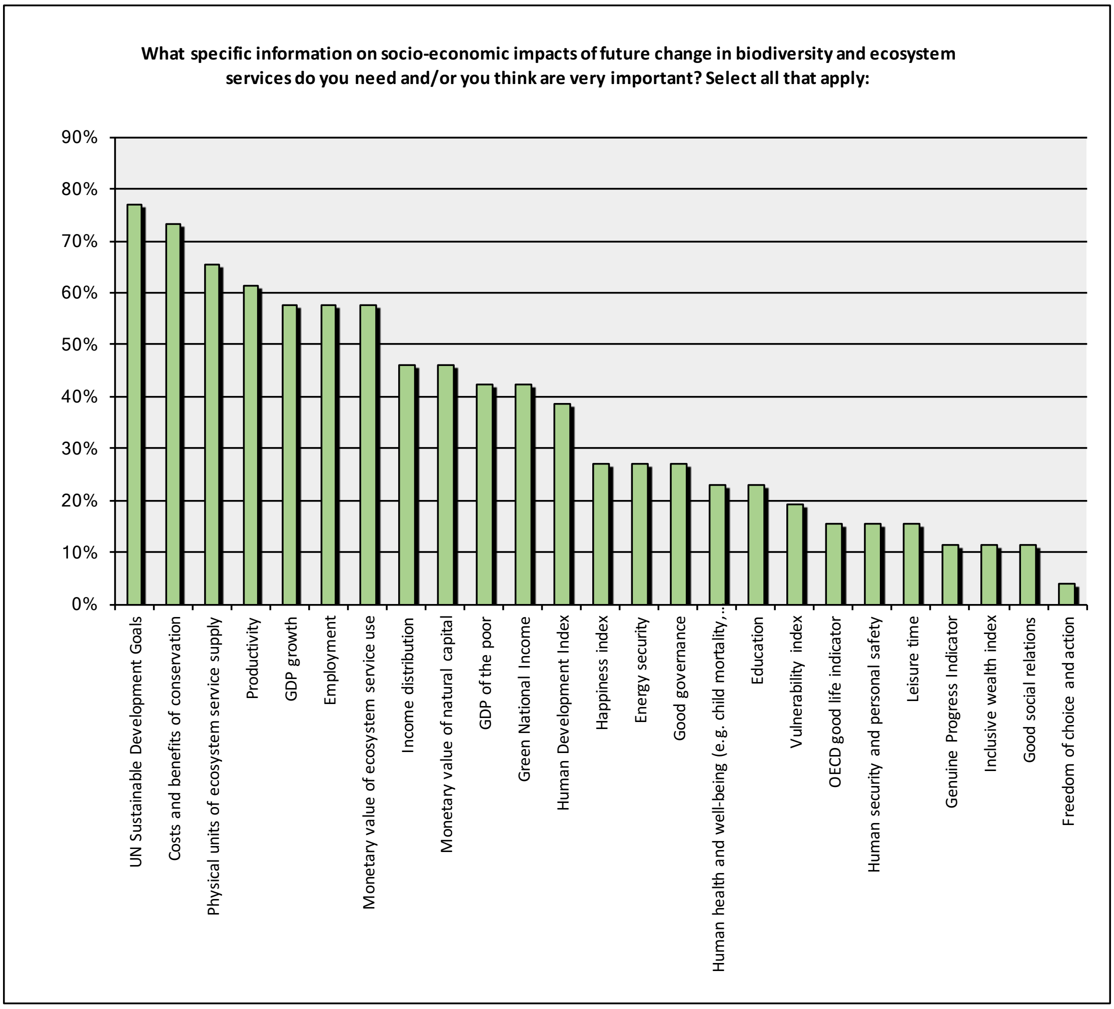

Figure 2. Summary of key information requirements on socio-economic impacts of future changes in BES.

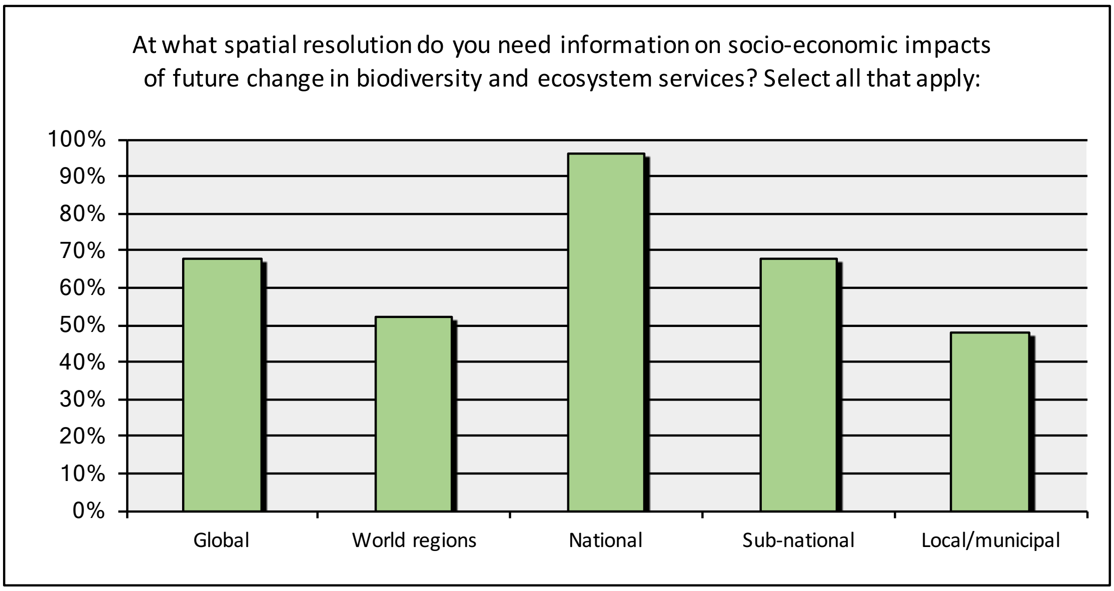

Figure 3. Summary of required scale of resolution of information on socio-economic impacts of future changes in BES.

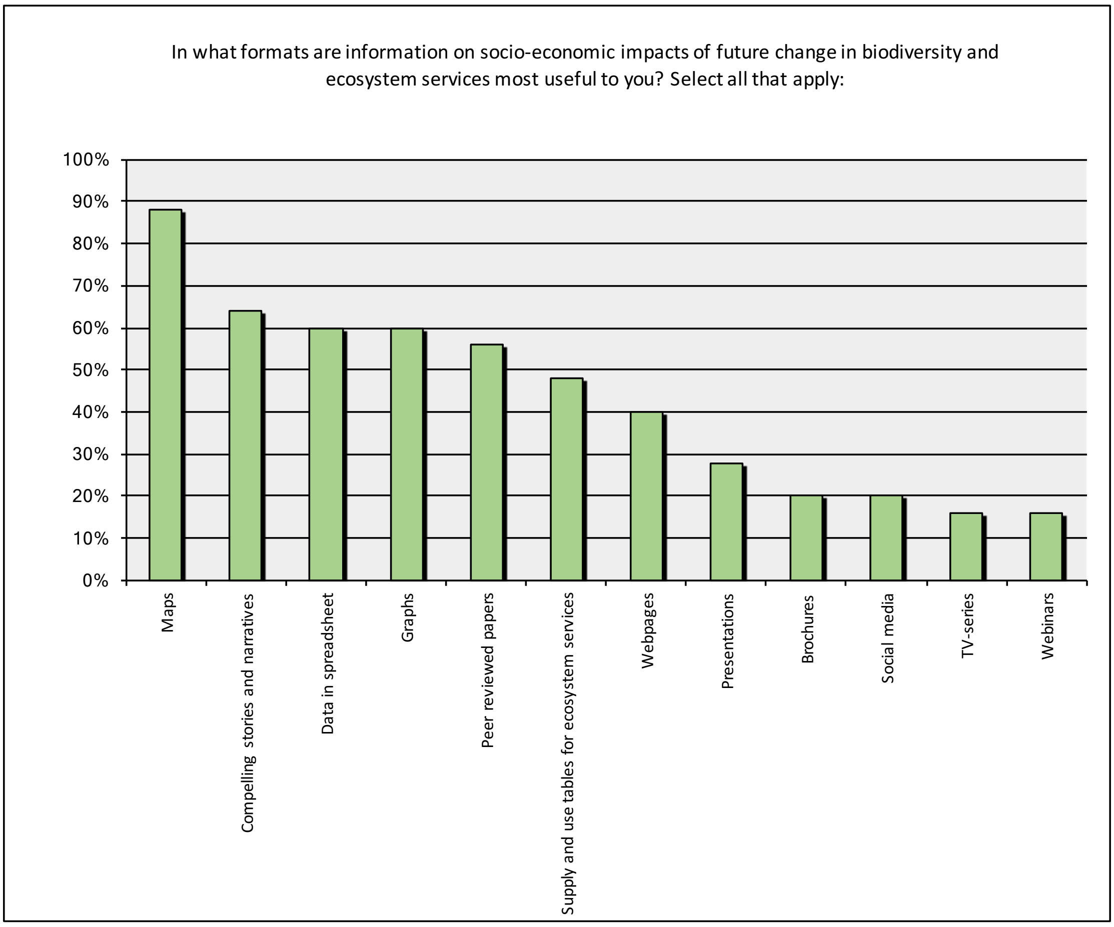

Figure 4. Formats for information on socio-economic impacts of future changes in BES.

2.3.3 Timeline of key initiatives

Figure 5 shows the timing of the key events and needs for information on socio-economic impacts. The timeframes presented are summarised from the needs analysis survey results and our review of the key reports and initiatives.

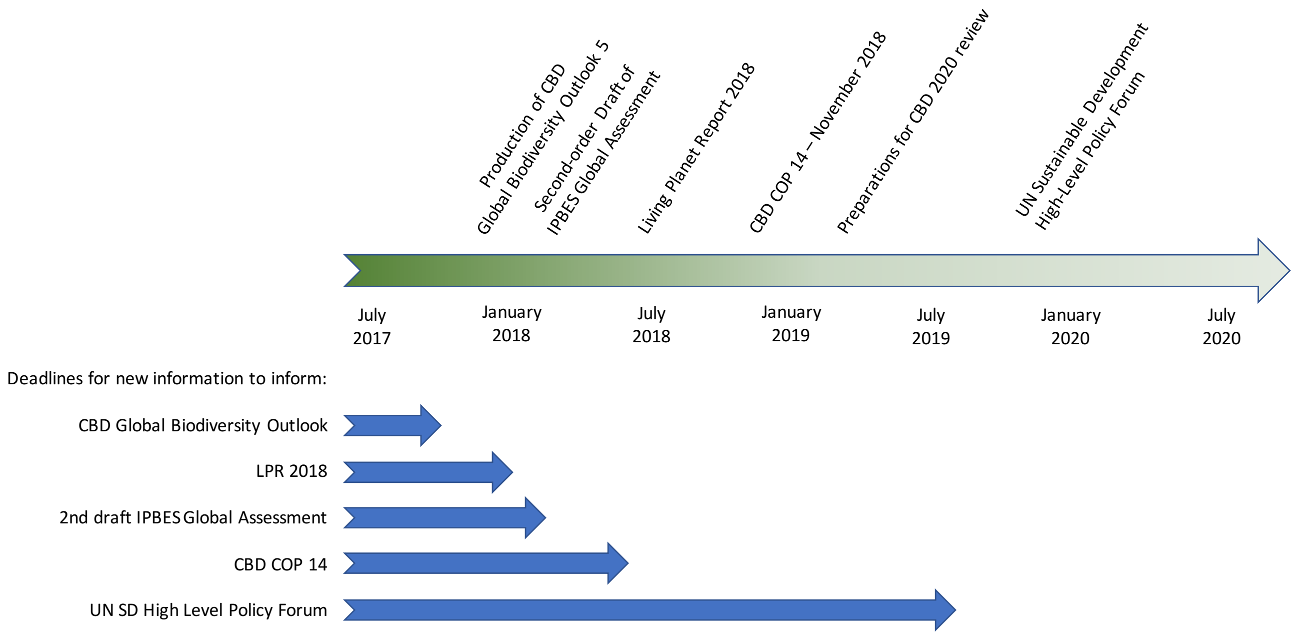

Figure 5. Timing of key events to 2020 requiring information on the socio-economic impacts of modelled changes to BES.

2.4 Summary and key findings

The results of the needs analysis are summarised in Table 3.

Table 3. Major needs of international initiatives to protect biodiversity

Major need	Details
New models and scenarios	• Models that are integrated and can assess the interplay between natural resources and social wellbeing. • Models that assess consequences of degrading BES to the economy or to human wellbeing. • Scenarios that show the impact of policy intervention and/or target achievement, such as reaching new global biodiversity targets and/or the SDGs. • Business-as-usual scenarios to demonstrate the impacts of current trajectories of BES declines. • Models and methods that comply with the UN SEEA so linkages can be made to national accounts.
IPBES needs	• Models and data describing the impacts on ordinary people from continued biodiversity decline. • Information that explains why biodiversity loss matters (i.e. because it's a critical to economies and societies) and pathways to reverse current trends. The avenue is through the IPBES Global Assessment which will provide the foundation for the CBD's next Global Biodiversity Outlook #5 (deadline early 2018). • Material on changes to BES and socio-economic that creates a buzz and supports targeting of key media outlets and opinion-shapers in line with the release of the four regional assessments and land degradation assessment in 2018-19. • IPBES stakeholders are most interested in engaging with IPBES through efforts that value biodiversity and nature's benefits to people.
WWF needs	• New information on socio-economic impacts of future changes to BES for the 2018 Living Planet Report, which will underpin WWF activities leading to 2020 and enable WWF to have impact and influence in international initiatives to protect biodiversity.

	• New information channelled through regular coordination meetings and linked to critical moments along the timeline between now and 2020 (e.g. briefing notes/reports before CBD COP 14 & 15).
Urgency	Information on the socio-economic impacts of future changes to BES is needed urgently. The timeframes are: • By early 2018 to inform the IPBES Global Assessment and the 2018 Living Planet Report • Mid-2018 to inform the CBD COP 14 • Mid-2019 to inform the UN SDG reporting (via the UN High-Level Policy Forum).
Modelled timeframe	The periods to model to have most relevance for the international initiatives to protect biodiversity are through to 2030 and 2050.
Indicators	The key indicators that would be most useful are: • Relevant indicators used to report against the UN SDGs (could include health, food/energy/water security, migration, demographic change) • Costs and benefits of conservation • Macroeconomic impacts of changes to biodiversity (GDP, economic productivity and employment) • Supply and economic value of ecosystem services.
Data and modelled outputs	• Visual products (maps) and qualitative narratives and storylines, at national to global scale, and across all biomes (terrestrial and marine). • Focus could be on where future environmental change is likely to present particularly significant future economic risks, such as water scarcity, degradation of river catchments, loss of coral reefs etc. • Greatest priority at national scale to attract attention of national policy-makers. • Quantitative information on impacts at national and global scales. • Wide range of ecosystem services should be covered in the analysis. A more aggregated approach would be better at capturing possible trade-offs between ecosystem services.

3 Gap analysis

3.1 Aims of the gap analysis

To date, much of the global BES-related modelling (including to support IPBES and the CBD) has been focused on assessing the impacts of socio-economic drivers on ecosystems (e.g. via waste and emissions, as shown Figure 6). Assessment of the impacts of ecosystem-related changes on socio-economic systems (e.g. via changes in resources and ecosystem services, as per Figure 6) has received far less attention.

An important focus in this gap analysis is to get more of an understanding of the extent to which existing models could be suitable for filling this gap – either as they are, or by extending them and/or linking them with other models – and suitability of existing data and scenarios to support such modelling.

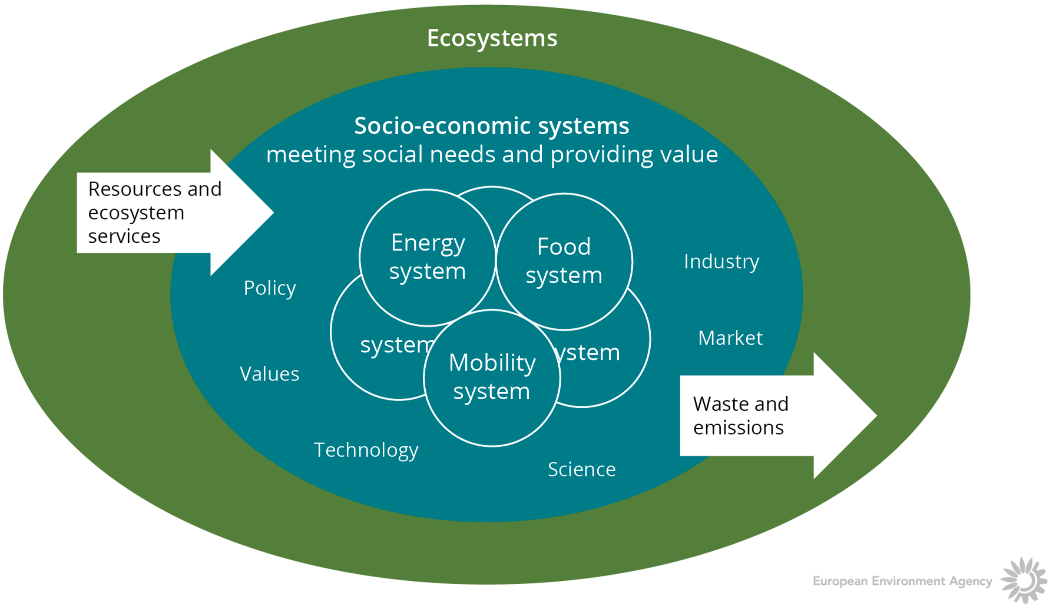

Figure 6. Ecosystems underpin socio-economic systems of production and consumption. Source: www.eea.europa.eu/soer-2015/europe/natural-capital-and-ecosystem-services

3.2 Methods

The task was split into four areas of effort to determine the suitability of existing 1) BES models, 2) integrated environment-economy models, 3) datasets, and 4) scenarios, to support new modelling of the global socio-economic impacts of future changes in BES.

The project team's extensive expert network and knowledge on models, data, scenarios and valuation approaches was drawn on to complete these assessments. Other material used to provide context and support the assessments includes the UNEP-commissioned review of tools to support a green economy (UNEP 2014), Chapter 5 of the IPBES Modelling and Scenarios assessment (IPBES 2016), and the WWF-commissioned review of approaches for scenario modelling to support development planning (Bassi & Roxburgh 2015).

3.3 Results

3.3.1 Suitability of existing BES models and modelling approaches for assessing the global socio-economic impacts of future changes in BES

We reviewed existing BES models for their potential to be used to assess possible socio-economic impacts of future changes in BES, particularly their ability to produce results that can estimate effects on macroeconomic indicators such as GDP, growth, productivity and jobs.

The previous reviews of relevant BES-economy models by IPBES (2016) and UNEP (2014) provided the starting point for the present assessment. The IPBES review considered several BES models for their usefulness to support the IPBES regional and global assessments, according to the models' ease of use, community of practice, scale of operation, spatial explicitness, and whether they are static or dynamic. The results of the IPBES assessment are shown in Figure 7 and Figure 8. The models reviewed by IPBES (2016) and UNEP (2014) that we suggest are of potential use to meet the needs identified in Chapter 3 are InVEST and Systems Dynamics because they are spatially explicit (InVEST; Figure 7) and are less difficult to use (InVEST and Systems Dynamics; Figure 8), which is important given the short timeframes to produce results identified as a key need.

Here we extend the IPBES review by assessing the major BES models against specific criteria (many not considered in the IPBES review), and then use a traffic-light scoring approach to assess how well the models meet the key needs identified in the needs analysis in Chapter 2. The key BES models are reviewed and assessed for their ability to model socio-economic impacts, which was not a major consideration in the IPBES review. The summary of model characteristics against key criteria is presented in Table 4. The list of models assessed here is by no means exhaustive; they were chosen because they appear more frequently in the literature and in applications where global scenarios of future BES are modelled.

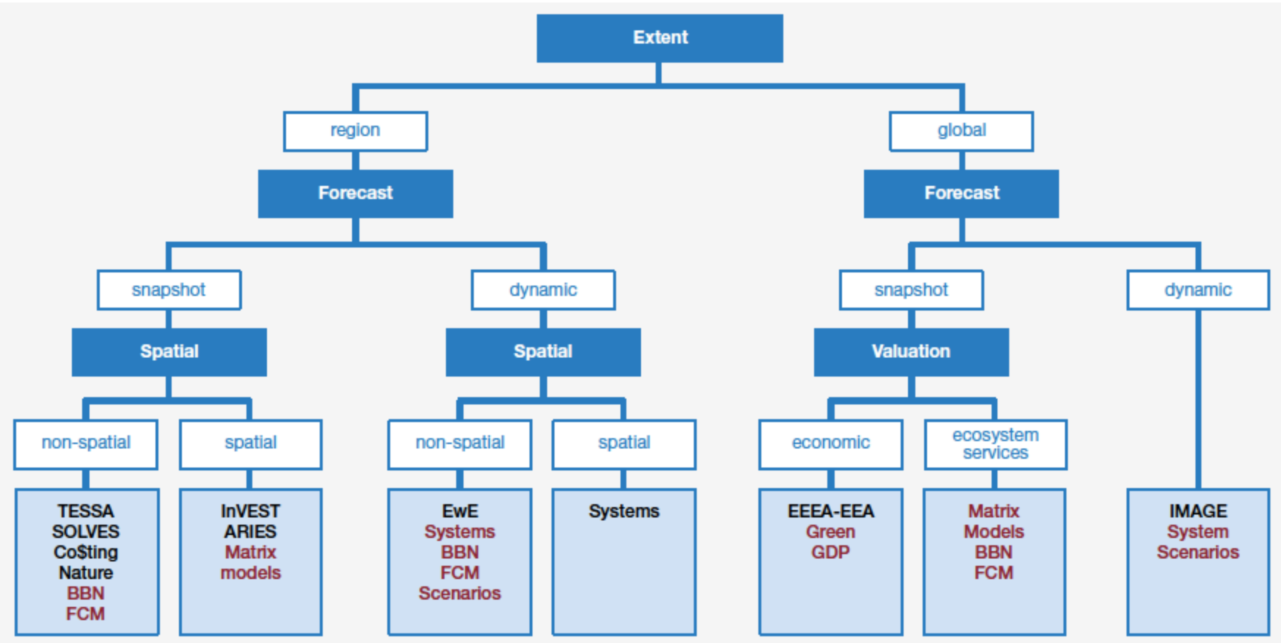

Figure 7. Key ecosystem service modelling approaches (red) and models (black) grouped by IPBES according to their ability to operate at global or regional scale, provide dynamic or snapshot analyses, and spatial explicitness. EwE = Ecopath with Ecosim, BBN = Bayesian Belief Networks, FCM = Fuzzy Cognitive Maps. Source: IPBES (2016)

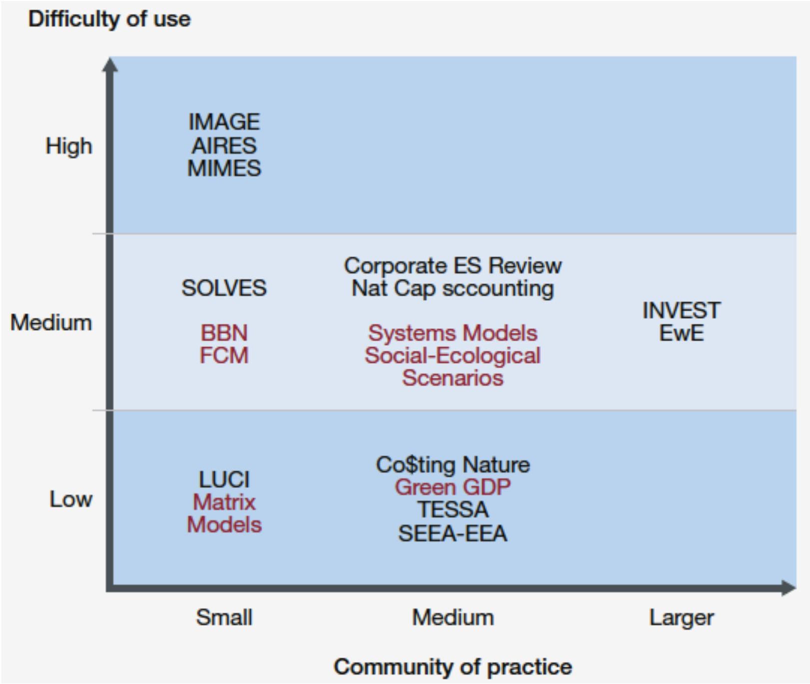

Figure 8. Key ecosystem service modelling approaches (red) and models (black) compared by IPBES for their ease of use and community of practice. Source: IPBES (2016)

3.3.1.1 Madingley model

The Madingley model is a new model developed principally by UNEP-WCMC and Microsoft Research at Cambridge University (Harfoot *et al.* 2014b; Bartlett *et al.* 2016). The model aims to inform decision-makers about the impacts of their choices on BES, and on trajectories of biodiversity change under different scenarios of human development. It is a General Ecosystem Model (GEM), based on similar principles as Ecopath with Ecosim. Initially it models the flows of biomass (organic carbon) of collections of species (cohorts) based on series of fundamental ecological processes (primary production for autotrophs, and eating, metabolism, growth, reproduction, dispersal and mortality for heterotrophs).

The Madingley model is in a relatively early stage of development and at the time of this review is still at an experimental and proof-of-concept stage for assessing anthropogenic impacts on ecosystems. The model uses a novel approach (GEMS), but it's not clear how added complexity from scenarios and external drivers will impact its performance. The model does not consider any impacts to society or the economy from changes to ecosystems.

3.3.1.2 Generalised Dissimilarity Modelling (GDM)

GDM (Ferrier *et al.* 2007; Fitzpatrick *et al.* 2011; Laidlaw *et al.* 2016) is a statistical technique for analysing and predicting spatial patterns of turnover in community composition (beta diversity) across large regions. GDM can be further adapted to accommodate special types of biological and environmental data including, for example, information on phylogenetic relationships between species and information on barriers to dispersal between geographical locations. The approach can be applied to a wide range of assessment activities including visualisation of spatial patterns in community composition, constrained environmental classification, distributional modelling of species or community types, survey gap analysis, conservation assessment, and climate-change impact assessment.

