SAT-BBE

# Design of a systems analysis tools framework for a EU bioeconomy strategy

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REPORT D 3.3

# Design of a systems analysis tools framework for a EU bioeconomy strategy

Overview of WP3 of the EU FP 7 SAT-BBE project:
Systems Analysis Tools Framework for the EU Bio-Based Economy Strategy

Report for public dissemination

31 May 2015

SAT-BBE Consortium

**Preface**

This document is based on the contribution of all project partners (see box below). This deliverable builds on the two interim project deliverables in Work Package 3 'Systems analysis protocols' and on the results of Work Package 1 'Scoping and definition of the systems analysis framework' and Work Package 2 'Tools for evaluating and monitoring'. All SAT-BBE partners have contributed to this report.

All information is available on the SAT-BBE website.

| | Short name | Full Name | Member State | Contributed to WP 3 |
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| **1** | LEI-WUR | Agricultural Economics Research Institute | Netherlands | X |
| **2** | UU | Utrecht University | Netherlands | X |
| **3** | EFI | European Forest Institute | Finland | X |
| **4** | WI | Wuppertal Institute | Germany | X |
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| **6** | VUA | Vrije Universiteit Amsterdam | Netherlands | X |
| **7** | TI | Thünen-Institut | Germany | X |
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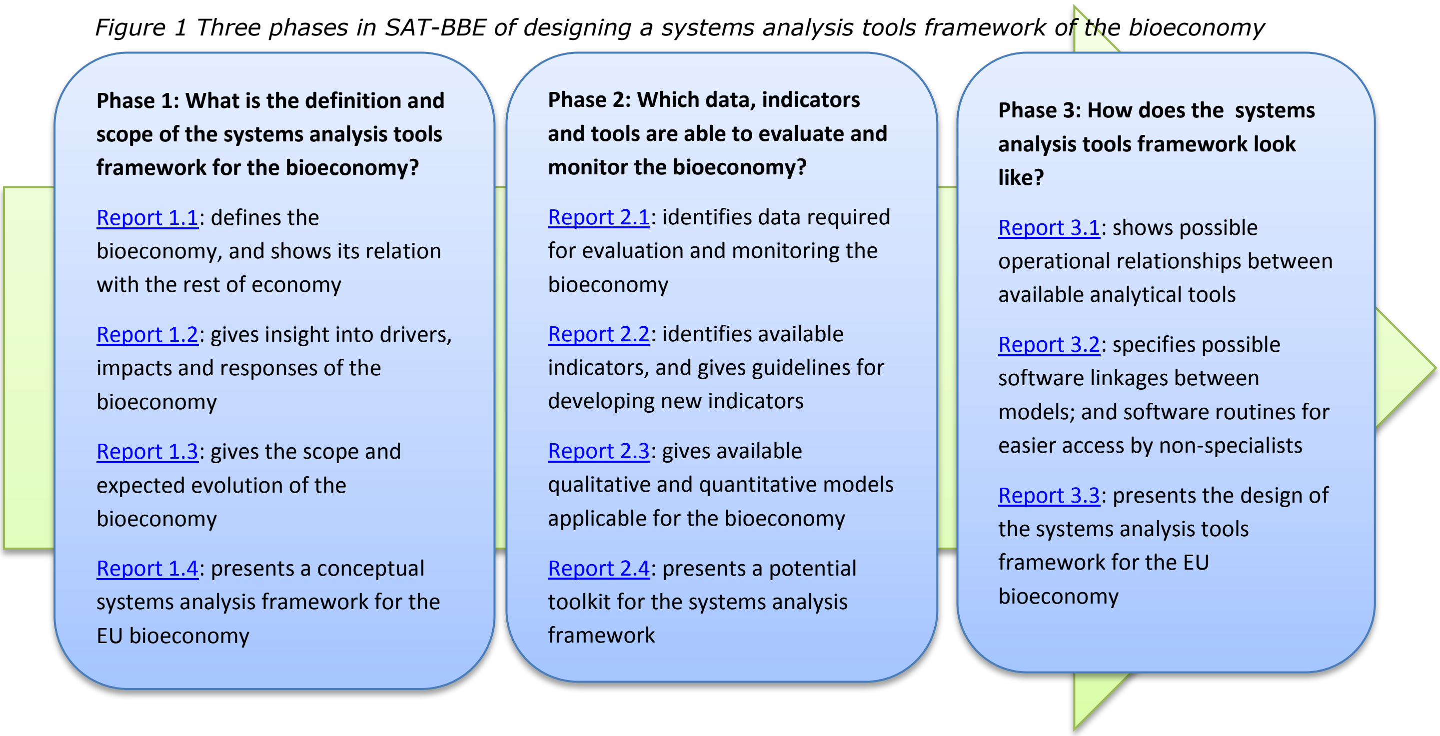
# Executive summary