The GDM model has been around for some time but is not as well used as some other biodiversity prediction models. Applications are predominantly in Australia. The model is very useful when biological data is limited because it uses correlates with environmental data. The model does not consider any impacts to society or the economy from changes to ecosystems.

Table 4. BES models assessed against key criteria.

Name	Year of production	Economic and social impacts	Static/ Dynamic	Scenarios used	Impacts assessed	Biomes modelled	Ecosystem services modelled	Scale	Resolution (analysis)	Resolution (reporting)	Available	Possible to extend	Organisation s involved	Link
Madingley	Ongoing; first publication of model in 2014	No	Dynamic. Can be used to investigate tipping points, resilience	Climate, land-use change	Species, biomass impacts	All, including marine	None	Global	Grid-based; flexible	Regional, national, global	Yes - can be freely downloaded and run	Yes - code is freely available	UNEP - WCMC	madingley.github.io
Generalised Dissimilarity Modelling (GDM)	First publication appeared in 2007. Applied recently, e.g. Laidlaw *et al.* 2016	No	Static	Climate, land cover	Changes to community assemblages	All terrestrial	None	Regional (though could be applied globally)	Grid-based; flexible	Regional; national	Yes, available as R code	Yes - code is freely available	Development led by Simon Ferrier (CSIRO)	
PREDICTS	Project in operation since 2012	No	Static	No	Land-use impacts; human population pressures	All terrestrial	None	Global	Point-based	Local - global	Database freely available	Data can be added to. Database can be interpreted in any way	Led by Andy Purvis (British Natural History Museum)	www.predicts.org.uk
GLOBIOM	2010 - ongoing	Yes	Static	Yes, many. Recent scenarios defined to achieve SDGs	Policies of food, biofuels, livestock, forestry and how they drive land-use change	All	Producing ES (food, fibre, timber, biofuels)	Global and regional	Raw grid data between 5-30 arc-minutes. Simulation Units of relatively homogenous areas within country of altitude, slope, soil	Regional - global	No		IIASA	www.globiom.org
GLOBIO	Long history dating back to 1990s. GLOBIO3	No	Static	Yes, typical IPCC/MA style futures to 2050	Land-cover change, land-use intensity, fragmentation, climate change,	All	None	Regional to global	Grid-based (0.5 degree)	Regional to global	Beta version freely available	Not easily	PBL; UNEP-WCMC; UNEP GRID-Arendal	http://www.globio.info/home

Name	Year of production	Economic and social impacts	Static/ Dynamic	Scenarios used	Impacts assessed	Biomes modelled	Ecosystem services modelled	Scale	Resolution (analysis)	Resolution (reporting)	Available	Possible to extend	Organisations involved	Link
	published in 2009, but first used in 2005				atmospheric nitrogen deposition, infrastructure development									
CLUMONDO	2012-13	No	Dynamic.	Yes - user defined (recently used OECD Environment Outlook 2050 scenario)	Sustainability policies	All	Food production; can be expanded to include other ES as part of the land system	Global	5 arcmin land systems	Global	Yes	Yes - code is freely available	VU University	www.ivm.vu.nl/en/Organisation/departments/Environmental-Geography/CLUMondo/index.aspx
Ecopath with Ecosim (& Ecospace, EcoOcean, EcoVal)	Ongoing. Initial models produced in 1990s	Fishery yields	Dynamic	Yes	Changes to fishery yields	Marine	Food (fish)	Global	Marine benthic units	Fisheries / MPAs	Yes	Yes	University of British Columbia	
InVEST	Ongoing. Initial toolbox produced around 2008	No	Static	Yes	Changes to many ecosystem services	Terrestrial and marine	Yes, ~19 in total	Any – though no global application exists at present	Grid-based, flexible	Local, watershed, national, regional	Yes	No	Natural Capital Project (Stanford University, University of Minnesota, WWF, TNC)	www.naturalcapitalproject.org

3.3.1.3 PREDICTS

PREDICTS is a global database led by Andy Purvis at the British Natural History Museum (Newbold *et al.* 2016; Hudson *et al.* 2017). The PREDICTS project has compiled a large, reasonably representative database of comparable samples of biodiversity from multiple sites that differ in the nature or intensity of human impacts relating to land use. Data is used to develop global and regional statistical models of how local biodiversity responds to these land-use intensities. The database contains more than 3.2 million records sampled at over 26,000 locations and representing over 47,000 species.

At present, PREDICTS does not forecast biodiversity extent or changes under future scenarios. It is not a modelling or prediction tool. It is a large, current database of biodiversity with useful attributes of land use and it could be used to explore relationships between human pressures and biodiversity.

3.3.1.4 GLOBIOM

IIASA's Global Biosphere Management Model (GLOBIOM) (Havlík *et al.* 2011; Obersteiner *et al.* 2016) is used to analyse the competition for land use between agriculture, forestry and bioenergy, which are the main land-based production sectors. As such, the model can provide scientists and policy-makers with the means to assess, on a global basis, the rational production of food, forest, fibre and bioenergy, all of which contribute to human welfare. As of 2016, 57 world regions are represented in the global model. Regional models have been developed to provide more detailed spatial representation of land-use changes to assess the impact of specific regional policies.

The GLOBIOM model is a global-scale land-use change model of significant note. It is current, well resourced, and developed by the highly reputable IIASA. At its core is a partial equilibrium economic model that allocates land uses given the objective of maximising consumer/producer surpluses, with rules defined by scenarios/targets/production constraints. It operates efficiently because it aggregates spatial environmental heterogeneity to a small number of simulation units. The representation of biodiversity is limited to inputs of six land-cover classes and global biodiversity hotspots. GLOBIOM was originally developed to assess carbon emissions from the land sector under alternative future scenarios. The recent paper by Obersteiner *et al.* (2016) presents the latest version of the model applied to assess trade-offs for achieving some land-related targets of the UN SDGs.

3.3.1.5 GLOBIO

Developed by the Dutch Environment Agency, PBL, GLOBIO is a modelling framework to calculate the impact of environmental drivers on biodiversity for past, present and future (Alkemade *et al.* 2009). GLOBIO is based on cause-effect relationships. The model uses spatial information on environmental drivers and their changes as input, sourced from PBL's IMAGE integrated assessment model. The mean abundance (MSA) of original species relative to their abundance in undisturbed ecosystems is used as the indicator for biodiversity. Drivers considered are land-cover change, land-use intensity, fragmentation, climate change, atmospheric nitrogen deposition, and infrastructure development. GLOBIO3 addresses: i) the impacts of environmental drivers on MSA and their relative importance; ii) expected trends under various future scenarios; and iii) the likely effects of various policy response options. The GLOBIO modelling framework consists of a model for terrestrial ecosystems and a model for the freshwater environment. The Sea Around Us project of the University of British Colombia (UBC) has developed a similar model for marine ecosystems: EcoOcean, a member of the Ecopath with Ecosim family.

The GLOBIO model estimates changes to a biodiversity proxy index (MSA, similar to the biodiversity intactness index) based on changes to environmental drivers. It's most relevant and useful across large scales and regions. The model employs basic statistical relationships between environmental drivers and biodiversity, but it is not possible to investigate processes which may be critical in forecasting changes to BES. The model has wide uptake in global assessments (e.g. CBD, UNEP, Millennium Ecosystem Assessment) and the developer (PBL) is very well connected into IPBES through hosting of the technical support unit for the IPBES Modelling and Scenarios Assessment.

3.3.1.6 CLUMondo

CLUMondo (van Asselen & Verburg 2013; Eitelberg, van Vliet & Verburg 2015) is a forward-looking global model that simulates land system changes as a function of exogenously (i.e. externally) derived demand for crop production, livestock, and area for urban uses. The land system map combines data on land cover (tree and bare land cover, cropland area, built-up area), livestock density and intensity of agricultural production. The model allocates at time (t) for each grid cell (i) the land system with the highest transition potential. The transition potential is a function of the local land suitability, the conversion resistance and the competitive advantage of a land system.

CLUMondo was developed by Peter Verburg's research group. It's a robust land-use change model with pedigree and is well published in the scientific literature. It is used in the PBL IMAGE model framework to assess land-use change from different policy scenarios. It arguably leads the pack of the many standalone land-use models (and modules of integrated assessment models (IAMs)) that have been developed with different modelling approaches, scales and resolutions. Examples of other land-use change models include CAPS (Meiyappan *et al.* 2014), GLM (Hurtt *et al.* 2006), LandSHIFT (Schaldach *et al.* 2011), MAgPIE (Lotze-Campen *et al.* 2010), the Nexus land-use model (Souty *et al.* 2012), the Land-Use Trade-Offs (LUTO) model (Bryan *et al.* 2016).

CLUMondo and other land-use change models typically rely on indicators of the economy to build scenarios of future drivers of land change and land-use dynamics. Some models also estimate the impacts on macroeconomic indicators from the forecast land-use changes. But this family of models rarely estimate changes to BES from land-use change; instead they may be loosely coupled to ecosystem service models which take land-use change scenarios to model impacts on BES.

3.3.1.7 Ecopath with Ecosim

Ecopath with Ecosim (EwE) (Christensen & Walters 2004) was developed to dynamically represent energy flows through marine and aquatic ecosystems. Its structure means that it can easily include fishers and fish consumers in its models. EwE describes a static mass-balanced snapshot of the stocks and flows of energy (usually biomass) in a marine ecosystem. The modelled food web is represented by functional groups that include one or multiple species with similar life history characteristics and trophic ecology, and biomass removal by fishing is explicitly represented. Ecopath is described by two basic equations describing biomass production and consumption. It uses a system of differential equations to describe the changes in biomass and flow of biomass within the system over time, by accounting for changes in predation, consumption and fishing rates (Walters, Christensen & Pauly 1997). The spatial resource use of predators and prey is implicitly represented. It is primarily designed to explore fishing scenarios and their implications for the exploited ecosystems and fisheries catches. The model also examines the impacts of environmental change scenarios, such as climate change. It allows users to explore the effects of spatial fisheries management policies such as marine protected areas.

EwE has very strong pedigree and publication and has been widely used to generate scenarios of changes in fishing effort or fisheries management on flows of services from marine ecosystems. It is one of the few biodiversity models that explicitly represents both species and specific groups of beneficiaries. However, it can only assess limited fisheries-related impacts.

3.3.1.8 InVEST

The Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) is a toolbox used to investigate the changes in supply of 19 ecosystem services under different scenarios, such as land-use change and climate change. Originally developed as a plug-in to the ESRI ArcGIS software, InVEST is now available as a standalone toolbox. Users prepare spatial data and biophysical parameter files prior to running individual ecosystem service tools. The spatial data requirements for each ecosystem service tool vary according to the ecosystem service modelled, but land use is common across all terrestrial ecosystem service tools in InVEST.

InVEST has a wide user community with an estimated 19,000 members and the toolbox is under continual development and improvement with new versions released regularly. The tools are easy to use. However, intermediate GIS skills are a minimum for spatial data preparation. At least an intermediate level of technical skills is needed to understand the biophysical models and processes central to each ecosystem service tool, which is important for interpreting model outputs.

At the time of writing (late 2017), a small number of InVEST ecosystem service models are being applied at global scale to support the IPBES Global Assessment. The Natural Capital Project is partnering with PBL to estimate change in ecosystem service supply under alternative land-use change scenarios. The land-use change scenarios are provided by PBL's IMAGE integrated assessment model (see Section 3.3.2.1 below).

3.3.2 Suitability of existing integrated environment-economy models and modelling approaches for assessment of the socio-economic impacts of future changes in BES.

There is a significant literature on the economic modelling of a change (policy or exogenous shock) on provisioning ecosystem services such as food, fuel and fibre, both at the national and global scale. Economy-wide dynamic computable general equilibrium (CGE) models are particularly well suited for this type of analysis as they may be used to estimate overall economic and welfare impacts, both short and long run, of policy and other shocks. CGE models capture the dynamics between economic sectors, have an endogenous price and demand system and consider factor constraints, thus overcoming the absence of feedbacks which is a major limitation of input-output modelling. The theoretical underpinnings of CGE models are relatively consistent across models, with some variation depending on the research question being addressed. There are CGE models available for many countries around the globe. At the global scale, the Global Trade Analysis Project (GTAP) database and modelling framework is the most prominent approach.

Economy-wide models that enable policy simulations and generate results in terms of economic and welfare impacts, as well as impacts on non-provisioning ecosystem services and biodiversity, are largely absent at the national and global scales. Partial equilibrium or case study approaches are the most common in estimating policy impacts on some economic indicators and specific ecosystem service supply. What is missing is an integrating framework which enables policy and scenario analysis, where a policy change or shock has an impact on an economic system; the shock is then transmitted to ecosystem assets which can affect ecosystem service supply and use, and this in turn has feedbacks to the economy.

Here we assess the major integrated economy-environment models against specific criteria, then at the end of Chapter 3 use a traffic-light scoring approach to assess how well the models meet the key needs identified in the needs analysis in Chapter 2. The key integrated economy-environment models are reviewed and assessed for their ability to model socio-economic impacts arising from changes in BES. The summary of model characteristics against key criteria is presented in Table 5. The models assessed here are by no means exhaustive, but were chosen because they appear more frequently in the literature.

3.3.2.1 IMAGE

IMAGE 3.0 is an integrated assessment modelling framework developed to analyse the dynamics of global, long-term environmental change and sustainability problems (Stehfest *et al.* 2014). IMAGE contains an ecosystem service module that quantifies the supply of eight ecosystem services. Ecosystem services derived directly from other IMAGE components include food provision from agricultural systems, water availability, carbon sequestration and flood protection. Estimation of the ecosystem services of wild food provision, erosion risk reduction, pollination, pest control, and attractiveness for nature-based tourism requires additional environmental variables and relationships (Maes *et al.* 2012; Schulp *et al.* 2012), in particular, fine-scale land-use intensity data from the GLOBIO model (Alkemade *et al.* 2009). IMAGE compares the supply of different services with estimates of the minimum quantity required by people to assess surpluses and deficiencies. This translates, for example, into minimum amounts of food and water for humans to stay healthy, or the minimum amount of natural elements in a landscape to potentially pollinate all crops.

IMAGE has been coupled to the OECD's ENV-Linkages CGE model to analyse environmental implications of economic policies. The coupled IMAGE-ENV-Linkages model supported the OECD 2050 Environmental Outlook (OECD 2012) to assess what demographic and economic trends could mean for the environment under current policies, and the impacts on the environment of adopting green policies. The assessment follows the more typical approach of looking at future impacts to BES under different social and economic scenarios.

Table 5. Integrated economy-environment models assessed against key criteria.

Name	Year of production	Economic and social impacts	Static/ dynamic	Scenarios used	Impacts assessed	Biomes modelled	Ecosystem services modelled	Scale	Resolution (analysis)	Resolution (reporting)	Available	Possible to extend	Organisations involved	Link
IMAGE (Integrated Model to Assess the Global Environment)	Ongoing – most recent version 2014	Yes	Static	Yes	Changes in land cover and use	Global	Yes, 8 in total	Global	Grid-based (0.5 degree)	Global	Yes		PBL	themasites.pbl.nl/models/image/index.php/IMAGE_framework
IFs (International Futures simulator)	Ongoing; development started in early 1980s	Yes, many economy, demography and human development indicators. Prominent indicators include GDP, Human Development Index (HDI), GINI coefficient	Dynamic	Yes - user defined. Model is scenario driven	Policy scenarios. Recently investigated environmental declines (mostly through severe climate change)	Global model at country resolution	Food production	Global	Country	Global	Yes	Not sure	University of Denver	pardee.du.edu
GUMBO (Global Unified Metamodel of the Biosphere) and MIMES (Multiscale Integrated Model of Ecosystem Services)	GUMBO - 2000; MIMES - 2015	Ecosystem service values	Dynamic	Yes - user defined. Typically follow BAU, nature, development focus	Land-cover changes driven by human development and policy scenarios	All for the global model - based on 240 countries. Administrative units are the main resolution	Yes, 12 in the global model	Global - watershed	Global - units of analysis are countries	Global to catchment	No	Yes	Roel Boumans (private consultant, AFORDable Futures LLC). Originally developed at Gund Institure at University of Vermont	www.afordablefutures.com
Systems Dynamics (SD)	Broad family of models; ongoing,	Yes, able to include most	Dynamic	Yes, user defined	Any indicators of interest within the	Not spatially explicit	Possible, but constrained	National - watershed	Coarse units (e.g.	National	Yes	Yes	Many. Of note is recent work of	www.millennium-institute.org

Name	Year of production	Economic and social impacts	Static/ dynamic	Scenarios used	Impacts assessed	Biomes modelled	Ecosystem services modelled	Scale	Resolution (analysis)	Resolution (reporting)	Available	Possible to extend	Organisations involved	Link
	pioneering work dating back to 1950s	macroeconomic indicators			system modelled		by limited spatial resolution of SD models		administrative units)				Millennium Institute and UNEP Green Economy modelling (Threshold21 World model)	
CGE models (e.g. GTAP)	Type of economy model. Ongoing development; early work dating back to 1950s	Whole economy model	Dynamic	Yes, user defined	Macroeconomy (e.g. GDP, employment, trade)	Coarse – agro-ecological zones	Mostly provisioning (food, biomass, water)	Agro-ecological zones	Agro-ecological zones; countries; coarse administrative units	National-global	Yes	Yes	Many	www.gtap.agecon.purdue.edu
IEEM + ESM (Integrated Environment Economy Model + Ecosystem Service Models)	Ongoing	Yes, uses GTAP whole economy model	Dynamic	Yes, user defined	Economy and BES	Terrestrial – uses grid-based land change model	Current applications food, water (quantity and quality), carbon, flood risk, pollination	National	Grid-based	National - watershed	No	Yes	Inter-American Development Bank, World Bank, Monash University	www.ieemplatform.org

3.3.2.2 GUMBO and MIMES

GUMBO is a global system dynamics (SD) meta-model for exploring possible future planetary scenarios. GUMBO is the first global model to include the dynamic feedbacks among human technology, economic production and welfare, and ecosystem goods and services within the dynamic Earth system. MIMES is an SD model of human-environment systems at different scales. MIMES projects aim to integrate participatory model building, data collection and valuation. GUMBO was a predecessor to MIMES.

GUMBO/MIMES to date has a small number of real-world applications. The model simulates future land-use changes (across 11 land-use types) based on ecosystem service production functions (12 ecosystem services) and economic production functions. An object function aims to maximise outcomes based on economic development, population and climate change scenarios.

3.3.2.3 IFs (International Futures simulator)

The IFs is large-scale, long-term, integrated global modelling system (Hughes & Johnston 2005; Hughes *et al.* 2012). The IFs was designed to facilitate exploration of global futures through alternative scenarios. Originally developed for educational purposes, IFs is increasingly used in policy analysis and international assessments. It has been applied in the UNEP GEO-4 and for assessing UN Millennium Development Goals. The model represents demographic, economic, energy, agricultural, socio-political, and environmental subsystems for 183 countries interacting in the global system. It is integrated with a large database containing values for its many foundational data series since 1960, effectively operating as an input-output model.

The IFs model was developed by Professor Barry Hughes. The model was originally developed for teaching but has more recently been applied in several policy settings, such as European Commission-funded projects into sustainability futures and the UNEP GEO4. The land and biodiversity sectors are coarsely represented (forest cover is a single variable). The environment is represented by climate change aspects.

3.3.2.4 System dynamics

SD modelling is a pioneering approach to link economy and ecosystem models. SD is an umbrella term for a group of models that aim to reveal insights about system behaviour. The methods were originally developed in the 1950s to support managers in industrial manufacturing sectors. SD is now used widely in the public and private sector for policy analysis and design, and has recently extended to applications in green economy modelling and ecosystem service modelling and decision-making (UNEP 2014; Bassi 2015; Bassi, Gallagher & Helsingen 2016). A well-known application of SD is the Club of Rome's 1972 Limits to Growth model which forecast that the exponential growth of human population and capital, with finite resource sources and sinks and perception delays, would lead to economic collapse during the 21st century under a wide variety of growth scenarios.

The SD models are developed in participatory settings and can be used as management tools for comparing dynamic and incremental changes in a system under alternative scenarios. A key assumption is that the behaviour of a system emerges from its structure, represented through cause-effect relationships and feedback loops, rather than from the values of individual variables, which is the structure typical of most models.

SD offers a very powerful tool for describing the global BES-economy system, and has a deep pedigree to support decision-making. But the major drawback for application is that SD primarily uses non-spatial models that have a very high level of aggregation to single or very few spatial units (Bassi 2015). Spatial dynamics are essential in models to improve understanding of the socio-economic impacts of future changes in BES. A further challenge of SD approaches is deciding where to set the boundaries of the system description and parameterisation in a complex global, spatially explicit and dynamic system.

A recent review of models linking ecosystems to the macroeconomy (Smith 2013) concluded that SD models such as GUMBO, MIMES, IFs and Threshold 21 have the critical shortcoming of determining prices exogenously. Given that prices are the major way resources are allocated in most economies, economic predictions from these SD models cannot be relied upon (Smith 2013). The review concludes that models linking dynamic CGE economic models to dynamic ecosystem models, where prices and capital are endogenous, the ecosystem feeds back into the economy and the economy directly affects the ecosystem, offer the most robust way to assess the impact to the economy of changes in BES (Smith 2013).

3.3.2.5 CGE - GTAP

To model the global economic impacts of scenarios and policies (e.g. IPCC SSP scenarios, implementation of selected SDGs, new IPBES scenarios) on BES changes and vice versa, the GTAP Database provides the most complete statistical representation of the economies of the world. GTAP 9 is the latest release of the database which includes databases from 2004, 2007 and the most recent, 2011, for 140 countries/regions of the world and for 57 goods and services (Aguiar, Narayanan & McDougall 2016). Countries are quantitatively linked together through international trade, transport and protection linkages. The GTAP database is derived from contributions made by users, based on national accounts and related data, published by national governmental institutions responsible for the System of National Accounts in each country. This data is processed and delivered to GTAP in the format required to ensure consistency and compatibility within and between country datasets.

In terms of global economic modelling of provisioning ecosystem services, many examples exist. Burniaux and Truong (2002) developed an Energy-Environmental extension to the global GTAP model (GTAP-E), which is a widely used multi-region, multisector model used since 1993 for quantitative analysis of international policy issues. Burniaux and Truong's approach introduces substitutability between energy types in the GTAP model. In addition to substitutability, GTAP-E incorporates emissions as well as emissions trading. Berrittella *et al.* (2007) developed an extension to the GTAP model (GTAP-W) to evaluate groundwater scarcity in the context of international trade.

GTAP's Land Use and Land Cover Database builds on global land cover and land use and forestry remote-sensing products and databases (Baldos & Hertel 2012). This database contains three land-use classes: crops, with many types of crops within this class; pasture; and forests. These land-use classes are distributed in each country/region according to 18 agro-ecological zones (AEZs) (Stevenson *et al.* 2013; Byerlee, Stevenson & Villoria 2014).

GTAP-AEZ (Hertel *et al.* 2008) introduces intra- and inter-regional land and land-based greenhouse gas emissions heterogeneity. The crop production structure in GTAP is modified by introducing heterogeneous land endowments with differentiated productivities, and introducing land competition into land supply where crops compete with each other within AEZs; crops compete with grazing; agriculture competes with forest-based uses within an AEZ; and different types of land may be imperfectly substituted for the production of a given agricultural or forest product. To achieve this end, the GTAP land-use database was improved by disaggregating land endowments and land use (Hertel *et al.* 2008).

The GTAP-AEZ framework has advantages over other global economic models of land-use change such as IMPACT, the World Agricultural Trade Simulation Model (WATSIM), Agriculture and Land Use Model (AgLU), and the Forest and Agriculture Sector Optimization Model (FASOM). Specifically, the dynamic GTAP model, underpinned by the GTAP-AEZ database, considers general equilibrium impacts; in Stevenson *et al.* (2013), land market effects were found to be significant in driving results. Further application of the GTAP-AEZ database in evaluating crop intensification impacts on land use show that investment in research and development at the global level is an important strategy to reduce pressure on natural ecosystems, though global aggregates tend to obscure localized shifts that can impact ecologically important areas (Byerlee, Stevenson & Villoria 2014).

Steinbuks and Hertel (2012) develop a global partial equilibrium model, FABLE (Forestry, Agriculture Biofuels Land use and Environment) for analysing optimal global land use within a context of increasing demand for food, bioenergy, forest products, along with demand for non-provisioning ecosystem services and meeting greenhouse gas targets. As a partial equilibrium model, nine sectors are modelled: agriculture, livestock, food processing, biofuels, energy, forest, timber processing, and ecosystem services. While the model is a powerful tool for examining the optimal trajectory of a variety of land uses under certain demand assumptions, the emphasis is on specific sectors of the economy, which ignores general equilibrium effects and is not suitable for estimating overall socio-economic or household welfare impacts (Steinbuks & Hertel 2012; Hertel 2017).

The treatment of the ecosystem services sector is of interest in FABLE. It is treated as a sector that provides a public good to society in the form of aggregate ecosystem services. This sector combines different types of land to produce terrestrial ecosystem services. Ecosystem services, with their importance in the evolution of demand for land in the long run, are incorporated in the model in a stylised way, and their inclusion impacts the optimal land-use path in the future. Ecosystem services are represented by a constant elasticity function of different land inputs. Types of land substitute imperfectly in the production of ecosystem services, with protected forest land, for example, being more efficient in delivering some ecosystem services (Steinbuks & Hertel 2012; Hertel 2017).

The KLUM@GTAP framework links the Kleines Land Use Model (KLUM) with an extended version of GTAP, GTAP-EFL, to assess climate change impacts on cropland allocation. GTAP-EFL separates energy factors from intermediate inputs and nests them with capital, and the database is extended to consider CO_2 emissions. KLUM, on the other hand, is a global agricultural land-use model that links the economy to global crop allocation to maximise producer returns under certain assumptions about risk. In essence, KLUM@GTAP substitutes the land allocation mechanism within GTAP-EFL where regionally aggregated area changes in cropland determined by KLUM are used to update cropland shares in GTAP-EFL (Ronneberger *et al.* 2009).

3.3.2.6 IEEM + ESM

The Integrated Economic-Environmental Modelling (IEEM) Platform project has developed a framework for integrating data organised under the SEEA in a dynamic CGE framework. IEEM captures the dynamic of provisioning ecosystem services as inputs into economic processes and the returns to the environment in terms of emissions and waste. The IEEM Platform project is now integrating regulating and cultural ecosystem services in an extended IEEM + Ecosystem Services Modelling (IEEM + ESM) framework. In this work, IEEM generates results in terms of economic indicators and land-use change. The land-use change is transferred to a high-resolution spatial grid, and ecosystem service supply modelling is undertaken with the Natural Capital Project's InVEST modelling suite under future policy scenarios. This work is under way in Rwanda (Banerjee *et al.* 2017a), Guatemala and Colombia under the IEEM Platform initiative.

At the national level, IEEM land-use change results are allocated spatially to develop scenario-based future land-use and land-cover changes. This data is used to estimate future ecosystem service supply for a given scenario. Feedback loops are then integrated in the framework where scenarios have impacts on land use, land cover and future ecosystem service supply. These changes in future ecosystem service supply are iteratively implemented as shocks in IEEM dynamic CGE until the final period of analysis (Banerjee *et al*., in revision; Banerjee *et al*., 2017).

The IEEM Platform was developed to integrate ecosystem services in an economy-wide framework. In the past, integration of ecosystem services and assets in a CGE framework has typically considered only one ecosystem asset at a time (e.g. forests). The publication of the SEEA has enabled these challenges to be overcome where provisioning ecosystem services are concerned.

The first IEEM Platform was developed for Guatemala, the country with the strongest environmental accounts under the SEEA in the Latin American and Caribbean (LAC) region (Banerjee *et al.* 2017b; Banerjee *et al.* In revision). Since then, a generic version of the IEEM Platform was developed enabling its application to any country with robust national and SEEA accounts. The IEEM approach has been applied to several countries in the LAC region, including Costa Rica and Colombia, and beyond the LAC region with a first application in Rwanda.

With the first step taken to integrate provisioning ecosystem services into a CGE framework, the next step was to consider regulating and cultural/aesthetic ecosystem services. The linkage between IEEM or other economy-wide models and ecosystem service models is established primarily through changes in land use and land cover (LULC). These changes can be shifts from forests to agricultural land, as well as between different types of crops within agricultural areas. The IEEM for Rwanda (IEEM-RWA) was developed integrating Rwanda's recently published water and land accounts organised under the SEEA. With IEEM-RWA calibrated with Rwanda's land accounts, it has been used to simulate various policy scenarios related to Rwanda's Green Growth Strategy, giving results in terms of standard economic indicators, wealth indicators, and changes in LULC (Banerjee *et al.* 2017a). A land-use change model was developed for Rwanda to translate land-use change at the national level to a 30x30-metre grid, enabling new LULC maps for each future scenario to be developed. These new maps are being used to estimate future ecosystem service supply with the calibrated InVEST models for erosion mitigation, climate regulation and water provisioning services (Banerjee *et al.* 2017a; Bagstad In preparation). Similar efforts are now under way in Guatemala and Colombia where IEEM combined with ecosystem service modelling is being used for scenario analysis and the production of new LULC future scenario maps.

3.3.2.7 Other integrated economy-environment models and approaches

The MAES initiative aims to link socio-economic systems with ecosystem assets through the flow of ecosystem services. The initiative is pursuing the biophysical baseline mapping and assessment of major ecosystems and ecosystem services; the development of future scenarios depicting potential change; and the valuation of ecosystem services for scenario modelling. Efforts thus far have focused on the mapping and assessment of ecosystem assets and ecosystem services (European Commission 2015). This work establishes ecosystem asset classes based on CORINE Land Cover Classes, adjusted by the European Nature Information System (EUNIS) where necessary given the geographical focus of the project, which is the European Union. The Common International Classification of Ecosystem Services (CICES) framework is used for compatibility with the SEEA and to integrate ecosystem mapping and environmental accounting (European Union 2013).

In the European context, there are various initiatives that support MAES. OpenNESS (Operationalization of Natural Capital and Ecosystem Services) aims to develop operational frameworks for decision-making which consider natural capital and ecosystem services. OPERAs (Operational Potential of Ecosystem Research Applications) aims to improve understanding of how ecosystem services contribute to wellbeing. VOLANTE (Visions of Land Use Transitions in Europe) advances land system science to inform land use and natural resources-related decision-making. ESMERALDA (Enhancing ecoSysteM sERvices mApping for poLicy and Decision mAking) aims to deliver a flexible methodology to provide the building blocks for pan-European and regional mapping and assessment of ecosystem services.EU BON (Building the European Biodiversity Observation Network) is generating a European Biodiversity Portal (European Union 2013).

Gao and Bryan take a partial equilibrium approach to assessing the feasibility of achieving various SDG targets for Australia focusing on improving economic returns to land use, food/fibre production, water resource use, renewable energy, emissions abatement, and biodiversity and land degradation. The authors' approach is to translate and adapt global targets to national-level targets through downscaling and operationalising measures to achieve the goals. The Land Use Trade Off (LUTO) model was used to project future pathways for Australian land use; it projects outcomes of competition between 24 land-use types (Gao & Bryan 2017). While the emphasis is on provisioning ecosystem services, the study does consider biodiversity and emissions abatement and has potential for evaluating other non-provisioning ecosystem services through linkages with biophysical models.

3.3.3 Suitability of existing data for assessment of the global socio-economic impacts of future changes in BES

Models for BES and integrated environment-economy assessments depend on data and frameworks that can describe both the environment and the economy now and in the future. Data describing the state and trends in biodiversity, natural capital and the supply of ecosystem services has been reviewed many times before (Martínez-Harms & Balvanera 2012; Crossman *et al.* 2013; Andrew *et al.* 2015; IPBES 2016; Neugarten *et al.* 2016), and we feel there is little new that can be added here. Therefore, this section focusses on the data and frameworks that have received less attention but are critical to the application of integrated environment-economy models for assessing the socio-economic impacts of future changes in BES. First, we review the available data and databases on economic value of BES. Second, we describe the System of Environmental-Economic Accounting (SEEA) Central Framework and the associated Experimental Ecosystem Accounts (EEA). The SEEA-EEA takes the monetary value of ecosystem services as a major input, although only at the level of exchange value, rather than the broader welfare value.

3.3.3.1 Databases of ecosystem service values

A broad view of economic metrics linked to ecosystem services includes economic welfare, national income (i.e. GDP), employment, factor productivity, competitiveness, poverty, resource dependence, income inequality, and others. Past research, and as a result the available literature, is dominated by efforts to estimate the monetary value of economic welfare derived from ecosystem services, and to a lesser extent impacts on GDP. Evidence on the links between ecosystem services and other economic metrics exists at the level of individual case studies for specific locations but this information has not yet been organised into available databases. In addition, there is currently a revived interest in measuring the importance of ecosystem services using alternative value systems (alternative to conventional welfare economics) using concepts such as nature's contributions to people and associated shared, plural, social and intrinsic values. Applications that measure and integrate such concepts are still limited. The material reviewed here therefore focuses on available data and databases of economic welfare estimates for ecosystem services.

The number of studies that estimate monetary values for ecosystem services has grown dramatically over the past 20 years. Figure 9 represents the cumulative number of valuation studies included in the Environmental Valuation Reference Inventory (EVRI) up to the year 2008. The number of valuation studies published since 2008 is even greater and the EVRI database now contains over 4,000 records.

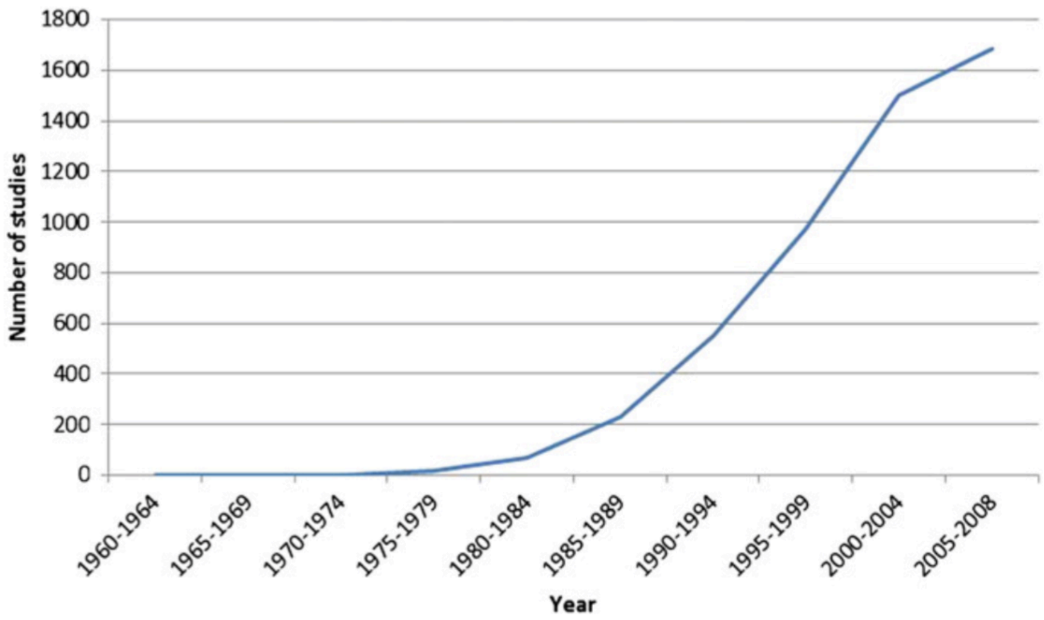

Figure 9. Cumulative total of ecosystem services valuation studies. Source: De Groot *et al.* (2012)

Individual 'primary' economic valuation studies have the following general characteristics:

- They provide an estimate of the monetary value of one ES, multiple ES, or bundles of ES for a specific case study location.
- They apply a single valuation method. In a small number of studies, two methods may be applied to value the same ES in order to cross-validate results.
- The scale of study sites is generally small (e.g. individual ecosystems, watersheds or protected areas).
- Values are estimated for marginal changes in ES provision or marginal changes in study site area or quality; or for total ES provision over a period of time.
- Values are generally estimated per beneficiary (e.g. US$/household/year); as total values for the study site (e.g. US$/year); or as average values per unit area of the study site (e.g. US$/hectare/year).
- Values are generally reported per year; or occasionally as present values (discounted stream of future values over a number of years).

In short, individual ecosystem service values are generally for small study sites and provide a snapshot of value for a very specific set of biophysical, socio-economic and methodological conditions; it is therefore not necessarily possible to make generalisations from these values.

Several initiatives have attempted to organise the expanding number of valuation studies into publicly available online databases. Table 6 provides a summary of these databases. The EVRI database is the largest available repository of economic valuation studies but from the perspective of using this information to model global ES values, there are several limitations: i) the information is organised per study (not per value estimate); ii) value estimates are not standardised to common units (e.g. US$/ha/year) and so cannot be immediately compared or pooled without first undertaking standardisation; and iii) some of the studies included in EVRI value environmental benefits/costs other than ecosystem services, such as air pollution. EVRI is a useful resource for finding individual studies but is not a database of values that can be readily summarised or used in a meta-analysis for value transfer purposes.

The Ecosystem Service Valuation Database (ESVD) developed by the TEEB initiative provides a more readily usable dataset in that it contains only valuation studies for ES and values have been standardised to common units (US$/ha/year at 2007 price level). See de Groot *et al.* (2012) and McVittie and Hussain (2013) for overviews of the ESVD.

Several other global databases of ecosystem service values have been developed but now appear to be offline or discontinued. The Ecosystem Valuation Toolkit developed by the consultancy firm Earth Economics claims to contain thousands of ES value estimates but is not publicly available. Summary information about this database is also unavailable so it is not possible to judge its merits.

In addition to global databases, Table 6 lists several publicly available regional or national databases for SE Asia, US, Australia, New Zealand and Sweden. Maintaining and updating such databases appears to be challenging, with most remaining frozen at the time that the funding project/initiative ended.

3.3.3.2 Meta-analyses of ecosystem service economic values

Estimated values for ecosystem services are observed to vary significantly across biomes, environmental conditions and socio-economic contexts (not to mention valuation methods). To synthesise this expanding body of information and make sense of the variation in values, there has been considerable research interest in meta-analysis of ecosystem service valuation studies. Meta-analysis is a statistical method of combining estimates from multiple studies that allows the analyst to systematically explore variation in existing estimates and its determinants (Stanley, 2001).

In addition to summarising existing value data and exploring determinants of variation, meta-analysis provides a means for predicting the value of ecosystem services. The prediction of values is referred to as value transfer. Value transfer, and particularly meta-analytic value transfer, provides a viable means of estimating the value of ecosystem services at a global scale. The regression equation estimated through a meta-analysis can be interpreted as a value function (i.e. an equation that relates the value of an ecosystem service to the characteristics of the ecosystem and the beneficiaries of the ecosystem service). A meta-analytic value function can be used in conjunction with information on parameter values for the “policy site” to calculate the value of an ecosystem service that reflects the characteristics of that site. A key advantage of using a meta-analytic value function over other value transfer methods is that it is estimated from the results of multiple studies and is therefore able to represent and control for greater variation in the characteristics of ecosystems, beneficiaries and methodological aspects of the underlying primary valuation studies. Many of the important determining characteristics of ecosystem service value vary spatially, and so the use of meta-analytic value functions for value transfer has proved useful in generating value maps (i.e., estimating and representing spatial variation in values) – see Schägner *et al.* (2013). Appendix 2 provides an overview of 55 meta-analyses of ecosystem service values. Largely following the availability of underlying primary valuation estimates, there are many meta-analyses examining values for wetlands (10), forests and woodland (7), and fresh water (9). There are relatively few meta-analyses that examine values for agricultural land (2), coastal ecosystems (3), and urban green space (1).

Generally, meta-analyses of valuation estimates have focused on specific ecosystems (e.g., wetlands, forests) rather than on specific ecosystem services. Such meta-analyses attempt to examine variation in values for a range of ecosystem services or bundles of ecosystem services. Meta-analyses that do focus on a single ecosystem service (possibly provided by a range of different ecosystem types) most commonly examine recreation values (e.g. Sen *et al.*, 2013). This reflects the relative abundance of valuation estimates for this ecosystem service. There are also a few meta-analyses that examine values for conservation of biodiversity or endangered species. This distinction between value functions estimated for specific types of ecosystem (land-use class) vs. specific ecosystem services is important for making the link to the results of biophysical models of land-use change and ecosystem service provision. Some biophysical models produce results primarily in terms of changes in land use whereas others generate estimates of changes in ecosystem service provision.

Table 6. Ecosystem service valuation databases

Database name	No. values	Geographic coverage	Comment	Link
Environmental Valuation Reference Inventory (EVRI)	4000	Global	Large repository of study data. Values not standardised to common units. Not restricted to ES values and also includes estimates for air pollution etc.	www.evri.ca
Ecosystem Service Valuation Database (ESVD)	1350	Global	Values standardised to common units (US$/ha/year). Contains a large number of coded variables for each value estimate describing ES, ecosystem, location, method.	www.es-partnership.org/services/data-knowledge-sharing/ecosystem-service-valuation-database
Marine Ecosystem Services Partnership Library	1054	Global	Searchable map of study sites	www.marineecosystemservices.org/explore
Ecosystem Valuation Toolkit		Global	Private database. Unresponsive to sharing summary information	www.esvaluation.org/gap_analysis.php
ConsValMap (CI 2006)		Global	Offline	www.consvalmap.org
Ecosystem Services Project Database		Global	Offline	www.naturalcapitalproject.org/database.html
ASEAN TEEB Valuation Database (Brander and Eppink, 2012)	787	Southeast Asia	Values are not standardised to common units (i.e. values are recorded in original currencies per physical and temporal unit)	lukebrander.com
Envalue		US and Australia	Not updated	www.environment.nsw.gov.au/envalueapp
National Ocean Economics Program (NOEP)		US	Values are not standardised to common units	www.oceaneconomics.org/nonmarket/NMsearch2.asp
Non-market Valuation Database		New Zealand	Values are not standardised to common units	www2.lincoln.ac.nz/nonmarketvaluation
ValueBaseSwe	122	Sweden	Values are not standardised to common units	www.beijer.kva.se/valuebase.htm

The definition of the dependent variable (i.e. ecosystem service value) in a meta-analysis is crucially important for how the meta-analytic value function can be linked to the outputs of biophysical models and used for value transfer. Generally the values that are being 'explained' in the meta-analysis are either defined in terms of units of area (e.g. US$/ha/year) or in terms of units of beneficiaries (e.g. US$/household/year). The selection of the units in which the dependent variable is expressed is largely determined by the underlying primary valuation data. Some ecosystem service values may be expressed more straightforwardly and meaningfully in one set of units than another. For example, recreation values or non-use values may be directly estimated and expressed per person rather than per unit of ecosystem area. On the other hand, services such as pollination of crops and carbon sequestration are not straightforwardly expressed per beneficiary but can be described per unit area of ecosystem providing the service.

The choice of the appropriate unit in which to transfer values is also determined by the type of information that is available for the policy site(s) to which values are being transferred. If information is available on the number of beneficiaries at the policy site then values can be transferred in those terms. Equivalently, if information is available on the quantity of an ecosystem service or area of the ecosystem at the policy site then values can be transferred using those units. Ideally, any value transfer and aggregation of values would account for both the number of beneficiaries and the scale of ecosystem service provision.

Regarding the meta-analyses summarised in Appendix 2, there is an even split of studies that define the dependent variable in terms of units of area (generally for multiple ecosystem services) and those that use units of beneficiaries (generally for recreation, biodiversity conservation or water quality improvement). Returning to the key question of how to link mapped biophysical data on ecosystem service provision with ecosystem service values, it is arguably more straightforward to make the link when values are defined in units of area since this is a directly observable quantity from a map. In the case that values are defined in units of beneficiaries, it is necessary to additionally model or estimate the number of beneficiaries that are affected by an environmental change (i.e. the 'economic constituency' that holds values for a particular ecosystem and its services). Examples of this additional step in conducting value transfer is provided by Sen *et al.* (2013) for outdoor recreation in nature areas and Brander *et al.* (2015) for recreational use of coral reefs.

3.3.3.3 Global value transfer applications on ES economic value

Several studies have attempted to use the available primary ES valuation data in value transfer applications to estimate (changes in) ES values at a global scale. Table 7 provides a summary of a selection of these applications to highlight the characteristics of this approach to global modelling of changes in BES.

In general, this approach has been used for comparative static analysis of differences in total global value of ES over time or under alternative future scenarios. In other words, the value of ES under a baseline scenario is computed and compared with the value of ES under alternative policy scenarios. The analysis is static in the sense that there are no dynamic feedbacks from modelled impacts (changes in ES value) on drivers of change or other parameters. The time horizons of these analyses vary but extend to 2050 at a maximum, although Brander *et al.* (2012) model the impacts of ocean acidification of coral reef ES values for the period 2000-2100. Two of the studies listed in Table 7 are purely static analyses of the total value of ES in a given year (Costanza *et al.*, 1997; Ghermandi & Nunes, 2013).

In all applications, the modelling of biophysical changes in ES provision and biodiversity has been simplistic or non-existent. In general, these applications have used modelled changes in land cover as a proxy for changes in BES and in some cases applied simple empirically based adjustments to transferred values to reflect variation in factors that are assumed to affect ecosystem service supply (e.g. mean species abundance, fragmentation, ecosystem size).

The resolution of analysis varies across applications. The studies that use simple or adjusted unit transfer methods have conducted the analysis at national resolution. The studies that use a meta-analytic value transfer approach have conducted the analysis at a final spatial resolution, and arguably take better account of spatial variation in ecosystem service values across policy sites.

In terms of the resolution at which results are reported, most studies only report at the level of global or world regions. Only Ghermandi and Nunes (2013) produce a global map that represents the spatial variation in ES values at a sub-national level (the size of grid cells is not reported).

3.3.3.4 General limitations of global value transfer applications

Using value transfer methods is one of the few (perhaps the only) viable means of estimating ecosystem service values at a global scale but it is important to note the limitations and potential inaccuracies involved (Rosenberger & Stanley, 2006). In other words, transferred values may differ significantly from the actual values of the ecosystem services at the policy site. Brander (2013) identifies the main sources of uncertainty in the values estimated using value transfer:

1. Primary value estimates used in value transfer are themselves uncertain. Inaccuracies in primary valuation estimates may result from weak methodologies, unreliable data, analyst errors, and the whole range of biases and inaccuracies associated with primary valuation methods.
2. The available stock of information on ecosystem service values may be unrepresentative due to the processes through which primary valuation study sites are selected and results are disseminated, which can be biased towards certain locations, services, methods and findings (Hoehn, 2006; Rosenberger et al., 2009).
3. The number of reliable primary valuation results may be limited, particularly for certain services, ecosystems and regions. As the number and breadth of high-quality primary valuations increases, the scope for reliable value transfer also increases. For some ecosystems, ecosystem services and regions there are now many good-quality value estimates available whereas for others there are still relatively few.
4. The process of transferring study site values to policy sites can also potentially result in inaccurate value estimates (Rosenberger & Phipps, 2007). So-called 'generalisation error' occurs when values for study sites are transferred to policy sites that are different without fully accounting for those differences. Such differences may be in terms of beneficiary characteristics (income, culture, demographics, education etc.) or biophysical characteristics (quantity and/or quality of the ecosystem service, availability of substitutes, accessibility etc.). The availability of study sites that are closely similar to the policy site and/or the value transfer methods used to control for differences will determine the magnitude of generalisation error.
5. There may also be a temporal source of generalisation error since preferences and values for ecosystem services may not remain constant over time. A value function that can predict current values well may not necessarily perform as well in predicting future values. Accounting for diminishing marginal utility of ecosystem services with scale of availability (or conversely, increasing marginal utility with increasing scarcity) may be possible by including scarcity variables in estimated meta-analytic value functions.

Table 7. Summary of selected global ES value transfer applications

Title	Reference	Purpose/scope	Economic and social impact metrics	Scenarios	Biomes	Base year	End year	Resolution (analysis)	Resolution (reporting)
The Value of the World's Ecosystem Services and Natural Capital	Costanza *et al.* (1997)	Estimate the global annual value of ES in monetary units in 1997	Monetary value of ES	None	All	1997	1997	National	Global
Changes in the global value of ecosystem services	Costanza *et al.* (2014)	Estimate the global annual value of ES in monetary units in 2011 and compare with updated 1997 estimate	Monetary value of ES	None	All	1997	2011	National	Global
The Cost of Policy Inaction: The case of not meeting the 2010 biodiversity target	Braat and ten Brink (2008)	Estimate the cost (in terms of the monetary value of foregone ES) of not meeting the 2010 CBD biodiversity targets	Monetary value of ES	OECD baseline; land-use change and biodiversity loss modelled using IMAGE-GLOBIO	Terrestrial	2000	2050	National	World regions
TEEB Quantitative Assessment	Hussain *et al.* (2011)	Estimate the global benefits, in monetary units, of 8 policy options to reduce biodiversity loss	Monetary value of ES	OECD baseline; 8 policy options for reducing biodiversity loss modelled using IMAGE-GLOBIO	Terrestrial	2000	2030; 2050	50km raster; ecosystem parcels	World regions
The benefits to people of expanding Marine Protected Areas	Brander *et al.* (2015)	CBA of global MPA expansion scenarios	Monetary value of ES benefits and costs, and net present value of alternative MPA expansion scenarios	OECD and Reefs at Risk baseline; 6 scenarios for expanding MPA coverage to 10% and 30% of total marine area	Coral reefs, mangroves, coastal wetlands	2015	2050	Ecosystem parcels; MPAs; national EEZs	Global
A global map of coastal recreation values	Ghermandi and Nunes (2013)	Produce a global map of coastal recreational values	Monetary value of ES	None	Coastal	2003	2003	Grid cells (uncertain of size)	Grid cells (uncertain of size)
Beyond GDP: Measuring and achieving global genuine progress	Kubiszewski (2013)	Compare the GPI and GDP over time	Genuine Progress Indicator (GPI), GDP, Human Development Index (HDI), Ecological Footprint, Biocapacity, Gini coefficient, and Life Satisfaction	None	NA	1950	2003	National	National

3.3.3.5 SEEA Central Framework and environment-economy modelling

To enable the integration of provisioning and non-provisioning ecosystem service data into an economy-wide model, ecosystem service data must be consistent with the data structure of a CGE model. This implies consistency with the SNA, which is the primary data source for calibrating a CGE model. In this regard, the first international standard for environmental statistics, the SEEA Central Framework, is a critical advance enabling the integration of provisioning ecosystem services data. To address the challenge of regulating and cultural/aesthetic ecosystem services, the SEEA EEA approach was developed.

The SEEA was developed to combine economic data with environmental information in a common accounting framework consistent with the SNA. This unifying framework enables the measurement of the contribution of provisioning ecosystem services to the economy and the impact of economic activity on stocks of environmental resources and environmental quality in terms of emissions and waste (Dube & Schmithusen 2003). The framework also provides a structure for organising information related to investments in the environment, for example to mitigate or prevent environmental damage. Environmental-economic accounting overcomes two core limitations of the SNA with regards to ecosystems: (i) in the SNA, the depletion of environmental resource stocks is accounted for only in terms of its positive contribution to economic output; and (ii) the condition of a nation's ecosystem assets is not accounted for, thereby enabling ecosystem degradation to proceed undetected. Box 1 provides an overview of the overall SEEA structure and its accounts.

The development of the SEEA and the fact that it is compatible with the SNA offers an unprecedented opportunity to advance the field of integrated economic-environmental modelling. The SEEA Central Framework is compatible with international statistical standards including the SNA (2008), the Balance of Payments and International Investment Position, the International Standard Industrial Classification of All Economic Activities (ISIC), the Central Product Classification, and the Framework for the Development of Environment Statistics (European Commission *et al.* 2009). This international consistency of the SEEA is a significant strength, which facilitates comparative analysis across countries and time.

The SNA provides the core data source in the construction of a social accounting framework (SAM), the underlying database for a CGE model, Integrating data organised under the SEEA into a SAM framework enables a robust and consistent representation of ecosystem assets and provisioning services, which may be subsequently used in scenario analysis with a CGE model. Previous integrated economic-environmental modelling efforts have tended to focus on one provisioning ecosystem service of interest (e.g. water, timber or energy), collecting the required data for the service of interest and integrating it into the SAM framework. The SEEA circumvents this resource-intensive and time-consuming process. An important finding from Banerjee *et al.* (2016) is that strong assumptions are needed to reconcile ecosystem service and economic data for use in an economy-wide framework. With the SEEA, by contrast, this data reconciliation and strong assumptions are no longer required (Banerjee *et al.* 2016).