*Background and objectives*

One of the biggest challenges facing global society today is the provision of food, water, energy, healthcare and other resources and services to a world that will see its population increase by a third in the face of mounting environmental stresses over the next 20 years. SAT-BBE explored the data, indicators and models that help to assess the contribution of a bioeconomy in many of these areas to ensure long term economic and environmental sustainability. Given that the lead time for arriving at the solution to some key social and technological challenges is long, there is a need for a framework to structure long-term analytical capacity. This framework should provide guidance to the analysts and researchers studying the issues and problems. Such an analytical framework can also help in providing guidance and decision-support to the policy-makers responsible for the execution of consistent, coherent, and long-term strategies with desirable consequences, and on the bioeconomy as an increasingly leading part of the economic system. SAT-BBE brought together a consortium of internationally recognised and respected researchers who work on the bioeconomy and the topic of sustainability at both European and international levels.

The objective of SAT-BBE was to design a systems analysis tools framework, which must be useful to a) monitor the evolution of the bioeconomy in the EU, and b) to analyse the socio-economic and environmental impacts of the bioeconomy and its relevant policies. Figure 1 shows the three phases of SAT-BBE and includes links to the project reports.

*Figure 1 Three phases in SAT-BBE of designing a systems analysis tools framework of the bioeconomy*