Once such a framework is developed, it can be used to investigate a diversity of public policy issues, generating timely evidence to support policy- and decision-making at a lower cost. Additional advantages include the ability to estimate measures of semi-inclusive wealth complemented with physical measures of ecosystem assets and services (Stiglitz, Sen & Fitoussi 2010; Arrow *et al.* 2012; Polasky *et al.* 2015); and the estimation of standard economic indicators which are regularly used as measures of economic performance, such as GDP and employment. These indicators communicate well to policy- and decision-makers in ministries of finance responsible for allocating the public budget.

Box 1: Basic SEEA structure and overview of accounts

The standardisation of environmental accounting has a history dating back more than two decades, originating with the 1991 Special Conference on Environmental Accounting in Baden (Austria) and the 1992 United Nations Conference on Environment and Development. The latter launched Agenda 21, which emphasised the importance of environmental accounting and called for a programme to develop national systems of integrated economic and environmental accounts for all nations (United Nations et al., 2014). The outcome of numerous consultations and revisions of draft standards, led by the UN Statistical Commission, with input from the UN Committee of Experts on Environmental-Economic Accounting, the London Group on Environmental Accounting, the European Commission, the International Monetary Fund, the OECD and the World Bank (Edens & Haan 2010; United Nations *et al.* 2014). As an outcome of these efforts, the SEEA Central Framework was adopted as the international standard for environmental-economic accounting at the Statistical Commission's 43rd Session in March 2012, and in 2014, the SEEA 2012 Central Framework was published (United Nations *et al.* 2014). Two key publications complement the Central Framework: (i) SEAA Experimental Ecosystem Accounting (European Commission *et al.* 2013); and (ii) SEEA Applications and Extensions (UN *et al.* 2017).

The SEEA Central Framework uses a systems approach to organising information, covering both stocks and flows relevant to environmental goods. For compatibility, the accounting concepts, structures, rules and principles of the SNA are used. The Framework is designed to allow for flexible implementation; a modular approach may be taken where one or two environmental accounts are prioritised to address the most urgent policy needs (United Nations *et al.* 2014).

The SEEA is composed of three main types of tables: physical/monetary supply and use tables; environmental asset tables; and environmental transaction tables. Physical supply and use tables record all physical flows from the environment, within the economy, and back to the environment. Since not all physical flows should be recorded similarly or aggregated, three subsystems were developed to account for material flow (tonnes), water (cubic meters) and energy (joules). Monetary supply and use tables organise the same information as the physical supply and use tables, but record data in monetary units.

Environmental asset tables record the opening stocks of environmental assets, additions to stocks, reductions of stocks, a revaluation of the stock at the end of the period and the closing stocks, all in physical and monetary units. The revaluation of stocks at the end of the period serves to account for changes in the price of assets. Asset accounts exist for all resources except for mineral resources. All asset and flow accounts are measured in physical and monetary units except for the water accounts and land-cover accounts, which are only recorded in physical units. Finally, the environmental transaction tables record information on public and private transactions related to the environment including expenditures on environmental management, mitigation and expenditure.

Environmental resource account overview

Basic SEEA accounts are: forests and plantations, water, energy and greenhouse gas emissions, underground resources, fisheries, land, residuals, and environmental expenditures and transactions. A brief overview of each of these accounts follows.

Forest and forest plantation accounts

Forests in the SEEA are quantified in terms of their contribution in the form of firewood, logs, timber and non-timber forest products. In addition, the contribution of forests to hydrological regulation and their habitat and carbon capture functions are registered in the SEEA. In the forest asset accounts, forest stocks at the beginning and end of the fiscal year are represented in physical (millions of hectares, thousands of tonnes and thousands of cubic metres) and monetary units (millions of units of currency). Flow accounts register the movement of forest goods between the forest and the national economic system in physical and monetary units (thousands of tonnes, thousands of cubic metres and millions of units of currency). These flow accounts include output, intermediate consumption and final consumption of forest products. Environmental transaction accounts represent expenditures by the public and private sector to prevent, mitigate and restore damage caused to forests as well as actions taken to improve their management.

Water accounts

Water asset accounts measure the average annual availability of water and its use in physical terms. Water availability is measured in millions of cubic metres per year while relatively stationary surface water sources (lakes, lagoons and reservoirs) may be expressed in hectares by slope and watershed. Flow data is arranged in supply and use tables. Three sources of water are quantified: soil water, superficial water (rivers and lakes) and groundwater.

Box 1 cont.

In the supply table, water collected for use and distribution, water returned to the environment, and effective consumption by economic sector are accounted for. Two important accounting distinctions are made in the water accounts: (i) situations where activities capture water for their own use or through other economic activities; and (ii) economic activities that use water and return it to the environment in a modified form. Also specific to the water flow accounts, use is water used, return is water returned to the environment after use, and effective consumption is the difference between the two. Environmental transaction accounts register expenditures to manage and protect the water resource.

Energy and greenhouse gas accounts

The energy and emissions accounts record measurements of how, where and what type of energy is used in the economy, and what residuals are directly and indirectly produced through energy consumption. The accounts measure: (i) the level of energy use by each economic activity; (ii) carbon dioxide, nitrous oxide and methane released by economic activities through combustion; (iii) expenditures and transactions related to energy use; and (iv) the energy efficiency of economic activities. The units of measurement are terajoules and millions of units of currency.

Energy is produced by silviculture, the extraction of natural gas and petroleum, sugar production, and electrical energy production and distribution activities. Outputs of these energy-related activities are: wood; crude oil and natural gas; other non-metallic minerals; gasoline, gas oil/diesel; fuel oil and boiler fuel; kerosene; gaseous petroleum and other gaseous hydrocarbons; waste for food and tobacco industries; and electrical energy, gas, vapour and hot water. Emissions accounts represent emissions for the principal economic activities and describe both the activity producing the emissions and the type of emission.

Underground resource accounts

The underground resource accounts describe relationships between underground mineral and oil resources and the economy. Stocks and flows of resources are expressed in tonnes and in currency units. The costs associated with extraction, as well as environmental transactions, are also registered. Asset accounts measure three categories of underground resources: (i) hydrocarbons (e.g. petroleum and natural gas); (ii) metallic minerals (e.g. magnesium, gold, silver and zinc); and (iii) non-metallic minerals (e.g. barite, bentonite, feldspar, marble and gypsum). Economic activities that extract these resources are: extraction of petroleum and natural gas; extraction of rock, sand and clay; extraction of metallic minerals; extraction of non-metallic minerals; and fabrication of cement, lime and gypsum. Products that result from the extraction process are: crude oil and natural gas; non-metallic minerals; metallic minerals; common salt and sodium chloride; and other non-metallic minerals.

Fisheries and aquaculture accounts

Fisheries and aquaculture accounts provide an inventory of aquatic assets; they measure the flow of aquatic resources between the environment and the economy and they quantify the expenditures related to the protection and management of the resource. Activities related to fisheries and aquaculture are: the capture of fish; fish rearing; capture of shrimp/lobster; shrimp farming; capture of crustaceans, molluscs and other aquatic products; and wholesale commerce. Products resulting from these activities are: other fish live, fresh or frozen; shrimp live, fresh or frozen; and other aquatic products. Units of measure are millions of tonnes and millions of units of currency.

Residuals accounts

The solid residuals accounts register solid residuals of economic and consumptive processes. These accounts register the flows of residuals from the economy to the environment and the expenditures and transactions related to the management of these residuals by the public sector. Residuals are distinguished by productive sector. Residuals are classified as: (i) biological infectious residuals: animals and organs, hospital waste; (ii) metallic residuals; (iii) non-metallic residuals: paper, glass, rubber, plastic and other/textile wastes; (iv) accumulated equipment; (v) excrement; (vi) vegetable and animal waste: pulp, peels and other vegetable residuals, vegetable and animal residuals, wood left in the forest, sawdust, loss of wood through disease, loss of wood; (vii) ordinary residuals; (viii) mud; (ix) mineral residuals: hydrocarbons, metallic minerals, non-metallic minerals; (x) stable residuals; and (xi) other residuals.

Land accounts

The land accounts may be used to understand the dynamics of land-use change and deforestation. They contain various land uses, depending on the country's natural endowments, and are measured in hectares. These accounts track land-use change, erosion (tonnes/year), nutrient loss and the release of carbon as a by-product of deforestation.

Environmental expenditures and transactions

Both public and private expenditures and transactions are considered in the environmental expenditure and transaction accounts. The accounts are classified into Environmental Protection Activities and Resources Management Activities.

3.3.3.6 *The System of Environmental-Economic Accounting: Experimental Ecosystem Accounting*

The SEEA EEA framework moves beyond provisioning ecosystem services to consider regulating and cultural and aesthetic ecosystem services. Another important aspect of the SEEA EEA is that the accounts are spatially explicit, which is particularly relevant for the modelling of ecosystem service supply changes arising from policy and other shocks. The SEEA EEA integrates measures of ecosystem assets and flows with measures of economic activity and is consistent and complementary to the SEEA Central Framework and the SNA. As with the SEEA Central Framework, the EEA structure makes it also compatible with the underlying data structure of CGE models. The SEEA EEA was published in 2013 (European Commission *et al.* 2013) and is currently under a technical review process.

The SEEA EEA defines five main types of ecosystem accounts: the extent account (physical units), the condition account (physical units), the supply and use accounts (physical and monetary units) and the ecosystem monetary asset account (monetary units). The ecosystem asset is defined as occurring in a specific geographical area and contributes to benefits that are within the production boundary of the SNA (denominated 'SNA benefits') or benefits that are beyond the production boundary of the SNA and not produced by economic units ('non SNA benefits').

The starting point for developing ecosystem accounts is the definition of the extent of an ecosystem asset. A related concept is the ecosystem type, which may be an aggregation of different ecosystem assets. The SEEA EEA provides 15 classes of ecosystem assets, which are land cover classes that range from artificial/urban areas, to tree-covered areas, to marine areas. Establishing ecosystem extent provides the basis for all subsequent measurements related to the ecosystem and the economy (UNEP, UNSD & CBD 2017).

Ecosystem condition accounts provide physical indicators of the condition and capacity of an ecosystem, for each ecosystem asset. These physical indicators may be related to extent of vegetation, water quality, soil characteristics, carbon, biodiversity and habitat continuity/fragmentation. These accounts, as with extent accounts, are measured at two points in time, that is, the opening and closing of the reference period, which would typically be one year. The types of indicators developed can be guided by the degree to which the indicator is linked to measures of ecosystem service supply; the degree to which the indicator summarises the condition of the ecosystem; ease of interpretation; data availability; and cost effectiveness.

Ecosystem supply and use accounts record flows of final ecosystem services generated by ecosystem types and used by economic units, which include households and productive sectors. For accounting purposes, supply of ecosystem services is equal to demand. The structure of the supply and use table (SUT) follows that of the SEEA Central Framework, with two adjustments. First, instead of one column representing the environment, there is more than one column representing an ecosystem type. Second, while the Central Framework has three types of flows (natural inputs, products and residuals) the ecosystem service SUT has only two, which are the ecosystem services and products. Residual flows are not considered ecosystem services but rather are considered physical flows originating from economic units and returned to the environment. The standard ecosystem *supply* table will have columns for the different ecosystem types while the rows present the different ecosystem services. The *use* table will record the beneficiaries of each ecosystem service. As ecosystem accounting in the SEEA EEA framework is relatively new, there are only a few examples of ecosystem accounts to report. They are currently at the regional level, including the development of physical and monetary supply and use accounts for Limburg province in the Netherlands (CBS & WUR 2015b; CBS & WUR 2015a). Under a Science for Nature and People Partnership project, ecosystem service supply and use accounts are for the first time being developed at a national level for Rwanda (Bagstad In preparation).

SUT measurement is usually first estimated in physical units, and then in monetary units where possible. For provisioning ecosystem services, direct measurement of ecosystem service values is usually possible. Regarding biodiversity, the SEEA EAA perspective is that biodiversity is relevant in the measurement of the condition of ecosystem assets, and therefore accounted for in the ecosystem condition accounts. That being said, some characteristics of biodiversity can supply final ecosystem services where, for example, people value iconic species. This implies that measures of biodiversity may apply to various accounts including ecosystem service SUT.

An important point in terms of generating monetary estimates of ecosystem service flows is that the values of ecosystem services need be consistent with the valuation approaches used in the SNA. As such, the concept of exchange value is used, where ecosystem services are valued at the price at which the service would be exchanged if a buyer/seller and market existed. In this case, while consumer surplus is not part of this value when used for accounting purposes, measures of consumer surplus may be important for other welfare analytical purposes.

The ecosystem monetary asset account measures the monetary value of opening and closing stocks of ecosystem assets. Exchange value again is the relevant concept. The net present value of the expected future flows of all ecosystem services generated by an ecosystem asset is one approach to valuing the asset in monetary terms. Certainly, in terms of measuring the value of future flows, the future condition of the asset is important and is related to ecosystem capacity.

3.3.4 Suitability of existing scenarios for assessment of the global socio-economic impacts of future changes in BES

Scenario construction is especially valuable when ecological outcomes are highly contingent on uncertain indirect drivers such as economic growth and demography. Scenarios are employed to account for such uncertainty within models of the future. In these cases, rather than attempting to project from a specific set of values for driver variables onto a specific future, it is preferable to employ a variety of scenarios based on knowledge of a range of potential alternative futures.

Scenario construction begins with the preparation of qualitative narrative storylines of future social-economic development that provide the descriptive framework from which quantitative scenarios can be formulated. Such qualitative scenarios are particularly valuable as the temporal scale under examination increases and there are greater chances that exogenous influences may introduce unforeseen systemic change (e.g. a technological shift) (Rounsevell & Metzger 2010).

Biodiversity scenarios provide quantitative estimates of the future trajectories of biodiversity (Pereira *et al.* 2010). These are typically based on the coupling of several components describing habitat and species characteristics (Figure 10). The starting point of most socio-economic development scenarios are trajectories of key indirect drivers of ecological change, such as human population growth and greenhouse gas emissions, developed under different assumptions regarding society's development and often associated with 'storylines'. These storylines are designed to capture the variance in the most uncertain and most important (to the anticipated output) drivers of change. These trajectories are then fed into models that project changes in direct drivers of ecosystem change, such as climate and land-use change. Finally, the projected drivers are used as inputs to biodiversity models. In some cases, associated changes in key ecosystem services are also modelled.

Typically, socio-economic development scenarios will include a 'business as usual' scenario. This enables modelling of the potential impacts of current trends continuing in the future and to provide a scenario against which to compare the impacts under 'alternative pathway' scenarios. There will also be one or more alternative development pathway scenarios to enable modelling of the potential impacts of, for example, meeting new environmental targets and/or of implementing new policies. Ideally the alternative development scenarios are policy relevant and include targets established in global agreements and policy frameworks such as the CBD, UN SDGs, UNFCCC and IPBES (see Box 2).

This section describes in detail the types of scenarios used in global assessments and discusses their suitability for quantifying the socio-economic impacts of future changes in BES.

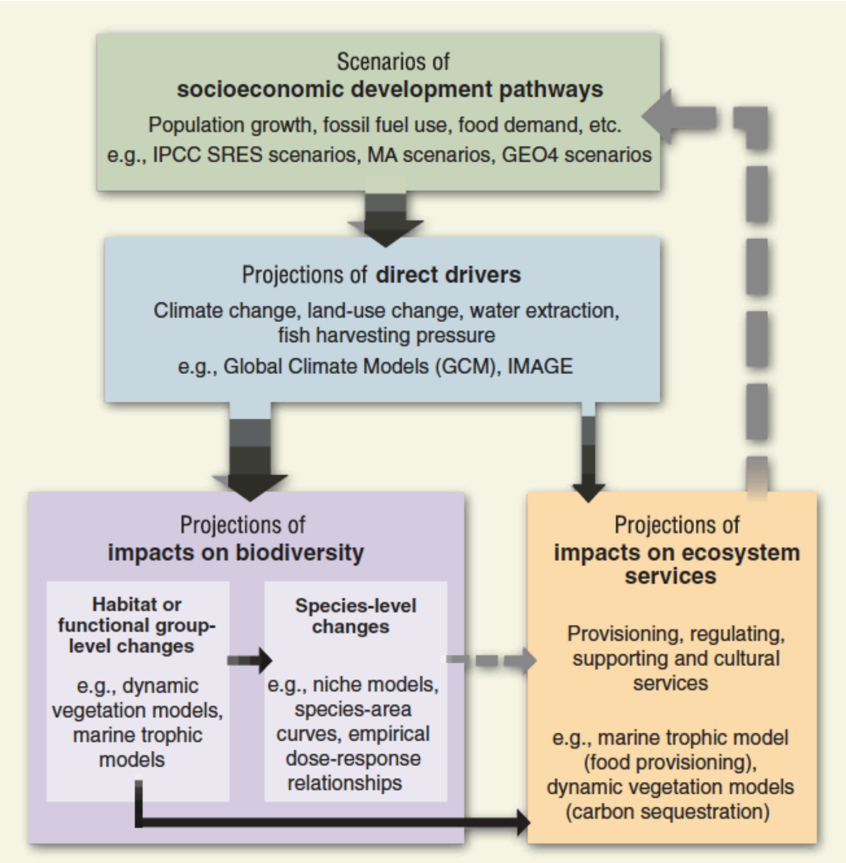

Figure 10. Overview of methods and models commonly used for constructing biodiversity scenarios. Dashed grey arrows indicate linkages that are frequently absent in current biodiversity scenarios. Source: Pereira *et al.* (2010).

Box 2: Example applications of scenarios

There is considerable literature on the development and use of scenarios to inform policy-making. While not aiming to provide a full overview, we do provide some examples that sketch a range of possible applications.

Optimising conservation priorities to achieve Aichi targets: Rather than exploring likely developments given socio-economic assumptions, Montesino Pouzols *et al.* (2014) use a prioritisation approach based on target-seeking scenarios to identify which areas it would be best to protect to achieve the Aichi target of protecting 17% of terrestrial ecosystems. Optimising on the species range covered by protected areas, the authors assess the effectiveness of this target depending on whether it is implemented at global or national level. The results indicate the spatial efficiency gains achieved from global rather than national implementation, and show the areas proposed for protection. In principle, these results could also be used for assessment of socio-economic impacts. However, the indicated areas are still far from a realistic implementation vision, as protected area conflicts with other potential uses and pressures are ignored. Similar considerations hold for other studies that identify 'optimal' areas for biodiversity conservation (Newbold *et al.* 2016; Dinerstein *et al.* 2017). In many cases these areas correspond to core agricultural production areas, leading to difficult trade-offs on food security objectives.

Multiscale, participatory scenarios in the Millennium Ecosystem Assessment: The Millennium Ecosystem Assessment applied a multiscale approach in its development of exploratory scenarios, acknowledging the importance of scale in assessing causes and impacts of ecosystem change (Zermoglio *et al.* 2005). For example, factors affecting ecosystems include drivers with global impacts such as climate change and invasive species introductions, regional impacts such as regional trade or agricultural policies, and local impacts such as land-use practices and the construction of irrigation systems. In addition, changes to ecosystems can have global consequences such as the contribution of deforestation to climate change; regional consequences such as the impact of nutrient loading in agricultural ecosystems on coastal fisheries production; and local

Box 2 (cont)

consequences, such as the impact of overharvesting or land degradation on local food security. Scale considerations are also important in the assessment of response options. Policy, institutional, technological, and behavioural responses to ecosystem-related issues can involve global actions such as international financial support for biodiversity conservation (e.g. Global Environment Facility and Conservation International); regional action such as regional agreements to promote wetlands conservation for migratory bird protection; and local responses, such as a decision by a farmer to alter land management practices to conserve topsoil. Indeed, unlike some global environmental issues such as climate change, a large share of the decisions affecting ecosystems take place at sub-global, including local, scales. The decisions that will ultimately matter most will be those taken by national governments, private companies, individual land owners, and local land managers.

The original Millennium Ecosystem Assessment design called for a relatively top-down approach to establish four clusters of sub-global, multiscale assessments, three of which were to be in developing countries/regions and one in an industrial country/region. Each of these multiscale clusters involved at least two nested assessments from the following broadly defined categories: one regional assessment, one or more national (or basin-level) assessments, and one or more local assessments. These clusters of assessments were to be complemented by one ‘’outlier assessment’’ (to address important ecosystems not included in the four clusters) and one ‘’cross-cutting assessment’’ to examine similar ecosystems at similar scales in different regions. Only one such cluster, the Southern African Millennium Ecosystem Assessment, was established following this top-down approach. This approach proved to be cumbersome, and by early 2002, the Millennium Ecosystem Assessment Sub-Global Working Group proposed a bottom-up approach for establishing other sub-global assessments.

The bottom-up development of the scenarios was based on participatory work involving a wide range of stakeholders. From this experience, tightly coupled cross-scale scenarios seem to work best when the main objective is to further the understanding of cross-scale interactions or to assess trade-offs between scales. The main disadvantages of tightly coupled cross-scale scenarios are that their development requires substantial time and financial resources, and they often suffer loss of credibility at one or more scales. The reasons for developing multiscale scenarios and the expectations associated with doing so therefore need to be carefully evaluated when choosing the desired degree of cross-scale linkage in a scenario exercise.

Biodiversity and carbon management scenarios: In contrast to the target-seeking and exploratory approaches described before, Eitelberg *et al.* (2016) implemented a hybrid scenario approach that explored plausible futures assuming policy implementation of different target sets. The approach was hybrid in the sense that the socio-economic assumptions and agricultural demands by society were fixed and assumed unaffected by the implementation of biodiversity or carbon targets (i.e., like the SSPs, many of the important feedbacks within the system are ignored). Building on an exploratory scenario and the FAO agricultural outlook, additional pressures on the land system were imposed by implementation targets ranging from the Aichi target of protecting at least 17% of terrestrial land area (implemented by world region), a no net loss of carbon target, and using a scenario of no protection even for the current protected areas as a counterfactual. When evaluating the biodiversity impacts (by assessing the loss of species ranges) all scenarios performed rather weakly compared to the results attainable using the Montesino Pouzols *et al.* (2014) approach. Moreover, the targeted scenarios performed almost no better than the counterfactual scenario. This may be explained by the selection of remote areas to fulfil the targets. These areas are often not facing large pressures and consequently the scenarios show similar impacts. Although these were not assessed, it is also unlikely that, at macro level, these targets would lead to major impacts on socio-economic conditions.

Use of restoration scenarios to inform global policy: To counteract negative externalities of unsustainable land management on human wellbeing there has been increased interest in land restoration. This is reflected in the targets of the UN SDGs, CBD, UNFCCC and the UNCCD. Wolff *et al.* (in progress) took a global perspective to understand the potential and aggregated consequences of meeting these restoration targets. They extracted and analysed policies from these commitments that target land restoration and protection. These were translated into a global land change model, the main objective being to investigate their influence on land cover and land system change and their impact on ecosystem services and human wellbeing. Combining methods such as policy review, spatial analysis and land change modelling, a restoration scenario was built and compared with two plausible pathways of socio-economic development in the absence of these policies: a middle-of-the-road (SSP2) and a sustainability scenario (SSP1). They reviewed and identified global policy goals and targets, as well as associated actors that focus on the restoration and protection of land-based ecosystem services. The review indicated that many targets across the different conventions have clear overlaps, but that there are also different foci on implementation leading to potentially different outcomes.

3.3.4.1 Types of scenarios

Exploratory scenarios: Exploratory scenarios (also known as 'descriptive scenarios') typically have both strong qualitative and quantitative components and are often combined with participatory approaches involving local and regional stakeholders. Exploratory scenarios describe the future according to known processes of change or as extrapolations of past trends. They are particularly relevant in the agenda-setting stage of the policy cycle where the scale, relevant stakeholders and problem specificities are first addressed as the problem is brought to public attention. Exploratory scenarios can identify the specific problems to be addressed by society in the presence of limited resources, by illustrating various potential futures starting from now. Exploratory scenario approaches have been utilised for climate change projections and were used in the IPCC assessments. This process started with the estimation of greenhouse gas emissions as the major driver for climate forcing, leading to the Special Report on Emissions Scenarios and the latest Representative Concentration Pathways (RCPs). These scenarios were initially applied at a global scale with regional-scale scenarios typically constructed through downscaling (i.e. the transformation of information from coarser to finer spatial scales through statistical modelling or the spatially nested linkage of structural models).

Despite their embedding in past and current conditions, the term 'business-as-usual' as a possible type of exploratory scenario may be misleading in the policy-making process because exploratory scenarios can also describe futures that bifurcate at some point (e.g. due to the adoption or rejection of a new technology) or that make some assumptions about the functioning of a system. Furthermore, in an ever-changing world it is unlikely that conditions in the future would resemble those of the past and current condition, rendering 'business-as-usual' approaches unrealistic.

Target-seeking scenarios: Target-seeking scenarios (also known as 'normative scenarios') are a valuable tool for examining the viability and effectiveness of alternative pathways to a desired outcome. Policy design, or formulation, is the stage in which the descriptive is transformed into the prescriptive according to the desired normative approach (Loorbach 2010). Here, the will to address a recognised problem is translated into a viable policy formulation with clearly defined objectives. Employing normative pathway analyses such as back-casting approaches at this stage of the policy cycle allows for the identification of multiple potential pathways to a desired future.

Target-seeking scenarios are mostly based on a set of goals and objective functions, as well as a set of constraints to ensure realism in the solutions. In the policy cycle, such scenarios may apply to both the design and implementation phases. However, here we distinguish target-seeking scenarios and the subsequent ex-ante assessments to highlight their relative contributions to weighing the relative desirability of different pathways.

Ex-ante (policy screening) and ex-post (retrospective) assessment: Ex-ante and ex-post assessments of environmental policies are tools in the policy-making process. Ex-ante assessment is a proactive approach, oriented to identify and address potential effects of environmental policies. Many decision-support protocols and tools provide a structured means of undertaking ex-ante assessments. Environmental impact assessment is a widely used tool within this perspective. Ex-ante assessment usually starts in the very early stages of a policy formulation and design. It may therefore contribute to the social acceptance of policies by anticipating and addressing conflicting objectives and adverse effects. When properly organised, this assessment may include expert considerations and consultations with relevant stakeholders such as government authorities, community representatives, NGOs and the public.

Other types of scenarios (e.g. target-seeking scenarios) can be used to complement and support ex-ante assessments. In some cases, these assessments are carried out through multiple scenario comparisons, and this approach helps policy-makers compare the potential consequences of various scenario-based options or test the robustness of a policy under different scenario conditions. In the intervention design phase, different alternative policy options or management strategies are often developed. Policy screening scenarios require a detailed specification of changes in drivers such as uptake of policy measures on human behaviour, often focusing on shorter, more policy-relevant timeframes than other types of scenarios. Economic and sector-based models are especially dominant here as the economic consequences and cost-benefit assessment of the proposed changes in drivers are essential in decision-making.

The policy review phase involves the ex-post retrospective assessment of the extent to which the policy implementation achieved the goals outlined in the initial stage of problem identification. In practice, evaluations are rarely consistent with underlying theory which stipulates that multiple criteria and methods are used. Some key obstacles to the realisation of policy goals include instrument design oversight, inadequate monitoring and an absence of effective enforcement mechanisms (Haug, Huitema & Wenzler 2011). Furthermore, due to the inherent complexity of the environment-policy nexus, the enactment of environmental policies may result in impacts that run counter to the original goals or encourage counterproductive behaviour such as rebound effects (Maestre Andrés *et al.* 2012).

Ex-post assessments can be based on the straightforward monitoring of variables of interest as well as on a comparison of the achieved change or status with the original targets and the anticipated impacts of the implemented measures. In many cases, it is important to distinguish the effects of the implemented policy or management scheme from autonomous developments. Econometric models are used to evaluate the contribution of different conditions to the monitored data. For example, straightforward ex-post assessments may assess forest loss within and outside protected areas to monitor the success of protected areas (Heino *et al.* 2015). However, such straightforward evaluations may be biased by the different locations of protected and unprotected natural areas, which heavily impact the risk of deforestation (Joppa & Pfaff 2010). Under such conditions, more sophisticated techniques for ex-post assessment need to be applied that can distinguish the influence of such confounding factors on the monitored impacts.

Irrespective of the scenarios type, most studies so far have depicted declines in biodiversity as an impact of global change processes or policy interventions. To better inform policy, scenarios must move beyond illustrating the potential impacts of global change on biodiversity toward more integrated approaches that account for the feedbacks that link environmental drivers, biodiversity, ecosystem services and socio-economic dynamics. In addition, current global biodiversity models rarely relate estimates of biodiversity loss to ecosystem services, infrequently explore policy options specifically focused at improved management of biodiversity, and do not account for the feedbacks from changes in BES to societal response. Introducing complex feedbacks to biodiversity scenarios will require moving away from the relatively linear, non-interactive relationships within the common scenario approaches (Figure 10).

3.3.4.2 Scenario needs for assessing the socio-economic outcomes of changes in BES

Most scenarios developed for global environmental assessments have explored impacts of society on nature, such as biodiversity loss using a wide range of metrics, but have not included nature as a component of socio-economic development (e.g. they ignore policy objectives related to nature protection and neglect nature's role in underpinning development and human wellbeing). Biodiversity impacts are an output of the model and most of the model approaches used to quantify the scenarios are unable to assess socio-economic impacts of such biodiversity impacts.

In this sense, the SSPs now proposed for IPBES are no different. They allow an assessment of impacts to biodiversity from these socio-economic development pathways, including the assessment of synergies and trade-offs of climate mitigation and adaptation measures on BES. Feedbacks on the assumed socio-economic scenario conditions are not considered. Adding biodiversity policies or 'reinterpreting' the SSPs for biodiversity assessment will not help to assess the socio-economic impacts of such policies as these are assumed in the storyline already.

Other scenarios have specifically assessed conservation measures, mostly by varying protected areas, within the context of assumed socio-economic developments. Similarly, they mainly aim at assessing the impacts on biodiversity of these policies, mostly as an ex-ante assessment.

These limitations are strongly acknowledged in a perspective paper by Rosa et al. (2017) who argue that the next generation of scenarios should explore alternative pathways to reach these intertwined targets, including potential synergies and trade-offs between nature conservation and other development goals, as well as address feedbacks between nature, nature's contributions to people, and human wellbeing. The development of these scenarios would benefit from the use of participatory approaches, integrating stakeholders from multiple sectors (e.g., fisheries, agriculture, forestry), and should address decision-makers from the local to the global scale. Rosa et al. (2017) further argue for the need for multiscale scenarios:

> *"Many of these social-ecological feedbacks play out across multiple scales and locations through tele-coupling between the production and consumption of ecosystem services, often mediated by trade, but also through institutional and governance linkages. Global and regional policies set the boundaries for national policies, which affect decision-making in local communities. In turn, the decisions of local stakeholders and how they respond and manage different nature trajectories can scale up to determine the dynamics of ecosystem change at regional scales."*

Although this is nicely said, little detail is provided in this perspective on how to achieve this. The SSPs do not adequately incorporate cross-scale dynamics and social-ecological feedbacks involving nature. This shortcoming leads, for example, to an underestimation of tipping points in ecosystems.

Target-based scenarios provide a promising alternative. Here the logic is turned around. Starting with a target or societal vision on nature the impacts of implementing such a vision or target are assessed. In this case, trade-offs of achieving this on other indicators (eg. SDGs) and socio-economic conditions are an output. Another advantage is the clear focus on trade-offs as opposed to visions that are derived from a single perspective. Climate adaptation and mitigation measures may have synergies with biodiversity conservation but clearly there are also many (short-sighted) conflicts between climate mitigation measures and biodiversity conservation such as afforestation of the savannah zone (Veldman *et al.* 2015b; Veldman *et al.* 2015a; Fernandes *et al.* 2016).

Simply adding some biodiversity-related policies to climate mitigation and adaptation scenarios, as in one of the proposed ways towards making the SSPs suitable for IPBES work, is not straightforward as the scenarios are designed from a climate perspective primarily and measures may not be optimal from a biodiversity perspective. However, confronting visions from different perspectives and assessing the trade-offs between the domains may stimulate such discussion. The long-term ambition of IPBES is in that sense important and will, if socio-economic impact models allow, contribute to filling the needs of the identified work. However, this may require a 5-10-year trajectory.

The few models and scenarios that project the combined impacts of multiple threats such as climate and land-use changes on biodiversity are based on integrated assessment approaches developed for the climate change community. These approaches simulate future changes in the main types of vegetation and their impacts on climate (Verburg *et al.* 2013) but only capture a small part of the key aspects of land use that impact on biodiversity. Land management regime and intensity of use will cause unprecedented habitat modifications in the future but they are largely ignored in such simulations (van Asselen & Verburg 2013). The single use of integrated assessment approaches adopted by the climate change community is therefore insufficient to properly predict the full range of responses of biodiversity to future land-use change (Harfoot *et al.* 2014a; Titeux *et al.* 2016). The research agenda needed to envision the future for biodiversity goes largely beyond the single use of these simulations. A wider range of novel approaches is required to integrate human and land management aspects that are critical to biodiversity into assessment methods.

Work on social-ecological feedbacks and the development of coupled analysis of society, nature and nature's contributions to people may ultimately lead to a revised set of SSPs, in which nature plays a central role alongside existing socio-economic considerations. This would require a different scenario set-up in which alternative interventions aimed at the different sustainability domains would be tested separately and in combination. By producing multiscale scenarios for nature futures enriched with local to regional models of BES, we can illustrate how a similar endpoint may produce distinct contributions to people in different areas of the world.

Furthermore, the lack of global data and impact assessment models on socio-ecological conditions, combined with the fact that the socio-economic impacts of biodiversity measures are very context dependent, may require multiscale scenario approaches. For specific contexts, global scenarios may be downscaled to assess the context-specific impacts. This could be combined with participatory scenario-building to develop bottom-up, diverse, multiscale scenarios within a consistent global scenario context. A bottom-up/top-down approach would build on many local scenarios, stakeholder networks and local research capacities as well as place these in a global context, focusing on the interactions between local trajectories and global dynamics (Kok *et al.* 2017).

3.3.4.3 The IPCC scenario framework to be used by IPBES

A scenario framework has recently been established by the climate change research community to support the integrated analysis of future climate impacts, vulnerabilities, adaptation and mitigation. The scenarios framework is organised around three important dimensions, which are considered together in Integrated Assessment Models (IAMs) used by the climate change community:

- The extent of climate change: described by the Representative Concentration Pathways (RCPs), which are scenarios that quantify the range of potential future greenhouse emissions and concentration pathways;
- Possible future socio-economic conditions: described as five Shared Socio-economic Pathways (SSPs), which depict substantially different socio-economic conditions (e.g. population growth, economic growth) and the challenges these present to mitigation and adaptation (**Error! Reference source not found.**);

- Climate policy application: described as Shared Climate Policy Assumptions that capture key climate policy attributes such as targets, instruments and obstacles. These can be applied in each SSP in the IAMs to reduce emissions and to enhance carbon uptake to reach radiative forcing level targets consistent with the RCP pathways. Because GDP and other variables would be affected by the climate policies and climate change impacts, model outputs would replace reference SSP assumptions when and where they were significantly different.

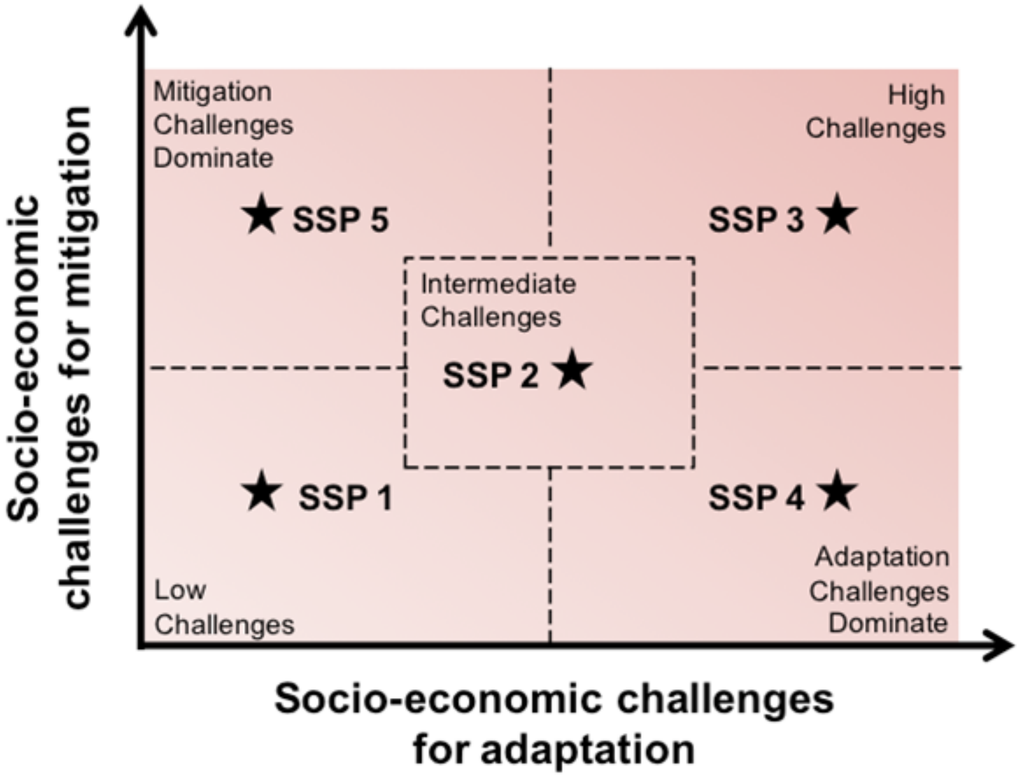

Figure 11. SSP scenario framework describing five alternative global development futures: SSP1: sustainable development; SSP2: middle-of-the-road development; SSP3: regional rivalry; SSP4: inequality; SSP5: fossil-fuelled development. Source: O'Neill *et al.* (2014)

Although the SSPs were designed to represent different climate mitigation and adaptation challenges, they have been constructed to also describe socio-economic futures in the absence of climate policies and climate change, thus enabling their application to non-climate issues. The underpinning narratives and quantifications of each SSP also cover a wide range of economic, social, institutional and organisational variables, which are applicable in broader sustainable development contexts. This holds promise for their utility as global development scenarios in assessments of BES, such as those currently being undertaken by IPBES for the Global Assessment. However, using the SSP global pathways to project changes in BES at multiple scales oversimplifies local social-ecological feedbacks and land-use dynamics that are critical for changes in BES. To capture the social-ecological dynamics of BES, it is essential to engage with the diversity of local contexts, while also including the global connections and flow of economic goods and services between local places.

Acknowledging this limitation, recommendations stemming from the Methodological Assessment on Scenarios and Models for IPBES (IPBES 2016) called for novel scenario approaches, which couple bottom-up, diverse, multiscale scenarios within a consistent global scenario context (see also Rosa *et al.* (2017)). However, because of the lack of sufficiently elaborated alternatives, IPBES has chosen to begin by adopting the SSP scenarios. This will be done by linking the SSPs to various assessment tools for BES indicators. Integrated assessment models and global climate models have converted relevant combinations of SSPs and RCPs into land-use change and climate change projections. Existing BES models then use these land-use and climate projections to assess the consequences of the different development pathways. This is an ongoing effort which uses a range of biodiversity models and some ecosystem service models, with first results delivered in late 2017.

3.3.4.4 IPBES long-term vision on scenarios

The SSPs were developed specifically for climate change assessments, and thus the selection of the key drivers and the design of the scenario framework may ignore critical ecological and land-use dynamics, as well as social-ecological feedbacks that are critical for assessing changes in BES. The IPBES community acknowledges the many limitations of the SSP scenarios for BES assessments, and regards the use of the SSP global pathways as an initial step in the process of scenario assessment. Different opinions on the ways forward exist. There is a very strong plea to hold on to the set of SSP scenarios but either expand or reinterpret these for biodiversity purposes by either introducing these in the storyline or as add-on policies. For example, it is suggested that the SSP1 storyline could include SSP1 climate policies with less bioenergy, which is regarded detrimental for biodiversity. The alternative is to just map the SSPs according to the targets for biodiversity. Both options, depicted in an early sketch in Figure 12, imply relatively little change to the scenario framework created for IPCC.

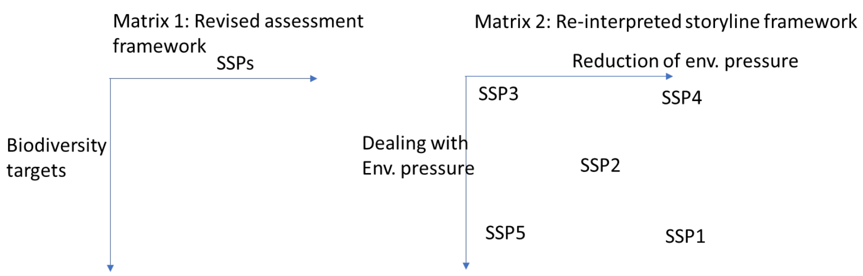

Figure 12. Options for expanding/reinterpreting the SSP scenarios for IPBES (slide from Detlef van Vuuren)

A major advance, in line with the methodological assessment of IPBES on models and scenarios (IPBES 2016), is an ambitious effort to create a novel set of multiscale scenarios of nature futures that consider human development and nature stewardship goals (Rosa et al. 2017). Rather than being based in the tradition of exploratory scenarios as the SSPs, a more target-seeking approach is proposed following the approach implemented for Europe by Verkerk *et al.* (2016), but focused on nature/biodiversity futures. Instead of using socio-economic assumptions as input to the assessment, the exercise aims to produce multiple, stakeholder-defined endpoints and then explore various pathways for reaching those. The nature futures should represent a wide range of human-nature interactions, and include a wide variety of human-modified ecosystems that have different degrees of human intervention and activities.

As in other visioning exercises, nature futures may range from seascapes and landscapes managed together as classes based on similarities in underlying assumptions, storylines and characteristics, which can then be used to integrate visions across scales. At the global scale, nature futures can, for example, explore multiple pathways to achieve the 2050 Strategic Vision of the CBD, and work in close collaboration with ongoing efforts across other sectors developing visions and pathways for the broader array of UN SDGs. At the regional scale, nature futures could be informed by the ongoing IPBES regional assessments, which are collecting information on trends and scenarios of BES, as well as by national and regional biodiversity targets (e.g. national biodiversity strategies and action plans). Once the alternative nature futures have been identified, a range of qualitative and quantitative approaches can be used to identify potential pathways for achieving these futures, including specific policy alternatives, and feedbacks between nature, nature's contributions to people, quality of life and decision-making. To be inclusive and multiscale, the production of these scenarios should use a variety of approaches including modelling, empirical studies and expert knowledge.

A first workshop conducted by IPBES in September 2017 elicited visions from a limited set of stakeholders. Plans for linking such visioning work to model-based assessment for pathways is considered for the long term. Given the required model modifications and related difficulties, a 5- to 10-year period is considered to be needed for full scenario development and implementation. IPBES is, as a science-policy activity, dependent on work by others that may be synthesised into the IPBES assessment. A potential shortcoming of the Nature Futures work is the focus on nature/biodiversity. As land and water are scarce resources such visioning work should account for the trade-offs on other sectors and other SDGs to avoid jeopardising other ambitions.

3.4 Summary of key findings of gap analysis

3.4.1 Suitability of existing BES models for assessment of the socio-economic impacts of BES changes

- There is no current BES model that estimates socio-economic outcomes (or macroeconomic impacts) under future scenarios of economic and demographic change. All models assessed could explore the impact of future scenarios (some combination of climate, and economic and human development) on biodiversity and, in some cases, ecosystem services. However, no model explicitly assesses the impacts to society and the economy from the changes in biodiversity they forecast.
- Some models (e.g. GLOBIOM) estimate the change in monetary value of some ecosystem services under future scenarios. These could be used to assess the benefits of conservation scenarios, but currently used global scenarios (e.g. SSPs) are not configured in this way.
- The BES models assessed have varying degrees of pedigree, credibility and currency. A few models stand out (e.g. Madingley, GLOBIOM, GLOBIO, CLUMondo, Ecopath, InVEST) as examples that are well published (and/or used) and supported by large research groups.
- The scale of analysis of the global BES models reviewed is variable but some model at relatively fine-scale. This is important for BES modelling, particularly if the BES models are linked to economy-wide models such as GTAP.
- BES models are an essential component of the integrated environment-economy models needed to assess socio-economic impacts of changes to BES.

3.4.2 Suitability of integrated environment-economy models and modelling approaches for assessment of the potential global socio-economic impacts of BES changes

- A group of models used to directly consider socio-economic impacts of a changing environment are the system dynamics models (e.g. International Futures simulator; GUMBO/MIMES; Threshold 21). However, these models typically have coarse spatial resolution and are constrained in their ability to represent the multisector global economy, prices and trade.
- A nascent approach to modelling socio-economic impacts is the linking of economy-wide CGE models with BES models.
- Integrating provisioning and non-provisioning ecosystem service data into an economy-wide model requires that ecosystem service data be consistent with the data structure of a CGE model. This implies consistency with the SNA, which is the primary data source for calibrating a CGE model.
- Only a handful of examples exist (at national scale) where dynamic CGE and BES models are linked (e.g. Inter-American Development Bank's IEEM + ESM), but this approach is what is needed to robustly quantify the socio-economic impacts of changes to BES. The approach draws on the strengths of whole of economy approaches with the inherently spatially explicit exercise of ecosystem service modelling. It enables the consideration of expectations of future economic development trajectories, how a specific trajectory affects BES in a given year, and consequently, how this change in BES may reorient that economic development trajectory.

3.4.3 Suitability of existing data and databases to support assessment of the potential global socio-economic impacts of future BES changes

- Economy-wide models and the underpinning data and databases that enable scenario simulations and quantify economic and welfare impacts, especially for non-provisioning ecosystem services and biodiversity, are confined to a very small sample of national-scale cases and largely absent at global scales.
- Data on the economic value of ecosystem services is more prevalent. Many studies have used selections of this data to estimate value functions, which may be useful for transferring and scaling up existing value information to measure impacts of future global changes in BES.

- The distinction between value functions estimated for specific types of ecosystem (land-use class) vs. specific ecosystem services is important for making the link to the results of biophysical models of land-use change and ecosystem service provision. Some biophysical models produce results primarily in terms of changes in land use whereas others generate estimates of changes in ecosystem service provision.
- Regarding the key question of how to link mapped biophysical data on ecosystem service provision with ecosystem service values, it is arguably more straightforward to make the link when values are defined in units of area since this is a directly observable quantity from a map.
- Using value transfer methods is one of the few (perhaps the only) viable means of estimating ecosystem service values at a global scale but it is important to note the limitations and potential inaccuracies involved.
- The structure and basis of measurement (exchange value) of the SEEA Central Framework, and the EEA extension, is consistent and compatible with the SNA. This is advantageous for economy-wide modelling of impacts from changing BES, as it is also compatible with the underlying data structure of CGE models.
- In the SEEA EAA, biodiversity is captured in the measurement of the condition of ecosystem assets, and therefore accounted for in the ecosystem condition accounts.

3.4.4 Suitability of existing scenarios for assessment of the potential global socio-economic impacts of BES changes

- Existing scenarios only describe the future impacts of global change (socio-economic and climate) on biodiversity. What is needed to assess impacts of BES changes on society and the economy are new integrated scenarios that account for the feedbacks between global change drivers, BES and socio-economic dynamics.
- Current global biodiversity scenarios rarely relate estimates of biodiversity loss to consequent changes in ecosystem services, infrequently explore policy options specifically focused at improved management of biodiversity, and do not account for the feedbacks from changes in BES to society and the economy.
- Most BES models base the development of scenarios on future socio-economic trends to assess the potential impacts on BES (though in some cases biodiversity policies are incorporated into these socio-economic conditions). Indicators of impacts on biodiversity and/or ecosystem services are therefore typically an end-point (Figure 13)
- Impacts on human wellbeing and socio-economic conditions, including feedbacks to decision-making and behaviour, are mostly not included in scenarios.
- IPBES is in the early stages of developing new nature futures scenarios which will extend the IPCC SSP scenarios to include goals for both human development and nature stewardship (Rosa *et al.* 2017). The ambition of the proposed nature futures scenarios is to include socio-ecological feedbacks and multiscale processes. They are expected to be produced in time to support the next IPBES work programme from 2019 onwards.

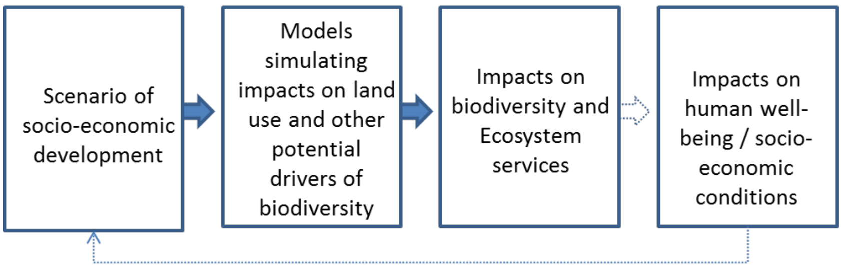

Figure 13. Standard approach in exploratory scenario studies. Full arrows indicate the common approach. Dashed arrows are mostly not included but are much needed.

3.4.5 Overall conclusions: how do existing models, scenarios and data meet needs?

The many needs and modelling and assessment gaps for measuring the future global impacts on society and economy from changes to BES should be summarised to provide the basis for future options. A matrix of the key needs and existing models and economic valuation approaches is presented in Table 8.

A complicated picture emerges from Table 8 as to how suitable existing models, data and scenarios are for meeting the needs identified for assessing the socio-economic impacts of future changes in BES. From the needs analysis, there is a clear urgency for this assessment, from IPBES, WWF and many other global policy and advocacy communities. Unfortunately, there is no off-the-shelf product available now to assess the socio-economic impacts at global scale. Some BES models of high pedigree could relatively quickly produce high-resolution outputs that could be suitable, such as the suite of tools in InVEST, but none of these models are linked or coupled to models of the global (or regional) economy. Alternatively, robust, dynamic economy-wide models that include aspects of the environment, such as GTAP, or other integrated economy-environment models, such as Threshold 21, contain or use relatively coarse representations of BES. A model that arguably meets many needs is the IMAGE integrated assessment modelling framework developed by PBL, which contains high-resolution global-scale BES models, and has been linked to a CGE to define future drivers. However, IMAGE itself does not report on future macroeconomic impacts.

Models need data as input, and the models need to be applied within a scenario framework because the problem of socio-economic impacts of future changes in BES contains substantial uncertainty. Unfortunately, current framing and design of scenarios is not sufficient to meet the need because the existing scenarios only tell half the story: they typically only include future changes in BES, and do not extend to the subsequent impacts to society and the economy. While there is much data on BES and economic values, it must use/conform to a framework that is consistent with whole economy models – here the SEEA-EEA provides a way which complies with national accounts and with whole economy models that use national accounts data.

Table 8. Matrix of how identified needs for modelling socio-economic impacts of future BES are or could be met by existing models and data.

Green = Does and/or could meets the need with minimal additional development/investment

Amber = Partially meets the need or could meet the need with modest development/investment

Red = Does not meet the need. Either it would not be possible to meet the need or substantial development/investment would be required.

Needs							
Existing models, data, scenarios		Able to assess socio-economic consequences of degrading ecosystems	Able to produce outputs within 12 months	Able to use/assess indicators of macroeconomy	Able to produce indicators of ecosystem service values	Able to be applied at global scale	Able to produce high-resolution, spatially explicit outputs
BES models	Madingley	Red	Amber	Red	Red	Green	Green
	GDM	Red	Red	Red	Red	Amber	Green
	PREDICTS	Red	Amber	Red	Red	Green	Green
	GLOBIOM	Green	Amber	Red	Green	Green	Green
	GLOBIO	Green	Red	Red	Red	Green	Green
	CLUMondo	Green	Amber	Red	Green	Green	Green
	Ecopath with Ecosim	Green	Amber	Red	Green	Amber	Red
	InVEST	Red	Green	Red	Red	Green	Green
Integrated environment-economy models	IMAGE	Green	Green	Red	Green	Green	Green
	GUMBO/MIMES	Green	Amber	Red	Green	Red	Green
	International Futures	Red	Amber	Green	Red	Green	Red
	System dynamics (e.g. Threshold 21)	Green	Amber	Green	Green	Amber	Red
	GTAP/CGE	Amber	Green	Green	Green	Green	Red
	IEEM + ESM	Green	Amber	Green	Green	Amber	Green
Data and scenarios	Existing global scenarios (e.g. SSPs)	Red	Amber	Green	Red	Green	Red
	ES values databases	Green	Green	Red	Green	Green	Amber
	SEEA - EEA	Green	Amber	Red	Green	Amber	Red

4 Recommendations for further modelling and analysis

4.1 Introduction

This scoping project has identified a strong case for pursuing further modelling, particularly to assess the potential global impacts of BES changes on the macroeconomic outcomes/metrics. This section sets out a proposed approach for how this work could be taken forward. The recommended approach has been identified from a range of potential options, taking into account the informational needs and timeline identified during the needs analysis (Section 2.3), and the suitability of existing models, data and scenarios for estimating the future socio-economic impacts of changes in BES discussed in the gap analysis (Section 3.3).