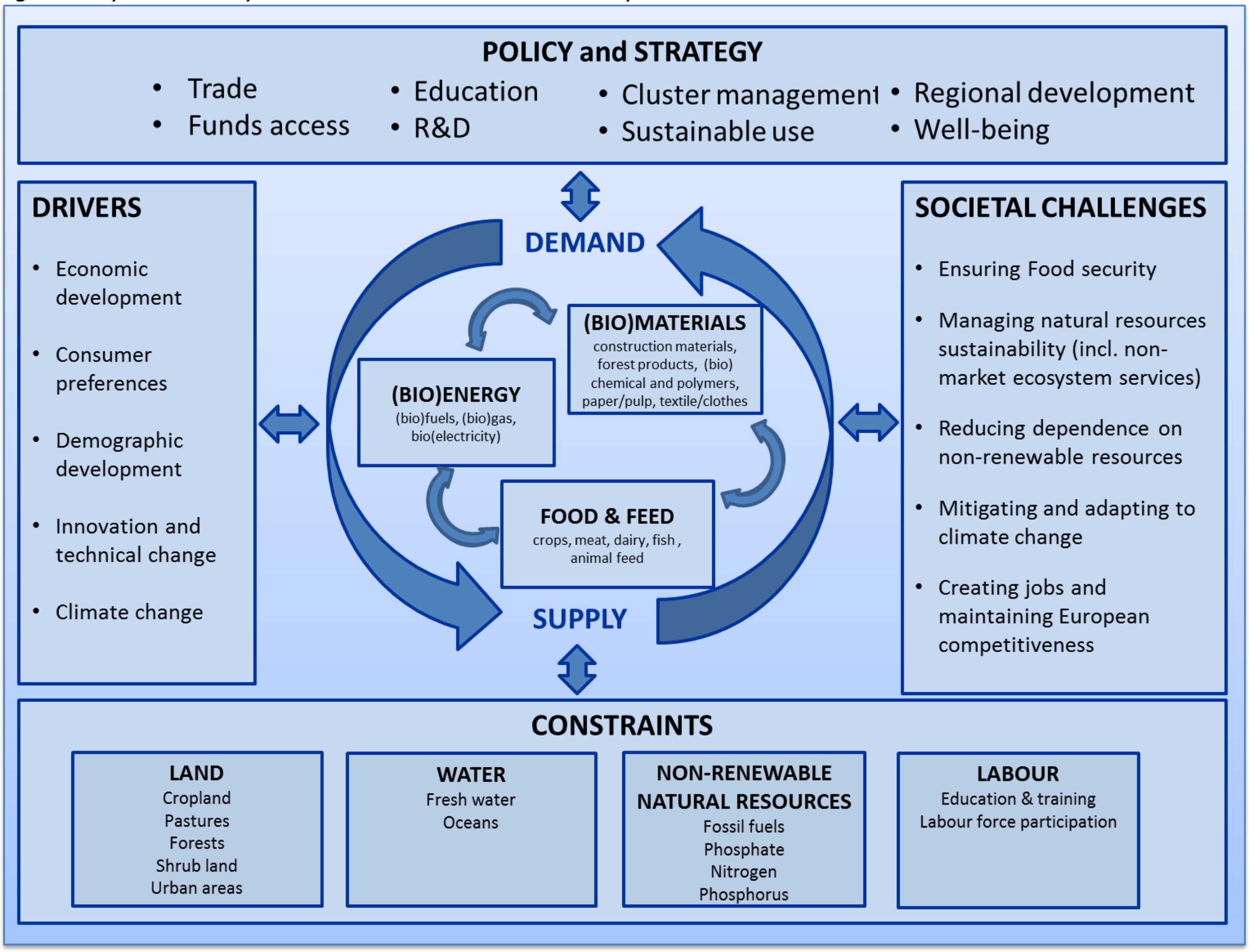



*Key findings*

**First**, the scope of the bioeconomy systems analysis tools framework has been defined using the relatively broad and generic definition of the EC (2012). '*The bioeconomy encompasses the production of renewable biological resources and their conversion into food, feed, bio-based products and bioenergy. It includes agriculture, forestry, fisheries, food and pulp and paper production, as well as parts of chemical, biotechnological and energy industries.....'* Though not explicitly mentioned it is essential that the bioeconomy moves from a linear to a (more) circular economy and values non-market ecosystem services, and at the same time contributes to competitive opportunities of the concerned biobased sectors through innovation and technical change.

**Second**, a conceptual system analyses framework for the bioeconomy has been developed based on a supply-demand framework that connects the building blocks (drivers, impacts, responses) for analysing impacts, trade-off and synergy effects that go along with a transition to a biobased economy (see, Figure 2). The SAT-BBE consortium identified and analysed the most important interactions and feedback effects between the bioeconomy and other parts of the economy (e.g. fossil and energy based industries), taking into account developments in system drivers (e.g. economic development, innovation and technical change) and constraints (e.g. land, water, non-renewable natural resources, labour). Impacts are measured in relation to the five societal challenges of the EC Bioeconomy Strategy: *ensuring food security*, *managing natural resources sustainability (incl. non-market ecosystem services), reducing dependence on non-renewable resources, mitigating and adapting to climate change,* and *creating jobs and maintaining European competitiveness*. Based on the impact of the bioeconomy on socio-economic and environmental indicators, policy and strategic management responses can be implemented in order to influence the demand and supply system drivers for meeting the targets of the Bioeconomy Strategy and other policies.

*Figure 2 Systems analysis framework for the bioeconomy*




*Source: SAT-BBE consortium*

**Third,** a systems analysis toolkit has been designed using existing data and model approaches (Figure 3). This figure shows the need to consider multiple scales and dimensions when monitoring the evolution and impacts of the bioeconomy. Tools are classified in General and Partial Equilibrium models (GE and PE), bottom up approaches and Integrated Assessment Models (IAM). Table 1 provides a more detailed description of these tools, in terms of their main applications, insights, and their strengths and limitations with respect to the assessment of biomass supply and its societal impacts. Table 2 indicates a number of operational models that are potentially suitable to monitor and evaluate the bioeconomy and its trade-offs. Existing models are currently extended to include more bioeconomy sectors (see, e.g. MAGNET and Globiom).