Several potential options were considered less feasible and/or useful at this stage and were set aside (see Appendix 4). These options were presented as background material for the delegates to the expert workshop held in Amsterdam on 6-7 June 2017 (see Appendix 3 for a list of participants).

4.2 Overall approach recommended

Based on the results of the needs and gap analyses, we suggest the most feasible and useful approach would be to develop a modelling framework based on the GTAP database and model, tightly integrated with ecosystem service models (for example those in the InVEST toolbox), to analyse how BES changes would affect global socio-economic outcomes. The validity of our approach is confirmed by Smith (2013) who reviews linked economy-environment models for assessing impacts to the economy from changes in BES. Smith concludes that models linking dynamic CGE economic models to dynamic ecosystem models, where prices and capital are endogenous, the ecosystem feeds back into the economy and the economy directly affects the ecosystem, offer the most robust way to assess the impact to the economy of changes in BES.

From the gap analysis, there is no existing BES model or modelling approach that sufficiently links or integrates with established models of the global economy. Although there are examples of integrated approaches and models that link with a CGE model (e.g. IMAGE and ENV-Linkages), none, as far as we are aware, integrate with the highly regarded GTAP model. For the modelling of BES, the InVEST modelling toolbox is arguably the gold standard – it has a substantial developer and user community, strong model pedigree, and offers the flexibility to choose and apply ES models of greatest relevance and priority in the study area.

The GTAP model of the economy is the gold standard in economy-wide modelling and is supported by many countries' statistical and economic agencies, as well as being used by large international organisations such as the World Bank. GTAP is a well-established and well-respected model of the global economy and trading patterns, which has been used to model numerous issues and questions, generating outputs in standard economic terms such as GDP, jobs, income, production, trade etc. Despite the potential, its application to environmental economics issues to date has been limited.

Here we briefly outline a phased approach to integrating BES and macroeconomy modelling, following on from the current scoping phase (Phase 1). Further explanation of each phase is presented in Table 9 and the next section (Section 4.3).

Phase 2:

This would involve a synthesis of the existing (currently fairly limited and country- and ecosystem service-specific) information and data on the impact of BES changes on socio-economic outcomes. This would be used to inform the development of a set of plausible future scenarios of changes in BES to be used in the model (ideally aligned with those emerging from modelling work being undertaken within the IPBES work programme), and a set of proposed 'impact pathways' (based on qualitative assessment of the various ways we would expect relevant socio-economic indicators to be affected under these scenarios).

Phase 2 would then undertake preliminary quantitative modelling using the GTAP model (or equivalent), informed by the scenarios and impact pathways, to assess the potential global socio-economic impacts of BES changes (under scenarios developed above). As a first of its kind, the work would be expected to involve a relatively simple modelling approach at this stage (e.g. relatively simple scenarios and assessment of impacts based on a limited set of specific BES changes), which would then be further developed and enhanced in Phase 3.

A report would be produced including results at both the global level and the country level (e.g. assessing how BES changes would affect national production, trading patterns and income). A workshop would also be undertaken with experts to discuss the findings, and best way forward.

Phase 3:

This would involve linking the GTAP model (or equivalent) to a number of BES models, such as InVEST, to better model the interlinkages between ecosystem services and economic outcomes, including models of land-use change. At this stage the aim would be to incorporate feedback loops into the GTAP + BES framework, in order to take better account of how socio-economic outcomes generated by changes in BES would affect the next iteration of the scenarios to be modelled, in an iterative process. Given the data requirements, this would likely only be possible by focusing on particular countries and/or regions in the first instance. A report would be produced and a workshop held to discuss the findings, decide how to refine the model, and agree on the best way forward.

Phase 4:

This would involve further refinement of the linked GTAP + BES modelling approach based, on learning in the previous two phases, and benefiting from additional data that is becoming available. The aim would be to scale up the work to a more sophisticated analysis to generate results at the global level.

Potential timing of the various phases is summarised below, and further detail on each phase is set out in Table 9.

Phase	Duration	Scope/focus
2) Development of scenarios and preliminary simple modelling	~ 6 months	Synthesis of existing global and national-level information/data to inform development of scenarios, and model calibration. Calibration of model, preliminary modelling and expert workshop.
3) Full model-development and detailed modelling at the regional level	~12 months	Refinement of scenarios and link GTAP model with BES models, and detailed modelling of a broader range of scenarios for key countries/regions.
4) Full model development and detailed modelling at the global level	12+ months	Further additional modelling and analysis, to enhance global coverage and strengthen consideration of environment-economy linkages and feedbacks.

Table 9. Summary of phased approach to modelling the potential global socio-economic impacts of BES changes

	Phase 2 (~ 6 months duration)	Phase 3 (~12 months duration)	Phase 4 (12+ months duration)
Summary	Synthesis of information/data, development of scenarios and preliminary modelling using GTAP (no BES).	Development of full model (GTAP+BES) and detailed modelling for specific focal countries/regions (not global level).	Further refinement of full model (GTAP+BES) and detailed modelling at the global level.
Key aspects	• Uses GTAP model or equivalent (no BES models). • Preliminary analysis of impacts at global level. • Impacts of BES changes considered exogenously. • Relatively simple modelling scenarios used – crude BAU and policy/target scenarios. • Models impacts of certain BES changes only (e.g. for provisioning services, e.g. food/fibre). • Limited set of impact metrics (e.g. GDP, income, trade, sectoral activity etc.)	• Uses linked GTAP + BES modelling framework. • Detailed analysis of impacts for specific focal countries/regions – identified based on WWF and/or other policy priorities. • Impacts of BES changes considered endogenously. • Environment-economy feedbacks to BES not considered. • More refined modelling scenarios used – e.g. new IPBES scenarios, more precise scenarios based on SDGs. • Broader range of ecosystem services considered. • Broader range of impact metrics (e.g. addition of emissions, soil/nutrient retention, water availability/use, land use/cover, etc.).	• Further refinement of linked GTAP + BES modelling framework (to achieve global coverage of ES models). • Detailed analysis of impacts at global level. • Impacts of BES changes considered endogenously. • Most critical environment-economy feedbacks to BES considered. • More refined modelling scenarios used. • Broader range of ecosystem services and impact metrics considered (as per Phase 3).
Description of phase objectives	1. Preliminary synthesis of existing information/data to inform scenario development and GTAP model calibration 2. Develop initial/basic modelling scenarios 3. Calibrate model 4. Undertake preliminary/simple modelling 5. Organise expert workshop to share/discuss results and refine approach for next phase.	1. Further synthesis of information/data to help refine scenarios and calibration of models 2. Develop more detailed scenarios 3. Begin calibration of BES models to be used in the linked GTAP + BES framework 4. Undertake preliminary modelling with GTAP + BES for focal countries/regions (no feedbacks) 5. Organise expert workshop to share/discuss results and refine approach for next phase.	1. Expansion of fully linked GTAP + BES for all countries/regions (with most critical feedbacks) 2. Further refinement of scenarios and model calibration 3. Further modelling runs using refined scenarios, based on suite of ecosystem services and impact metrics 4. Organise expert workshop to share/discuss results.

	Phase 2 (~ 6 months duration)	Phase 3 (~12 months duration)	Phase 4 (12+ months duration)
Consideration of BES in model	Changes in future BES supply are implemented as exogenous shocks on the model (based on scenarios developed). The standard GTAP framework considers impacts on food and fibre provisioning ecosystem services – the investigation will be limited to these provisioning services.	Scenario impacts on food and fibre provisioning services. BES changes are endogenised in the modelling framework. In the medium term, can prioritise specific services for priority countries/regions. Among the options for final ES, these could include climate regulation (carbon sequestration and storage), water yield and hydropower generation, and nutrient and sediment retention. Options for supporting ecosystem services could include biodiversity, habitat and pollinating services, for example, models that generate biodiversity metrics (GLOBIO), and indicators related to habitat quality/risk and pollinator abundance.	As in 3 and will depend on WWF prioritisation of services. Number and types of feedbacks will also require deliberation as the work advances.
Type of scenarios modelled	Given the time available, as well as the fact that modelling is not spatially explicit beyond the national/regional level, it would be prudent to focus on basic scenarios that explore changes in ecosystem service supply that are most likely to occur and would likely be the most disruptive.	Following on from phase 2, the scope and complexity of scenarios will be increased and the linked GTAP + BES framework developed. This endogenises BES and can explore trends that deviate from the past where BES is concerned (e.g. the rate of decline of BES accelerates when compared with recent history), as well as policy scenarios and other exogenous shocks. Policy scenarios could look at aspects related to the SDGs: (e.g. emissions reductions to meet NDCs, elements of green growth strategies, protected areas policies, etc.). Potential climate change impacts on the interaction between economies and BES is another area with wide scope for exploration.	Scenarios will follow from 3 based on 2020 priorities.
Inputs required	Literature/library access; GTAP database/licence; global economic model such as GTAP; full GEMPACK licence if GTAP model or GEMPACK-based model is used. GAMS software required for non-GEMPACK-based models. Scenarios developed by the project team with WWF input, based on the literature and IPBES scenarios and BES model outputs available.	In addition to inputs detailed in phase 2: GTAP satellite databases and applications; LULC model (developed by project team based on existing models); LULC basemap; new BES models (developed by project team using InVEST or similar tools); geospatial and other data inputs.	In addition to inputs detailed in 3: additional literature review for understanding and operationalising environment-economy feedbacks.

	Phase 2 (~ 6 months duration)	Phase 3 (~12 months duration)	Phase 4 (12+ months duration)
Outputs generated	Phase 2 final report with synthesis of the literature and preliminary scenarios developed based on this synthesis (including graphs, conceptual figures and tabulated data). If preliminary modelling is undertaken, outputs will include detailed/quantitative description of the scenarios and model results in tables/charts/figures. The indicators reported would include measures of changes in economic output (e.g. GDP, income, trade, sectoral activity, etc.), and analysis, interpretation and implications. Scenarios that explore future deviations in terms of BES, including a 'storyline' and a scenario description that frames how the narrative is operationalised in GTAP as a shock. Scenarios could also be policy-oriented or explore other exogenous shocks such as climate change impacts, economic shocks and others. The scope of scenarios evaluated, however, must consider the short time available for any preliminary modelling. Global results, based on simple modelling.	Phase 3 report that finalises the synthesis of the literature and the exogenous implementation of BES shocks in GTAP. This will include detailed/quantitative description of the scenarios and model results in tables/charts/figures. The indicators reported would include measures of changes in economic output (e.g. GDP, income, trade, sectoral activity, etc.), and analysis, interpretation and implications.. Scenarios of greater precision than Phase 2. These would be policy-oriented or explore other exogenous shocks such as climate change impacts, economic shocks and others. Calibrated BES models and the linked GTAP + BES framework for focal countries/regions; model results in tables/charts/figures. The indicators reported would include measures of changes in economic output (e.g. GDP, income, trade, sectoral activity, etc.). Depending on the BES considered additional metrics in physical units which could include emissions, soil/nutrient retention, water availability/use, LULC, among others; analysis, interpretation and policy implications. National / regional results based on more sophisticated modelling and more precise scenarios.	Same as the second component of Phase 3 with global coverage and consideration of feedbacks between economies and BES. Global results based on more sophisticated modelling.
Scale of analysis	National/regional/global.	National/regional.	National/regional/global.
Time horizon and time steps in analysis	The time horizon of analysis is 2030; one (static GTAP model) or periodic/annual time steps (dynamic GTAP model).	The time horizon of analysis is 2030; periodic/annual time steps.	The time horizon of analysis is 2050; periodic/annual time steps.
Partnerships	CGE modelling; environmental economics; ecology. Suggest small team of experts.	CGE modelling; environmental economics; ecology. Suggest small team of experts, and include independent panel for expert review.	As in phase 3.

	Phase 2 (~ 6 months duration)	Phase 3 (~12 months duration)	Phase 4 (12+ months duration)
Risks (and mitigation)	IPBES scenarios not available in time. Delays in initiating the work. Scope of analysis not clearly defined. Inadequate evidence base with which to properly inform / calibrate the model. Mitigation measures: team to define scenarios based on synthesis of literature in the absence of IPBES scenario information. Team defines scope with WWF in formulation of workplan.	Data availability/scope of coverage. Mitigation measures: pursue alternative approaches (e.g. different countries/regions, alternative BES) where required when data scarcity limits coverage.	Data availability/scope of coverage. Mitigation measures: pursue alternative approaches (e.g. different countries/regions, alternative BES) where required when data scarcity limits coverage.
Limitations	Exogenously determined BES impacts from multiple sources. Food and fibre ecosystem services aside, no feedbacks between economy and BES impacts.	Exogenously determined BES impacts from multiple sources for the first component of this phase which applies exogenous shocks related to BES supply in GTAP (the second component of this phase endogenises ecosystem service supply). Food and fibre ecosystem services aside, no feedbacks between economy and BES modelling.	High level of complexity in considering feedbacks between the economy and BES. Feedbacks may be country/region-specific and therefore data/time/resource intensive. Analytical complexity may cause difficulties in interpretation of results.
Feasibility	This option is technically feasible. The short time to start implementing this option and the availability of researchers with the necessary expertise at such short notice are the main constraints.	This option is technically feasible. Data availability/scope of coverage may impose limitations. Scope of analysis needs to be carefully defined.	This option is technically feasible. Data availability/scope of coverage may impose limitations.
Indicative budget[1]	GBP 50K-60K (+ GBP 15k for workshop)	GBP 150K-250K	GBP 500K-750K

[1] Ranges apply to alternative contracting options. Upper end applies to consultant(s) from large organisation with large overheads. Lower end applies to team of individual consultants with highly relevant expertise.

4.3 Detail on recommended phases

Phase 2: Synthesis of information/data, development of scenarios and preliminary modelling using GTAP (no BES models)

The first step in this analysis involves reviewing and synthesising existing studies on scenarios that evaluate differing development trajectories and changes in the environment, and how they impact BES and social and economic indicators (e.g. GDP, sector output, consumption, employment, government revenue, poverty, income inequality, genuine savings, inclusive wealth index, among others, depending on the indicators generated in each study). This review and synthesis will provide the evidence base upon which to develop scenarios and calibrate shocks to be implemented exogenously in GTAP for this Phase 2 (and could potentially also feed into drafting of the WWF 2018 Living Planet Report).

This synthesis would strengthen the case for ongoing and increased investment in landscape-scale restoration and conservation for achieving multiple benefits (e.g. SDGs). It would be geared towards government and business decision-makers using metrics and language that they find most compelling and valuable (e.g. narratives of how environmental change could affect economic outcomes such as GDP, productivity, growth, jobs, natural capital).

Projections on plausible future BES changes would be derived from the scenarios prepared by IPBES and the ongoing synthesis of the literature. The scenarios currently available, and likely to be used by IPBES to 2019, are the SSPs prepared for the IPCC and now adopted by IPBES.[2] These SSPs mainly distinguish different pathways towards adaptation and mitigation to climate change. Only in a longer time frame (2019 or beyond) are new scenarios tailored to IPBES likely to be available. In close consultation with the IPBES working group on scenarios, and where possible using the IPBES SSPs, narratives on changes to future biodiversity and ecosystem change will be developed. In the case of the SSPs, scenario development serves as a common starting point for the integrated analysis of future climate change and policy responses (O'Neill *et al.* 2017; Riahi *et al.* 2017). Narratives developed here on future biodiversity and ecosystem service supply would also serve as a common starting point for Phase 2 and subsequent Phases 3 and 4.

With preliminary narratives developed, the next step in this workflow, as indicated by Riahi *et al.* (2017) in the context of SSP development, is the translation of qualitative narratives into quantitative projections, or scenarios (Riahi *et al.* 2017). In the case of SSPs, this task involves generating projections for the main socio-economic drivers of each pathway, which include trajectories of key indicators describing population growth, education, urbanisation and economic development. Our Phase 2 also involves translating the narratives that describe trajectories for future BES supply into shocks that may be implemented in a GTAP-based modelling framework. The nature and size of the shocks would be identified during the translation exercise, and would be informed by the literature as well as expert consultation via targeted conversations with relevant experts. The translation and operationalisation of narratives that has already been undertaken (i.e. for IPBES scenario modelling for the Global Assessment) will be taken as the starting point for this exercise.

In modelling the socio-economic impacts of future BES changes, it is a prerequisite that the specific transmission pathways between the two are quantitatively described, and that bounds are set for the number of pathways that are considered in the analysis. A pragmatic approach will be taken where the preliminary focus would be on those BES changes that have the greatest probability of occurring and those that are expected to be the most disruptive to economies and wellbeing. Using data coming out of IPBES global modelling, the priority ecosystem services identified by IPBES are crop production, livestock, wild food, carbon sequestration, soil erosion control, pest control, water quality, flood protection and recreation, many of which will have impacts on food production.

These exogenous changes in BES are likely to have impacts on agricultural output –in other words, on food provisioning ecosystem services. GTAP runs can tell us how an exogenous shock impacts food provisioning ecosystem services. Declines in BES could have implications for the frequency and extent of crop/agricultural losses due to pest/disease outbreak. Also along the lines of reduced genetic diversity, the rate at which discoveries of new medicines occur may also decline, reducing human resilience to disease. Lower genetic diversity can result in a slower rate of development of

[2] The IPBES Modelling and Scenarios expert working group is planning to produce new scenarios 'in time for the 2019 IPBES Global Assessment', but there's no clarity on when scenarios will be available. They recently published a paper on need for new scenarios. See Rosa et al. (2017) Multiscale Scenarios for Nature Futures. *Nature Ecology and Evolution*.

more productive and resilient crops, thereby slowing growth in agricultural productivity and the pace at which food security is achieved. Habitat declines and destruction would lead to reduced pollinator diversity which has implications for future agricultural yields.

As another example, consider expectations about water provisioning services to produce biomass – specifically, water availability for rain-fed and irrigated crop production. A narrative that involved a decline in the supply of water provisioning services for some regions (and an increase in others) could be considered. This would have implications for agricultural productivity and could motivate investment in water-saving technologies and installation of greater irrigation infrastructure capacities, and/or improved watershed management policies.

Considering water provisioning services more broadly to include water produced for human and animal consumption, trade-offs between competing water uses and users could become more acute in some regions. On the other hand, those regions receiving more rainfall and run-off could suddenly face flooding and the impacts that this may have on natural and built assets. Conversion of forest to agriculture can have implications for erosion mitigation services that can translate directly into increased sedimentation and higher water utility and hydropower generation costs. Eutrophication of waterways may increase in new agricultural areas, particularly where fertiliser use becomes more intense.

Figure 14 describes the general workflow for implementing a specific component of a narrative in the dynamic GTAP-based modelling framework. The first step in the workflow is to generate the baseline forecast with expectations on GDP, population and labour force (skilled/unskilled) growth. The baseline forecast provides estimates of all standard economic indicators including GDP and income for the period of analysis (base year to 2030, for example). Next, an operational version of a narrative is implemented in the GTAP model. In the example presented in Figure 14, this is an expectation about decline in biodiversity and a reduction in pollinator diversity. This impact is transmitted through the model as an agricultural productivity shock implemented in the production function for a specific agricultural sector and country/region[3]. The model is run and again, and the standard economic indicators are produced annually for the period of analysis. In Figure 14, the difference between the baseline and the scenario, in global GDP, is the impact of the loss of pollinator diversity.

The indicators generated through this analysis are standard economic indicators that include changes in national or regional GDP, income and international trade flows. Indicators would be reported at the global and regional level where appropriate, as well as the national level for all 140 GTAP countries/regions.

[3]Other shocks asides from agricultural (and forestry and fisheries productivity) that may be relevant can include factor endowments, population, sector output, prices, intermediate consumption, household consumption, changes in household preferences, tariffs, tax policies, among others.

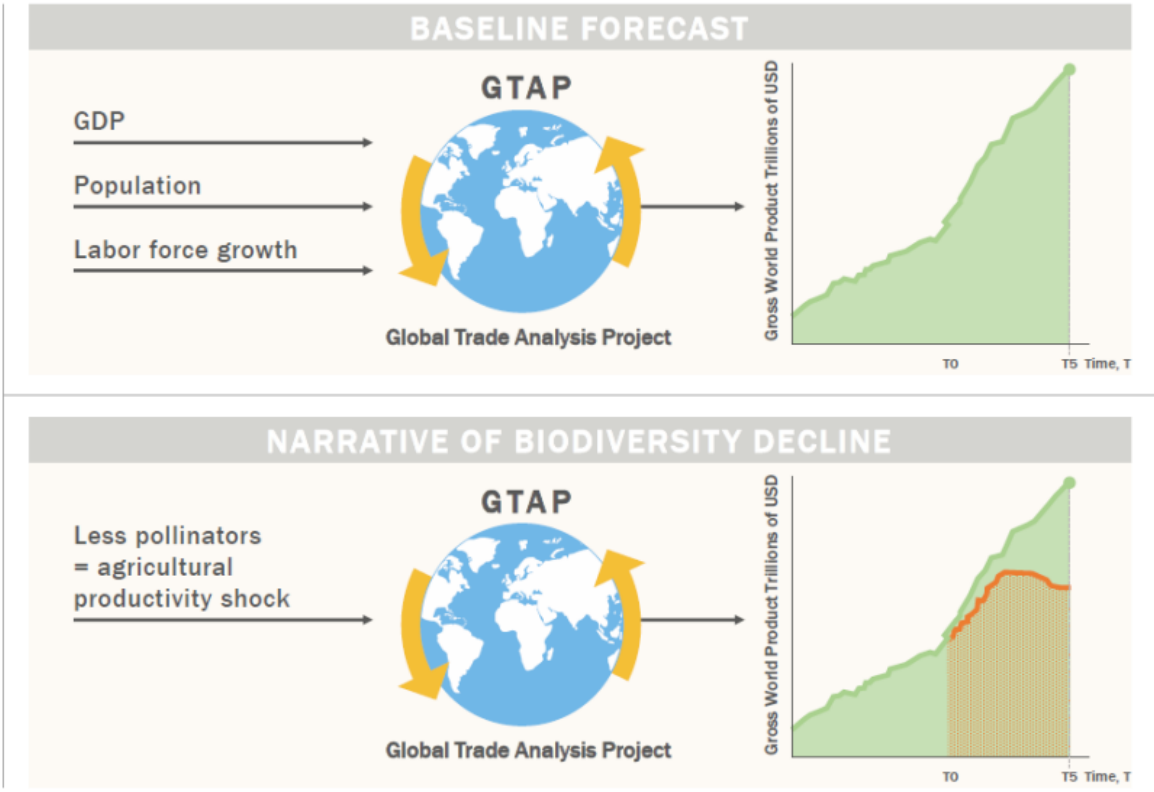

Figure 14. Implementation of narrative of pollinator abundance in GTAP as exogenous shock.

Phase 3: Development of full model (GTAP + BES) and detailed modelling for specific focal countries/regions

Phase 3 would build on the work in Phase 2, the main differences being the complexity of the scenarios and impact pathways (e.g. specific ecosystem services considered), the number of scenarios evaluated (introduction of additional BES policy and target-setting scenarios), and the endogenisation of BES modelling.

The indicators would be similar or the same as Phase 2, though additional indicators could be considered depending on the specific scenarios/transmission pathways and databases used. Indicators related to irrigation water use (Haqiqi *et al.* 2016), CO_2 emissions (McDougall & Golub 2007), other greenhouse gas emissions (Lee 1997), electricity use (Peters 2016), land-use change (Baldos & Hertel 2012) and detailed poverty impacts (Zekarias, Thomas & Alla 2013; Hertel *et al.* 2015) could also be generated through this analysis, depending on the priorities identified and databases used. Based on modelled outputs and the indicators generated, metrics of semi-inclusive wealth (Stiglitz, Sen & Fitoussi 2010; Arrow *et al.* 2012; Polasky *et al.* 2015) could be estimated on the basis of environmental resource rents and emissions as an example (UNU-IHDP & UNEP 2014). Inclusive wealth is a measure of the aggregate value of all capital assets (human, manufactured and natural capital); a metric of inclusive wealth requires measurement and valuation of all assets that contribute to human wellbeing. This is of course challenging, so semi-inclusive measures of wealth have been proposed which focus on those assets that are more readily valued, complementing this valuation with biophysical metrics where natural capital is concerned (e.g. standing volume of forest stocks).

The second component to this phase is the development of a linked GTAP + BES framework. This could be based on the approach developed by IADB in its IEEM + ESM project, which is in progress in Guatemala, Colombia and Rwanda (Banerjee *et al.* 2016; Banerjee *et al.* 2017a). In this component, the main GTAP database and the GTAP land-use database will be used to undertake analysis of economic impacts of changes in biodiversity and ecosystem service supply.

There are several key differences between the GTAP-only (Phase 2) and the linked GTAP + BES approach (Phases 3 and 4). First, the narratives developed in the GTAP-only approach are built around the outputs of projections related to future expectations of BES change. The specific shocks implemented in this approach operationalise these narratives and quantitatively describe the transmission pathways between changes in BES and their impacts on the national/regional and global economy through time. Thus, all expectations on BES change are imposed on GTAP as external shocks throughout the period of analysis. The GTAP + BES approach is an advance because it has a much higher level of dynamism. For each scenario considered, GTAP + BES enables the endogenous estimation of change in ecosystem service supply, for specific ecosystem services and focal countries/regions.

Consider first the baseline (or business-as-usual) scenario. Note that in both the dynamic GTAP-only and GTAP + BES approaches and in economy-wide modelling in general, the baseline is always the reference to which all other scenarios are compared. Expectations on GDP growth, population and labour force growth are drawn from the literature to establish the baseline trajectory of the global economy. The model is run and the baseline forecast is generated.

The dynamic GTAP modelling platform, without any specific BES modelling, provides results on standard economic indicators as well as sectoral output. This includes the value of agricultural and livestock output,[4] and forestry and plant fibre output – or food and fibre provisioning ecosystem services. For Phase 3, the next step is to produce a land-use change matrix based on the baseline forecast. This is undertaken based on the GTAP land-use database which contains data for crops, pasture and forests for the 18 agro-ecological zones globally. Based on this matrix, new LULC maps are generated for each year (or pre-defined period) between the base year and final year of analysis (2030, for example). This would involve development of a LULC change model, preferably building on an existing model such as CLUMondo, which would run through a set of decision rules to allocate any change in land use (crop, pasture and forest) across the landscape.[5]

The next stage is to build and run BES models using LULC to estimate changes in ecosystem service supply under the baseline and alternative scenarios. As a starting point, the ecosystem service models implemented for the IPBES Global Assessment could be used, but other models would be investigated. The global-scale version of InVEST is one option and has advantages such as its widespread use and accessibility. For final ecosystem services, the InVEST toolbox includes ecosystem service models for climate regulation (carbon sequestration and storage), water yield and hydropower generation, and nutrient and sediment retention. Models are also available for some supporting ecosystem services, for example, models that generate biodiversity metrics (GLOBIO), and indicators related to habitat quality/risk and pollinator abundance. The ecosystem service changes would be driven primarily by changes to land use and land cover under the baseline and other (e.g. policy) scenarios.

Ecosystem service models will be built for the selected countries/regions for the base year, consistent with the base year of the GTAP database, and used to generate ecosystem service supply estimates that are consistent with SNA and SEEA-EEA accounts. Considering again the baseline scenario, GTAP is implemented to generate outputs in terms of economic indicators as well as LULC change for each agro-ecological zone. The LULC change model is then used to distribute land-use change across the landscape. The resulting new LULC maps are used as an input into the ecosystem service models to project future ecosystem service supply. Thus, what changes through time in terms of the ecosystem service models is the LULC map since most other variables in the ecosystem service models are relatively stable in the short run (e.g. elevation, slope, aspect, edaphic characteristics, and climate variables – though these need not remain static in the modelling exercise and future climate changes could be included). Estimations for ecosystem service supply can be made on an annual or other periodic basis depending on the intended use of the outputs.

By the end of this phase, the GTAP-based approach will be finalised with the development of more robust/detailed scenarios based on the comprehensive synthesis of the literature. The linked GTAP + BES approach will be well under way with numerous ecosystem service models developed for various focal countries and regions. Preliminary results

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[4] Agricultural and livestock products include paddy rice, wheat, cereal, vegetables, fruit, nuts, oil seeds, sugar cane/beet, oil seeds, other crops, cattle, raw milk, sheep, goats, horses, other animal products and fisheries.

[5] Various land-use change models exist including CLUE/CLUMondo implemented at both the European and global scale (Verburg *et al.* 2008) and the Land Use Trade-Off model (LUTO) in Australia (Gao & Bryan 2017) In the case of IEEM + ESM, a land-use change model was developed to enable maximum flexibility and compatibility with IEEM outputs and ESM inputs (Banerjee *et al.* 2017a).

will be generated with the linked GTAP + BES. Feedbacks between GTAP and the ecosystem service modelling will be explored in detail in phase 4 and global coverage of ecosystem service models will be achieved.

Phase 4: Further refinement of full model (GTAP + BES) and detailed modelling at the global level

Once the one-way interaction between GTAP, the LULC change mapping and BES modelling is established in phase 3, feedbacks between BES changes and the economic system can be considered, leading to a fully dynamic economy-BES modelling approach. Depending on the ecosystem service modelled, these feedbacks may be relevant across countries/regions, or specific to some countries/regions. The number of feedbacks and level of complexity considered in the analysis will depend on the time and data available and other resource constraints. Both short-run and long-run (post-2020) strategies can be developed once priority ecosystem services and country/regions are defined.

The feedbacks between the ecosystem service models and GTAP are implemented iteratively. One example of a potential feedback is related to erosion mitigation ecosystem services. If in the baseline or in an alternative scenario, LULC change leads the model to report a reduction in erosion mitigation services and an increase in sedimentation, this can have a direct impact on costs of hydropower generation or irrigation water supply, which can in turn be implemented in GTAP as a damage or mitigation cost. This type of feedback is run iteratively, so the increased cost may have subsequent impacts on LULC and ecosystem service supply. The iterations would continue until the end of the period of analysis (e.g. 2030).

Figure 15 illustrates the workflow for the GTAP + BES approach for one iteration between GTAP, LULC and an ecosystem service model for nutrient retention ecosystem services. Referring to Figure 15, A1 is a representation of the global economy in the base year. A2 is a base year LULC map developed from the base year land-use database. With this base map and other data, an ecosystem service model is calibrated for nutrient retention ecosystem services. Returning to the GTAP model at B2, the economy is projected for e.g. a five-year period (period #1) based on expectations on GDP, population and labour force growth across countries. Based on this model run, a new period #1 LULC map is generated (B3). Replacing the baseline LULC map with the period #1 LULC map in the ecosystem service model, the model is recalibrated and period #1 nutrient retention is estimated (A3). As an illustration, assume nutrient retention services are reduced between the baseline and period #1. One key impact of this ecosystem service loss is a reduction in the growth rate of agricultural productivity. This agricultural productivity shock is implemented in GTAP (C1) and will impact the global economy, LULC and thus subsequent period nutrient retention ecosystem services.

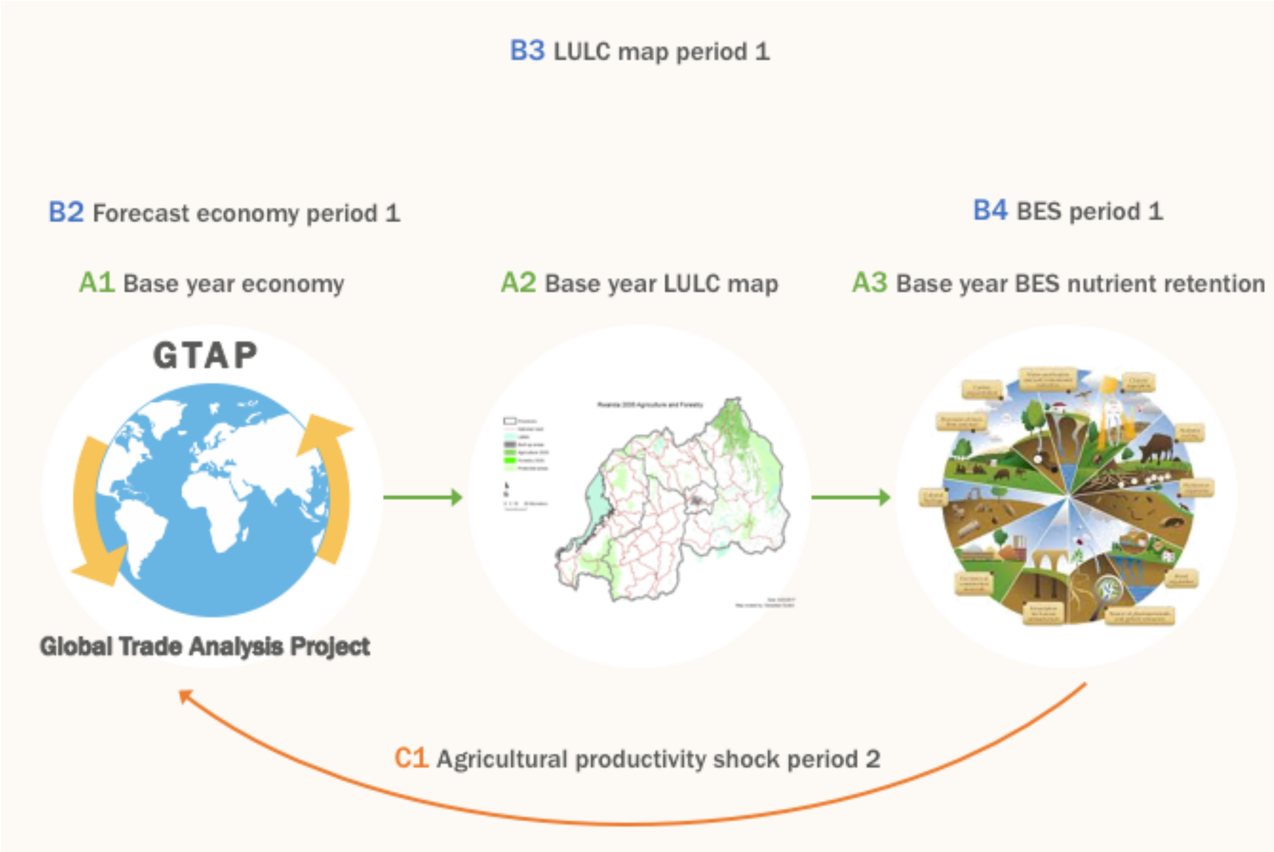

Figure 15. Workflow for GTAP + BES described in two periods with an example of nutrient retention. LULC = land use land cover and BES = biodiversity and ecosystem service modelling.

5 Conclusion

This report presents a detailed scoping of the needs and subsequent modelling and data gaps to estimate the global socio-economic impacts of future changes in BES.

From the needs analysis, it's clear that there is an urgent need to improve our understanding of how economies and societies will be impacted if current trajectories of BES continue. This information is critical to support decision-making across all sectors, but especially in parts of the government and the private sectors where the impacts to economies from declines in BES are not traditionally considered. Building this capability will also allow decision makers in policy and investment to better understand the benefits to society and economies from more sustainable policies that halt and reverse the declining trends in BES. The ability to test future scenarios of policies and targets for improving BES (such as those embodied in the SDGs), and the subsequent impacts on economies, will be of benefit to many global-scale organisations, especially IPBES and the CBD. Also benefiting from enhanced capacity to understand the socio-economic impacts of future changes in BES will be national governments who are guided by or aim to comply with international policies, and NGOs at all levels who make the case for a more sustainable future. They need this information now.

Existing models, data and modelling approaches are not, in their current form, ready to meet the identified needs. The current way that future scenarios are developed and implemented in modelling and assessment is not appropriate for estimating impacts to economies from changes to BES. While a number of models and approaches are close (e.g. the Dutch Environment Agency's IMAGE model), and there are examples of national-scale modelling of the socio-economic impacts of future changes in BES (e.g. the IEEM+ESM modelling at the IDB and the UNEP Threshold21 system dynamics model), effort is needed to link and integrate existing tools and approaches, incorporate new scenarios, and upscale for a global assessment.

It will be essential to ensure any integrated economy-environment modelling approaches build on or are compatible with economy-wide models that already underpin many policy and investment decisions in ministries of finance and economy. Economy-wide models, such as CGE, have widespread credibility for estimating economic impacts from alternative policies. So far, the application of these models to policy decisions related to the environment and sustainability are limited. Integrated economy-environment models, available to be applied at global scale, are urgently needed.

We propose a phased approach to building an integrated environment-economy model that assesses the impacts to the economy from future changes in BES. There is significant novelty in our approach so for this reason an approach that builds progressively on previous phases is recommended. We argue that a CGE model (e.g. the GTAP model and database), tightly coupled with models of BES, is the most robust and credible way to estimate impacts to the economy from changes in BES. The GTAP model and database is highly regarded and widely used by the economics discipline. Building onto that model will ensure credibility amongst economists who are very influential within key ministries where environmental impacts of policy decisions must have increased prominence.

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Appendix 1: Survey questions distributed to experts to illicit needs for modelling socio-economic impacts of future changes in BES

Key stakeholders and experts identified for the needs analysis

Name	Organisation	Expertise
Paul Leadley	University of Paris-Sud	Ecology
Thomas Koetz	IPBES	IPBES
Jozef Settele	UFZ	Ecology
Claire Brown	WCMC	Ecology
Dr. Henrique Pereira,	German Centre for Integrative Biodiversity Research (iDiv), Germany	Ecology
Sylvia Karlsson-Vinkhuyzen	Wageningen University, The Netherlands	Social science
Anne Larigauderie	IPBES	IPBES
Carlo Rondini	Uni Rome	Ecology
Kai Chan	University of British Columbia	Ecological economist
Isabel Rosa	German Centre for Integrative Biodiversity Research (iDiv), Germany	Ecology
Rob Alkemade	Netherlands Environmental Assessment Agency (PBL)	Environmental modelling
Salman Hussain	UNEP TEEB	Ecological economist
Pavan Sukhdev	GIST Advisory	Environmental economist
Simone Quatrini	UNCCD	Ecological economist
Mark Schauer	GIZ	Forestry management
Pushpam Kumar	UNEP	Ecological economist
Robert Costanza	ANU	Ecological economist
Lars Hein	WAGENINGEN	Ecosystem services
Stephen Polasky	University of Applied Economics	Environmental economics
Juhern Kim	Global Green Growth Insitute	Ecosystem services
Louise Gallagher	Luc Hoffmann Institute	ES research and communication
Rosimeiry Portela	Conservation International	Ecosystem service valuation and natural capital accounting
Simon Ferrier	CSIRO	Ecology
Patricia Balvanera Levy	Universidad Nacional Autónoma de México	Ecological economist
Christopher Golden	School of Public Health, Harvard	Ecologist and epidemiologist
Katherine Irvine	James Hutton Institute	Environmental psychology
Carl Obst	IDEA	Environmental accounting
Mark Gough	Natural Capital Coalition	Natural capital accounting
Neil Burgess	UNEP WCMC	Head of Science
Volker Mauerhofer	University of Vienna	
Garry Peterson	Stockholm Resilience Centre	Ecological modelling
Thomas Hertel	Purdue University	Applied economics
Arjan Ruijs	Netherlands Environmental Assessment Agency	Resource economist
Dominique Y van der Mensbrugghe	Purdue University	Economics

Name	Organisation	Expertise
Steven Stone	UNEP	Economics
Mark Horridge	Victoria University	Economics
Alessandra Alfieri	UN Statistics Division	Statistics
Angel Aguiar	Purdue University	Global economic database
Fred Boltz	Rockefeller Foundation	Natural resources economist
Mark Rounsevell	University of Edinburgh, UK & IMK-IFU, Karlsruhe Institute of Technology, Germany	Geography
Sander van der Leeuw	Future Earth	
Colin Butfield	WWF-UK	Executive Director of Our Planet, WWF-UK
Mike Barrett	WWF-UK	Director of Science & Policy, WWF-UK
Bernadette Fischler	WWF-UK	Head of Advocacy – Our Planet, WWF-UK
Mark Wright	WWF-UK	Our Planet Science and Policy Communications Manager

This short survey is part of a needs analysis for a new WWF project scoping options for modelling of the potential global socio-economic impacts of future changes in biodiversity and ecosystem services.

We want to identify the data/evidence/information on the socio-economic impacts of changes in biodiversity and ecosystem services needed to support the goals and objectives of IPBES, WWF and other global biodiversity-ecosystem-economy initiatives (e.g. CBD, UNFCCC, UNCCD, UN SDGs).

By socio-economic impacts, we mean consequences for economic metrics (e.g. GDP, economic productivity, employment, investment) and social impacts (e.g. physical health, sense of place, psychological well-being).

The work is a collaboration between WWF and a consortium of Dr Neville Crossman (University of Adelaide, Australia), Dr Luke Brander and Prof Dr Peter Verburg (VU University, The Netherlands), Dr Onil Banerjee (Inter-American Development Bank, USA) and Dr Jennifer Hauck (CoKnow Consulting, Germany).

For any questions or comments, please contact the project lead:
Dr Neville Crossman (neville.crossman@gmail.com)

1. Please provide:

Name ____________________

Organisation ____________________

Country ____________

2. Role (select all that apply):

- [ ] Government/Public administration & institutions
- [ ] Civil Society Organization/NGOs
- [ ] Business
- [ ] Research and academia

Other (please specify)

____

3. Are you familiar with the current IPBES work programme (2017-2019) or WWF's 2020 policy advocacy activities (select all that apply):

- ☐ Yes, familiar with the current IPBES work programme
- ☐ Yes, familiar with WWF's 2020 policy advocacy activities
- ☐ Familiar with other global frameworks and policies where biodiversity-economy relationships are important (e.g. CBD, UNFCCC, UN SDGs)
- ☐ Not familiar with any of the above

4. Given your response to Question 3, can you please briefly (< 100 words) explain in what way or capacity you are familiar with the IPBES work programme, WWF policy advocacy activities and/or other global biodiversity-economy frameworks and policies?

5. If you are familiar with the current IPBES work programme (2017-2019) or WWF's 2020 policy advocacy activities, please briefly suggest ways new information on socio-economic impacts of future change in biodiversity and ecosystem services could be introduced to these IPBES and WWF activities.

6. For what purpose, in your professional capacity, do you require information on socio-economic impacts of future change in biodiversity and ecosystem services? Select all that apply:

- ☐ Policy development
- ☐ Target setting
- ☐ Policy implementation
- ☐ Monitoring and evaluation of progress
- ☐ Communication with policy makers
- ☐ Public campaigns and awareness raising
- ☐ Conservation finance
- ☐ Fund raising
- ☐ Fund allocation
- ☐ National environment-ecosystem accounts (e.g. SEEA)

Other (please specify)

7. Given your selections in Question 6 above, can you please elaborate on why you need information on socio-economic impacts of future changes in biodiversity and ecosystem services?

8. What specific information on socio-economic impacts of future change in biodiversity and ecosystem services do you need and/or you think are very important? Select all that apply:

- [ ] GDP growth
- [ ] GDP of the poor
- [ ] Green National Income
- [ ] Employment
- [ ] Income distribution
- [ ] Productivity
- [ ] Physical units of ecosystem service supply
- [ ] Monetary value of ecosystem service use
- [ ] Monetary value of natural capital
- [ ] Costs and benefits of conservation
- [ ] Happiness index
- [ ] Genuine Progress Indicator
- [ ] Inclusive wealth index
- [ ] OECD good life indicator
- [ ] Vulnerability index
- [ ] UN Sustainable Development Goals
- [ ] Human health and well-being (e.g. child mortality, psychological stability)
- [ ] Human Development Index
- [ ] Human security and personal safety
- [ ] Energy security
- [ ] Good social relations
- [ ] Freedom of choice and action
- [ ] Education
- [ ] Leisure time
- [ ] Good governance

Other (please specify)

9. At what spatial resolution do you need information on socio-economic impacts of future change in biodiversity and ecosystem services? Select all that apply:

- [ ] Global
- [ ] World regions
- [ ] National
- [ ] Sub-national
- [ ] Local/municipal

Other (please specify)

____

10. Please rank the level of importance of resolution of socio-economic impact information for supporting global biodiversity policy and advocacy initiatives (1 = most important):

[ ]	Global
[ ]	World regions
[ ]	National
[ ]	Sub-national
[ ]	Local/municipal

11. For which biomes do you need information on socio-economic impacts of future change in biodiversity and ecosystem services? Select all that apply:

- [ ] All
- [ ] Tropical and subtropical dry and humid forests
- [ ] Temperate and boreal forests and woodlands
- [ ] Mediterranean forests, woodlands and scrub
- [ ] Tundra and High Mountain habitats
- [ ] Tropical and subtropical savannas and grasslands
- [ ] Temperate Grasslands
- [ ] Drylands and Deserts
- [ ] Wetlands – peatlands, mires, bogs
- [ ] Urban/Semi-urban
- [ ] Cultivated areas (incl. cropping, intensive livestock farming etc.)
- [ ] Cryosphere
- [ ] Aquaculture areas
- [ ] Inland surface waters and water bodies/freshwater
- [ ] Shelf ecosystems (neritic and intertidal/littoral zone)
- [ ] Open ocean pelagic systems
- [ ] Deep-Sea
- [ ] Coastal areas intensively and multiply used by humans

Other (please specify)

12. For what time horizon do you need information on socio-economic impacts of future change in biodiversity and ecosystem services (e.g. 2030, 2100, other)? Please state any key years or events for which this information should be modelled?

Time horizon

Key years or events

13. For what socio-economic scenarios do you need information on the socio-economic impacts of future change in biodiversity and ecosystem services? What variables of these scenarios are important for assessing socio-economic impacts?

Socio-economic scenarios

Variables

14. What global policy options or targets should be evaluated using information on socio-economic impacts of future change in biodiversity and ecosystem services?

15. How urgently do you need information on socio-economic impacts of future change in biodiversity and ecosystem services? Are there key dates by which this information should be available to support policy, investment or other significant decision-making?

Urgency (how soon?)

Key future dates

16. In what formats are information on socio-economic impacts of future change in biodiversity and ecosystem services most useful to you? Select all that apply:

- [ ] Maps
- [ ] Data in spreadsheet
- [ ] Supply and use tables for ecosystem services
- [ ] Graphs
- [ ] Compelling stories and narratives
- [ ] Peer reviewed papers
- [ ] Brochures
- [ ] Webpages
- [ ] TV-series
- [ ] Presentations
- [ ] Webinars
- [ ] Social media

Other (please specify)

17. Any additional comments you would like to make regarding the need for information on the impact of future change in biodiversity and ecosystem services on socio-economic wellbeing:

Appendix 2: Meta-analysis of ecosystem service values by ecosystem type

Reference	Year	Ecosystem(s)	Ecosystem service(s)	Dependent variable	Explanatory variables
Van Zanten et al.	2014	Agrarian landscapes	Aesthetic enjoyment	Preference direction	Land cover, population density, GDP per capita, historic buildings
Kukeilka et al.	2008	Agricultural land	Amenity	USD/acre/household/year	Area of study site, land use, access, household density, region, urban
Schmidt et al.	2016	All	22 ES with separate meta-analytic value functions	Int. dollar/ha/year	Various combinations of variables representing ecology, beneficiaries, scale and methods
Liu and Stern	2008	Coastal and near shore marine		USD/household/year	Ecosystem service, land cover, region, elicitation method
Ghermandi and Nunes	2013	Coastal ecosystems	Multiple	USD/ha/year	Ecosystem type, valuation method, GDP per capita, population, accessibility, marginal valuation
Brander et al.	2007	Coral reefs	Recreation	USD/visit	Dive site area, number of visitors, valuation methods
Brander et al.	2012	Coral reefs	Recreation, coastal protection, fisheries	USD/km²/year	GDP per capita, population density, visitors, location, reef quality, ES, valuation method
Brander et al.	2015	Coral reefs	Recreation	USD/visit	Visits per day, area of coral cover, location, method
Hussain et al.	2011	Coral reefs	Multiple	USD/ha/year	Area of study site, GDP per capita, coral abundance, human appropriation of net primary productivity (HANPP), net primary productivity (NPP)
Schild	2012	Drylands	Multiple	USD/ha/year	Ecosystem service, ecosystem type, valuation method, GDP per capita, population density
Barrio and Loureiro	2010	Forests	Multiple	USD (willingness to pay - WTP) for conservation scenario	Valued good, elicitation format, payment period, GDP per capita, area of forest in country
Chiabai et al.	2011	Forests	Recreation, non-use values	USD/ha/year	GDP per capita, population of country, size of study site, type of forest
Lindhjem	2007	Forests	Non-timber benefits	USD (WTP)	Forest area of proposed change, valuation method, survey method, users or non-users
Ojea et al.	2010	Forests	Provisioning, regulating, cultural	EUR/ha/year	Area of forest study site, type of forest, valuation method, biodiversity indicators, publication year
Zandersen and Tol	2009	Forests	Recreation	EUR/trip	Author, country, valuation method, area of study site, GDP per capita, population density, sample size
Eppink et al.	2014	Grassland	Multiple	USD/ha/year	Area of study site, GDP per capita, population density, valuation method, grassland abundance, human appropriation of NPP
Hussain et al.	2011	Grassland	Multiple	USD/ha/year	GDP per capita of the country, grassland abundance, roads, accessibility

Reference	Year	Ecosystem(s)	Ecosystem service(s)	Dependent variable	Explanatory variables
Randall et al	2008	Habitat and open space	Aesthetic enjoyment	USD/acre/year	Habitat type, methodological variables
Brander et al.	2011	Inland water	Change in water quality for recreation, drinking water, irrigation, non-use values	USD/household/year	Elicitation format, payment period, type of water body, ecosystem service
Hussain et al.	2011	Inland water	Change in water quality for recreation, drinking water, irrigation, non-use values	USD/ha/year	GDP per capita, baseline water quality, change in water quality, type of water body, urban, lake abundance
Johnston and Thomassin	2010	Inland water	Change in water quality affecting recreational fishing	USD (WTP)	Valuation method, survey method, income, non-users, type of water body, baseline water quality
Johnston et al.	2005	Inland water	Aquatic resources	USD (WTP)	Valuation method, survey method, income, non-users, type of water body, baseline water quality
Johnston et al.	2006	Inland water	Recreational fishing	USD/fish	Income, valuation method, estimation model, elicitation format, type of fish, age, trips
Moeltner et al.	2007	Inland water	Recreational fishing	USD/day	
Randall et al.	2008	Inland water	Water quality	USD/household/year	Water body size, change in water quality, methodological variables
Tomassin and Johnston	2010	Inland water	Change in water quality affecting recreational fishing	USD (WTP)	Valuation method, survey method, income, non-users, type of water body, baseline water quality
Van Houtven et al.	2007	Inland water	Water quality	USD/household or individual/year	Baseline water quality, change in water quality, type of water body, income
Vista and Rosenberger	2013	Inland water	Recreational fishing	USD/person/day	Fishing environment, valuation method, population characteristics, study attributes
Raynaud and Lanzanova	2017	Lakes	Mainly recreation and amenity	USD/user/year	ES, method, valuation scenario, lake abundance, GDP per capita, region
Brander et al.	2012	Mangroves	Coastal protection, fisheries, fuelwood, water quality	USD/ha/year	Area of mangrove study site, mangrove abundance, roads, GDP per capita, population density, ecosystem service
Hussain et al.	2011	Mangroves	Multiple	USD/ha/year	Area of study site, GDP per capita, wetland abundance, lake abundance, HANPP
Salem and Mercer	2012	Mangroves	Fisheries, forestry, recreation	USD/ha/year	Area of study site, GDP per capita, valuation method, ecosystem service
Jacobsen and Hanley	2009	Multiple	Biodiversity	USD (WTP)	GDP per capita, income, species, habitat, elicitation format, continent, payment vehicle
Martin-Lopez et al.	2004	Multiple	Biodiversity (WTP for preservation of single species)	USD (WTP)	Payment vehicle, elicitation format, payment timing, ecosystem type, anthropocentric usefulness, IUCN status
Nijkamp et al.	2008	Multiple	Biodiversity	EUR/person/day	Biodiversity related good, valuation method
Richardson and Loomis	2008	Multiple	Endangered species	USD/household	Payment frequency, type of animal, response rate, valuation method
Smith and Osbourne	1996	National parks	Visibility	USD (WTP)	Proportionate change in visibility, elicitation format, survey method