*Table 1. Overview of four key mode types in SAT-BBE toolkit, for assessing biomass supply, demand and impacts: their applications, typical timeframes, key strengths, and limitations*

| | GE models | PE models | Bottom-up analysis | IAMs (models combination) |
|---|---|---|---|---|
| **Application** | Economy-wide impacts of overall bioeconomy and related policies, including (in)direct effects on value added, employment, land-use change and GHG emissions<br>Competition with fossil based sectors and on factor markets induced by these policies. | Sectoral impacts of a bioeconomy sector (agriculture, forestry, energy system) and related policies. Focus on production, prices, land use and GHG emissions. | Wide variety of specific (technical) aspects of biomass production, conversion and use.<br>Validation of other studies with a broader scope, such as PE and GE models, and IAMs | Bioeconomy resource potentials under different assumptions (incl. sustainability criteria).<br>Contribution of bioeconomy to long-term climate policy.<br>Impacts of bioeconomy policies on global land use, water and biodiversity |
| **Strengths** | Comprehensive coverage of economic sectors and regions to account for interlinkages.<br>Explicit modelling of limited economic resources.<br>Measuring the total economy wide and global effects of bioeconomy policies (including indirect and rebound effects) | Detailed coverage of sectors of interest with full market representation.<br>Explicit representation of biophysical flows and absolute prices.<br>Usually more details on regional aspects, policy measures and environmental indicators | Detailed insights into techno-economic, environmental and social characteristics and impacts of biobased systems | Integrating different relevant systems in one modelling framework.<br>Possibility to analyse feedbacks between human and nature systems, and trade-offs and synergies of policy strategies.<br>Built around long-term dynamics |
| **Limitations** | Level of aggregation that may mask the variation in the underlying constituent elements.<br>Scope of GE models necessitates simplified, representation of agent choices, in particular favoring smooth mathematical forms and reduced number of parameters required to calibrate the models.<br>Often no or little explicit representation of quantities for biophysical flows<br>Do not deal with short run issues such as price volatility. | Optimization of agent welfare, but only the sectors in the model.<br>No consideration of macroeconomic balances and impacts on not-represented sectors.<br>Need large number of assumptions for long-term projections<br>Do not deal with market failures wrt unemployment, price volatility, land management | No inclusion of indirect and induced effects outside the boundaries of the study, i.e. often deliberately ignore interactions with other sectors | High level of aggregation or too complex systems.<br>Unsuitable for short-term assessments.<br>Large number of assumptions (and the corresponding challenge in the clear)<br>communication of these to the public) |

*Source: SAT-BBE consortium, adapted from Wicke et al. (2014)*

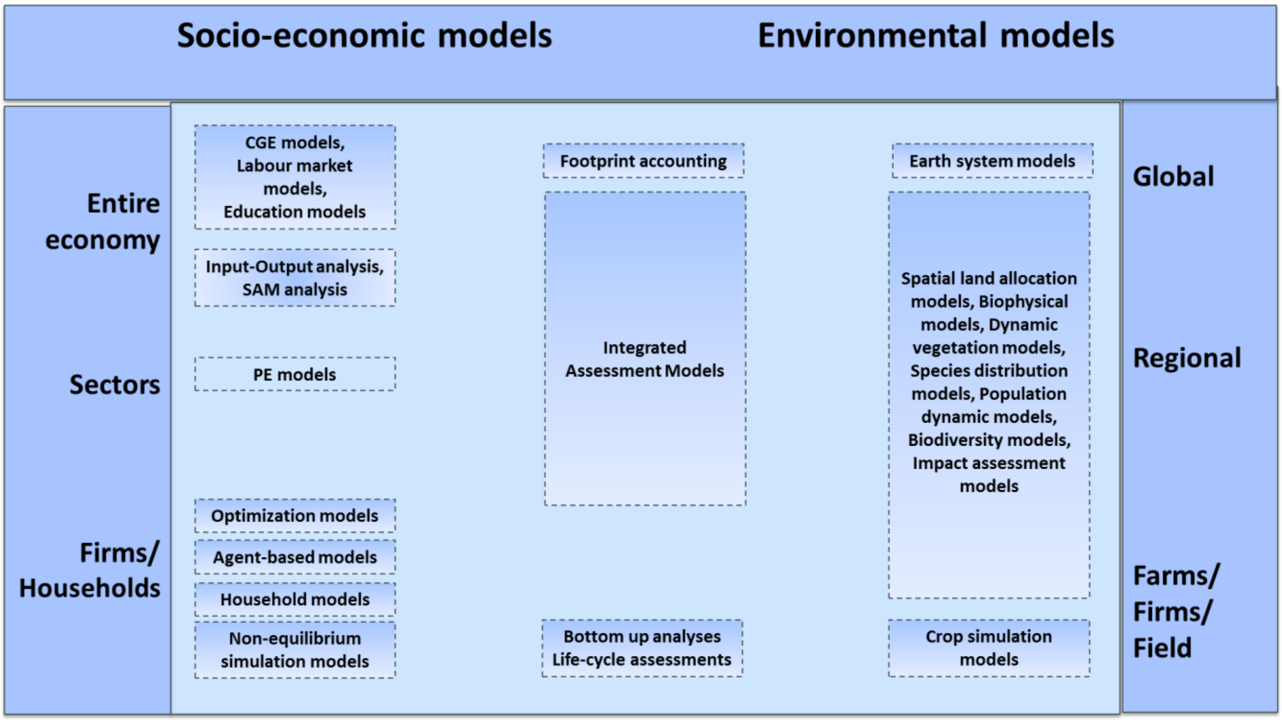
*Table 2. Overview of key current models potentially suitable in SAT-BBE toolkit, for assessing biomass supply, demand and impacts: their regional and sectoral aggregation and main applications.*