Reference	Year	Ecosystem(s)	Ecosystem service(s)	Dependent variable	Explanatory variables
Sen et al.	2013	Natural area	Recreation	GBP/person/visit	Habitat type, unit, survey year, sample size, valuation method
Shrestha and Loomis	2001	Natural area	Recreation	USD/person/day	Recreational activity, type of water body, valuation method, elicitation format
Smith and Kaoru	1990	Natural areas	Recreation		Type of travel cost model, type of natural area
Hussain et al.	2011	Temperate forest	Multiple	USD/ha/year	Area of study site, GCP, urban area, HANPP
Hussain et al.	2011	Tropical forest	Multiple	USD/ha/year	Area of study site, GDP, urban area, HANPP, forest abundance, roads
Brander and Koetse	2011	Urban green space	Recreation, aesthetic enjoyment	USD/ha/year	Land use, area of study site, payment vehicle, elicitation format, GDP per capita, population density
Johnston et al.	2016	Water quality	Recreation, non-use values	USD (WTP)	ES, water quality change, type of water body, publication type
Brander et al.	2006	Wetlands	Multiple	USD/ha/year	Area of wetland study site, GDP per capita, population density, continent, valuation method, wetland type, marginal value
Brander et al.	2012	Wetlands	Multiple	USD/ha/year	Area of wetland study site, GDP per capita, population density, valuation method, wetland type, wetland abundance, marginal value
Brander et al.	2013	Wetlands	Regulating services	USD/ha/year	Area of wetland study site, GDP, population density, wetland abundance, constructed wetland
Brouwer et al.	1999	Wetlands	Multiple	USD/household/year	Ecosystem service, North America, elicitation format, response rate
de Groot et al.	2012	Wetlands	Multiple	USD/ha/year	Area of study site, GDP per capita, population density, valuation method, wetland type
Ghermandi et al.	2010	Wetlands	Multiple	USD/ha/year	Area of wetland study site, GDP per capita, population density, valuation method, wetland type, wetland abundance, marginal value
Hussain et al.	2011	Wetlands	Multiple	USD/ha/year	Area of study site, GDP per capita, wetland abundance, lake abundance, HANPP
Moeltner and Woodward	2007	Wetlands	Multiple	USD/household/year	
Randall et al.	2008	Wetlands	Recreational fishing	USD/acre/year	Income, habitat type, methodological variables
Woodward and Wui	2001	Wetlands	Multiple	USD/acre/year	Area of wetland study site, wetland type, ecosystem service, valuation method, study quality
Bateman and Jones	2003	Woodland	Recreation	GBP/person/visit	Valuation method, elicitation method, forest indicator, author

Appendix 3: Expert workshop participants, 6-7 June, Amsterdam

Name	Institution
Rob Alkemade	PBL Netherlands Environmental Assessment Agency
Annela Anger-Kraavi	Downing College, Cambridge
Luke Brandner	Consultant
Raffaello Cervigni	World Bank
Rinku Roy Chowdhury	Clark University
Neville Crossman	University of Adelaide
Karen Ellis	WWF-UK
Jennifer Hauck	CoKnow Consulting
Hugo Herrera	Bergen University
Katherine Irvine	James Hutton Institute
HyeJin Kim	German Centre for Integrative Biodiversity Research (iDiv)
Thomas Koellner	University of Bayreuth, Germany
David Leclere	IIASA
Carlos Ludena	Inter-American Development Bank
Carolyn Lundquist	National Institute of Water and Atmospheric Research (NIWA)
Carl Obst	Institute for the Development of Environmental-Economic Accounting
Toby Roxburgh	WWF-UK
Peter Verburg	IVM VU - Vrije Universiteit Amsterdam
Mark Wright	WWF-UK
Jasper van Vliet	IVM VU - Vrije Universiteit Amsterdam

Appendix 4: Preliminary options developed on path to proposal for Phase 2

Option 1: Visioning and trade-offs, societal consultation and accounting for components of welfare

Rationale: as land is a scarce resource any option to conserve biodiversity will come with trade-offs. These concern trade-offs not only between individual SDGs but also between socio-economic benefits, such as fast growth of GDP vs. sustained livelihood options in less developed countries, health benefits of green space and access to natural resources. While an assessment of all these trade-offs on a global scale is difficult, there is evidence across the literature on potential benefits of different development options. Global land change models and scenarios show how different developments lead to different outcomes, often resulting in differential impacts around the world. However, the current scenario approaches take socio-economic conditions as an input, rather than treating them as an outcome (Figure 16)

Rather than exploring how different climate scenarios or large socio-economic development trends impact on biodiversity, an alternative approach starts with possible visions of the world we would like to live in, and looks at how these can be achieved and the trade-offs we are willing to accept. This provides a learning process in which important trade-offs are negotiated amongst societal sectors, cultures and stakeholders.

Method: The IPCC/IPBES philosophy used in the climate scenarios where potential endpoints (the RCP scenarios) and pathways to reach these endpoints are distinguished. However, rather than a sectoral focus on climate outcomes, the full range of conditions is included.

In a first step visions are elaborated through workshops or public consultation. Such visions should include both biodiversity conditions ('nature futures') as well as what we would like to achieve on other SDGs and socio-economic indicators. Both mid- and long-term visions should be considered given the different timescales at which the processes operate. Within the visioning process the topic of trade-offs should be comprehensively addressed: how much nature are people willing to jeopardise to retain the same level of mobility, diets and economic welfare? How important is reaching food security as opposed to climate and biodiversity objectives? Such visions can be elaborated during stakeholder workshops or through specially designed web consultation using techniques derived from choice experiments.

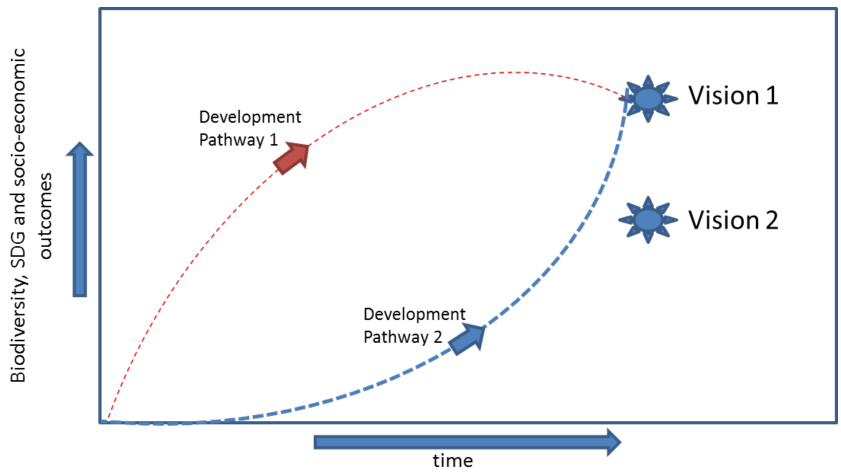

Figure 16. Conceptualisation of the approach: Visions are normative, stakeholder-derived visions about how the future should look and what trade-offs between societal objectives are acceptable. Development pathways include those measures and changes required to achieve these visions.

In a second step the derived visions are checked for feasibility using a range of methods including target-oriented modelling looking for those land-use configurations (under feasibility constraints) that would allow such visions. While the consultation process should already include feasibility aspects, here there could be a first learning on the actual feasibility of achieving the visions.

In a third step, exploratory scenario modelling is used to identify possible pathways to reach the visions. In this step, alternative policy and management options, including behavioural change, are evaluated in prospective modelling to see how to reach the established visions. This is an iterative process, shown in Figure 17. A summary of Option 1 is provided in Table 10

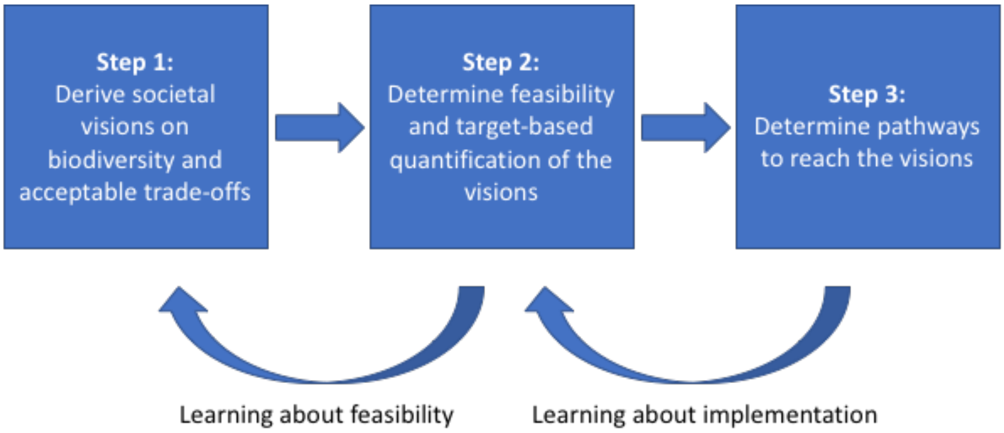

Figure 17. Proposed procedure for Option 1: Visioning and trade-offs, societal consultation and accounting for components of welfare.

Table 10. Summary of Option 1

Need/gap addressed:	Biodiversity conservation not an impact of socio-economic change but rather seen as a societal target where trade-offs and benefits on socio-economic conditions are explicitly addressed
Metric/indicator of socio-economic impact:	A wide range of societal indicators can be used, some explicit, others implicit through the expressed visions for biodiversity conservation reflecting the societal values attached to these Public engagement in visioning process
Information format:	Maps, graphs, tabulated data
Resolution of analysis:	Public consultation of visions global and local, resolution thematic rather than fine spatial. Pathway analysis resolution primarily determined by resolution of land-use and BES models
Resolution of reporting:	Descriptive with indicators Maps could show fine resolution images of how the visions would look
Time horizon and time steps in analysis	The time horizon is determined by the visioning process. As both short/mid-term land-use change and socio-economic development as well as long-term climate change are considered both mid-term (2040) and long-term (2100) visions should be included
Timing:	Short term (mid-2018): Within this timeframe it would be possible to create a web-based tool or conduct several regional workshops to consult on public opinions on visions for biodiversity, development towards the SDGs and socio-economic conditions and acceptable trade-offs between them Long term (2020+): Conduct the full proposed procedure including simulations and development of pathways towards reaching the societal visions
Partnerships:	Requires a team to work on developing the public consultation tools including some web-development skills or local experts in stakeholder consultation. In addition, a literature study on existing scenarios and literature would be needed to identify trade-offs and feasibility of vision options. The long-term work would require involvement of those working on land use and ecosystem models.
Challenges, limitations and risks	Insufficient interest of the public towards a visioning exercise. Underdevelopment of modelling tools to address the wide range of measures required (lock-in into the climate focus of the models)
Indicative budget:	Short term option: GBP 90k

Option 2: Linked land-use, ecosystem service and economic value models

This option aims to deliver information on the economic value of changes in ecosystem services use under alternative future scenarios at a global scale.

The general approach is represented in Figure 18. This option uses existing work on scenario development for alternative futures (e.g. IPCC, IPBES); existing modelling efforts that apply integrated assessment models (e.g. IMAGE, GLOBIOM, and others) to map changes in future land use under alternative future scenarios; and existing efforts to model subsequent changes in biodiversity (e.g. GLOBIO, PREDICTS, GDM, Madingley, UBC Oceans model, countryside SAR (cSAR)) and ecosystem services (e.g. GLOBIO, InVEST).

The proposed approach then estimates the economic value of modelled changes in ecosystem services using existing primary valuation study results (e.g. summarised in the Ecosystem Services Valuation Database – ESVD) and meta-analytic value transfer methods. The use of meta-analytic value functions enables the estimation of values that reflect (spatially) variable determinants of supply and demand for ecosystem services.[6]

The information produced by this option would be in the form of monetary estimates of changes in economic welfare. This information could be mapped at fine resolution (approximately 25km grid cells, or finer) and reported at the level of world regions. Note that the use of available IAMs does not allow results to be reported at national scale or lower. Note also that other metrics of potential interest (e.g. change in GDP per capita, poverty head count, income distribution, productivity, employment, migration, health) cannot be generated by this approach.

The level of detail at which this option could be operationalised is dependent on the time and resources available. As such, the option is elaborated on in three variants: short term, medium term and long term.

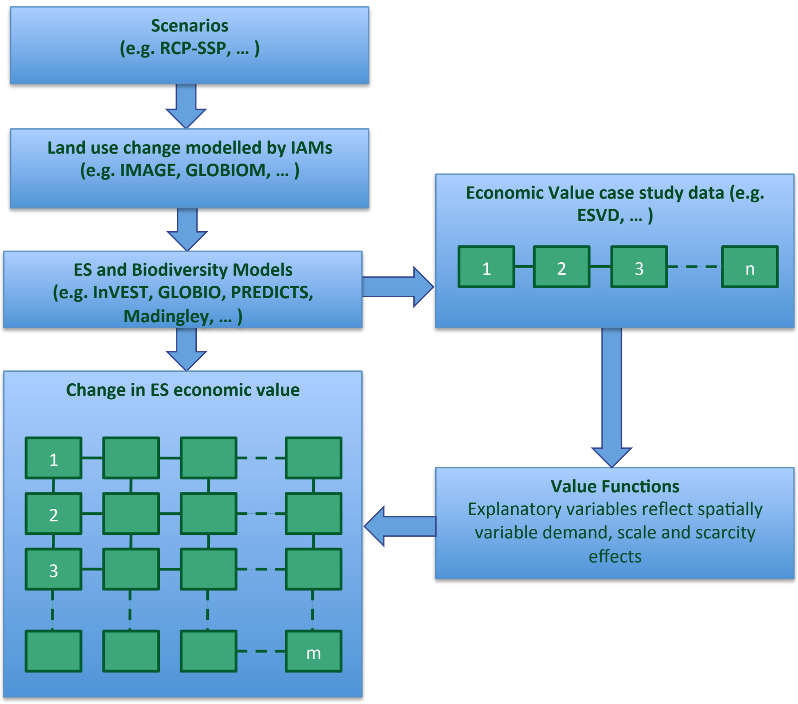

Figure 18. General methodological framework for Option 2 to link scenarios, IAMs, biodiversity models, BES models, and economic value functions.

[6] The use of meta-analytic function transfer also provides a means to account for simultaneous changes in the stock of ecosystems when estimating economic values for ecosystem services (the 'scaling-up problem'). By including an explanatory variable in the data describing each primary valuation study site that measures the scarcity of other ecosystems nearby, it is possible to estimate a quantified relationship between scarcity and ecosystem service value. This parameter can then be used to account for changes in ecosystem scarcity when conducting value transfers at large geographic scales.

Short term

In the short term, it would be feasible to combine the results of existing or ongoing IAM land-use modelling and BES modelling with existing (or slightly modified) meta-analytic value functions to produce a preliminary assessment of the expected changes in economic welfare resulting from changes in BES availability.

This short-term option could build directly on current work coordinated by Rob Alkemade at PBL for the IPBES Global Assessment. The PBL-coordinated effort is modelling changes in land use under IPCC RCP/SSP scenarios using five separate IAMs (IMAGE, GLOBIOM, Japanese group, Denver group, Potsdam group). The consequences of changes in land use for biodiversity are subsequently modelled using seven biodiversity models (GLOBIO, PREDICTS, GDM, Rome+Imperial+WCMC, Madingley, cSAR and UBC Oceans). Ecosystem service models (GLOBIO, InVEST) are then applied to estimate changes in the availability of a limited number of ecosystem services: crop production, livestock, wild food, carbon sequestration, soil erosion control, pest control, water quality, flood protection and recreation.

The time horizon of the PBL-coordinated analysis is to 2050; the spatial resolution of the land use and biodiversity models is 0.25 degrees (approximately 25km grid cells); and the spatial resolution of reporting is world regions.[7] The intention is to report the results for three selected RCP/SSP scenarios to reflect contrasting (extreme) outcomes.

The steps in implementing this short-term option are:

- Coordination with the above described modelling teams to obtain details on the outputs produced (land-use classification, ecosystem service definitions, physical units, qualitative scales, spatial resolution, time steps).
- Assessment of the availability and compatibility of meta-analytic value functions for each modelled land use and/or ecosystem service. Note that these first two steps can start before the land use and ES modelling results become available.
- GIS processing of mapped land use and ES output for each scenario into necessary formats for application of value functions (e.g. databases of ES producing units).
- GIS processing to add spatial variables included in the value functions.
- Application of value functions to estimate values of changes in land use and ES availability. Sensitivity analysis and computation of confidence intervals.
- Mapping and reporting of results.

Medium term

In the medium term, it would be possible to improve the approach in several key directions:

- Update ES valuation databases with recent primary research results (i.e. studies published in the period 2010-2017).
- Estimate value functions for specific ecosystem services, as opposed to value functions for bundles of services from specific biomes. This would allow results to be reported for specific ES and enable the analysis of trade-offs between different ES under alternative scenarios.
- Redefine the physical units in which economic values are standardised to match the physical units in which ES are modelled. This would enable a more coherent link between modelled changes in ES and estimation of economic value.
- Include biophysical data from IAMs and biodiversity/ES models on ecosystem condition in the value functions to better reflect variation in these determinants of ES values.
- Expand the range of ecosystem services that are modelled and valued.
- Expand the range of scenarios that are modelled and valued.

[7] It is not possible to report results at the national level due to the resolution at which land allocation is modelled. Reporting at a resolution below world regions could produce anomalous results.

Long term

In the long term, it could be possible to extend the methodological framework to include feedback effects from changes in the availability of ecosystem services to macroeconomic performance. This might allow additional economic indicators to be estimated, such as changes in GDP, employment and productivity. This extension involves linking the output of ES models and valuation results to the CGE models underlying the IAMs (e.g. IMAGE uses the GTAP CGE model). Such an extension to the methodological framework is represented in Figure 19.

The feasibility of this extension is unknown and would require careful consideration. The process of including feedbacks from changes in ES availability to CGE models could be informed by ongoing national-level case studies and by the development of a global modelling approach (see Option 3). The possibility of credibly linking changes in ES availability and values to CGE models, however, is highly uncertain due to incompatibility of ES welfare values with the underlying national accounting data and sector definitions used in CGEs. Simple or incomplete feedbacks may not be supportable or lead to invalid results. Moreover, the mechanisms or transmission channels through which changes in ES impact other economic sectors are largely unquantified. Current knowledge of how changes in biodiversity and ES affect GDP, poverty etc. is limited. This option would aim to deliver a major service to the global scientific and policy community by adding the missing feedback of changes in BES (through economic valuation) back to human wellbeing/drivers. This would be, however, a massive and long-term effort.

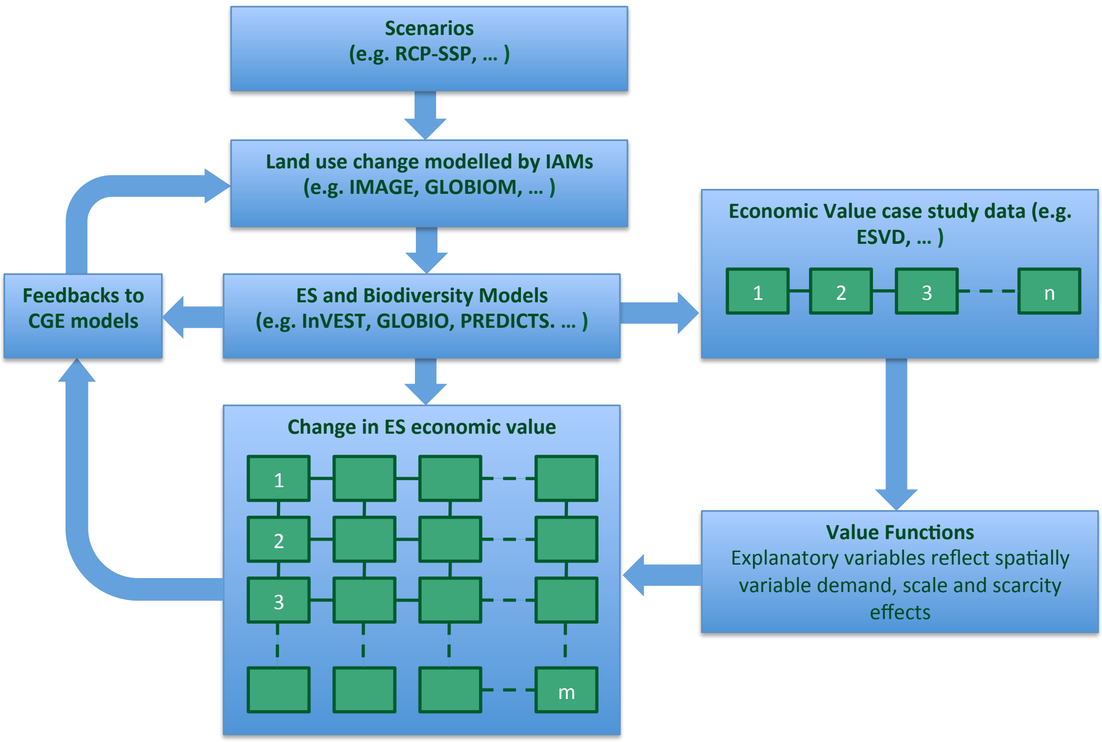

Figure 19. General methodological framework extended to include feedback effects from changes in ES to the CGE models underlying the IAMs.

Option 3: Modelling global environment-economy-wellbeing futures

This note sets out the concept for an innovative new global environment-economy modelling initiative, in order to help facilitate discussions with the World Bank on potential partnership options.

Overview

The overall aim is to estimate the potential impact on global and national social and economic indicators (e.g. GDP, sector output, consumption, employment, government revenue, poverty, income inequality, genuine savings, inclusive wealth index, among others depending on the accounts used to calibrate the model) of future environmental change under a range of plausible scenarios.

The proposed approach will develop an innovative multilevel modelling approach, integrating an environmentally extended global macroeconomy model (Input-Output or CGE) with environmental change data at relevant spatial scales, based on realistic assumptions about future trends in biodiversity, natural capital and the provision of ecosystem services.

Considerable innovation is required, particularly the integration of high spatial and temporal resolution environmental change datasets to models of the global economy (e.g. GTAP) to generate robust, timely, credible and policy-useful results. The major area of novelty is the interpretation and extension of environmental change datasets into measures that can be input into global economy models. National accounting frameworks such as the SEEA provide the direct link between environmental change and economic sector national accounts; the latter are key inputs into global economy models.

A key challenge is that only 8-10 countries so far have made significant progress in developing SEEA, and global coverage of SEEA data is likely to only be available within 5-10 years. To overcome this, a multiscale approach is proposed for delivering outputs in time to support global decisions and initiatives by 2020. Existing country-level data (e.g. from World Bank WAVES pilot countries) and new strategically selected national case studies will be extrapolated to global scale by selecting countries that represent a diverse typology of both environmental conditions and trajectories, and developed and less-developed economies. This 'federated' approach will aim to ensure key biodiversity and ecosystem service metrics are collected in common, which can then be aggregated and incorporated into the global macroeconomic model.

Given the need to generate outputs in time to feed into the 2020 discussions, a phased approach is likely to be useful, in which we'd first develop, pilot and apply this new modelling approach that could be launched in 2019 (and support broader 2020 discussions). The modelling framework and analysis would then be updated and refined as new SEEA data comes online, over the coming years.

Potential timeline and key milestones

- Develop/refine ToRs, and commission consultants (economic modellers, integration experts) to develop and pilot a framework and undertake initial analysis (by Jan 2019)
- Launch report based on preliminary outputs (late 2019 - e.g. potentially to coincide with the Sept 2019 annual High-Level Political Forum on Sustainable Development in New York).
- Further develop the model and incorporate new national data as it becomes available (ongoing).

Project outputs

Evidence from the project would strengthen the case for ongoing and increased investment in landscape-scale restoration and conservation for achieving multiple benefits (e.g. SDGs), and be geared towards government and business decision-makers using metrics/language that they find most compelling and valuable (e.g. how environmental change could affect economic outcomes such as GDP, productivity, growth, jobs etc.). The project would also aim to collaborate with and support IPBES, which could also help achieve the overall goal for 2020 (as IPBES' evidence/reports will be widely used for informing 2020 policy discussions).

For the World Bank, project outputs could support investment and loan planning by identifying spatially explicit links between environmental degradation and threats to human wellbeing. This link then provides important decision support for where to target World Bank investments that provide both positive environmental and wellbeing outcomes, and the quantification of those outcomes.

The long-term goal is that this work would help to secure stronger commitment towards protection of the world's natural environment in 2020, generate the inflexion point needed to reverse negative global environmental trends (by 2030) and help to secure economic and social prosperity.

Partnering options

A collaborative multi-partner effort appears to be the most sensible option, given the multidisciplinary expertise required and potential broad spectrum of beneficiaries. There is considerable interest from other relevant groups to collaborate on this. Notably, UNEP-WCMC has already confirmed interest in principle in technical collaboration and joint fundraising. Other interested organisations include those represented in the project team, and at the Amsterdam workshop, such as PBL (Netherlands Environmental Assessment Agency, which hosts the secretariat for the IPBES scenarios and modelling group), German Centre for Integrative Biodiversity Research (iDiv), IIASA, University of Bayreuth, University of Cambridge, NIWA, and the IDEEA Group.

Other relevant organisations which could be engaged include: academic/research organisations; national governments (planning ministries, ministries of finance, central banks, statistical agencies), UN Statistical Division; multilateral development banks (e.g. IDB, ADB, AfDB); modelling organisations (economy-wide, land use, ecosystem service); and the finance and business community (e.g. via WBCSD, Natural Capital Coalition, and Natural Capital Declaration, and/or GGGI).