| GE models & IAMs | PE models | Bottom-up analysis |
|---|---|---|
| **<u>GE models</u>**<br><br>**MAGNET**<br>*Regions:* 124 regions (incl. 28 EU MS)<br>*Sectors*: 70 sectors, 12 primary agricultures, 8 food processing, forestry, fishery, various residues, plantations, wood pellets, wood products, paper industry, biodiesel & ethanol from various feedstock (1st and 2nd G), bioelectricity, bioplastics (PLA), bio-polyethylene<br>*Focus*: CAP, biofuel policies, bioeconomy, trade policies, food security, food nexus, climate change<br><br>**MIRAGE**<br>*Regions*, 124 regions (incl. 28 EU MS)<br>*Sectors*: 58 sectors, 12 primary agricultures, 8 food processing, forestry, fishery, wood & paper, biodiesel & ethanol from various feedstock<br>*Focus*: trade policies, EU biofuel policies, food security | **AGLINK**<br>*Regions*: EU28,OECD regions<br>*Sectors*: agricultural commodities, biofuels<br>*Focus:* CAP, biofuel policies<br><br>**AGMEMOD**<br>*Regions*: 28 EU MS, Turkey Russia, Ukraine, Macedonia<br>*Sectors*: 30 agricultural and food commodities, bioethanol, biodiesel<br>*Focus:* CAP, biofuel policies<br><br>**CAPRI**<br>*Regions* : 75 countries, incl. detailed supply modules for 28 EU MS, Turkey and Western Balkans (NUTS3)<br>*Sectors*: 50 agricultural sectors, biofuels<br>*Focus:* CAP, environmental policies<br><br>**EFI-GTM**<br>*Regions*: 58 global regions, incl 33 European regions.<br>*Sectors*: woodworking (6 products), pulp and paper industries (16 products) electricity, heat energy.<br>*Focus*: Trade and FLEGT policies, EU climate and energy policies, forest conservation policies. | **Dyna-CLUE**<br>*Regions:* high spatial resolution (global 5 minute, EU 1 km)<br>*Sectors:* land use<br>*Focus:* spatial allocation of land use change and ecosystem service impacts<br><br>**EFISCEN**<br>*Regions:* 38 European countries<br>*Sectors:* Forestry<br>*Focus:* Forest resource information, realizable biomass potentials under variable policy and management alternatives, sustainability and ecosystem service impacts<br><br>**MARKAL/TIMES**<br>*Regions:* Multi-regional (user dependent)<br>*Sectors:* Energy (electricity, heat), transport, Industry (possible extension to other sectors)<br>*Focus:* Cost optimization of (fossil, bio- and other renewable) conversion technology deployment pathways, $CO_2$ tax $CO_2$ CAP, EU renewable energy and biofuel policies, etc. |

| GE models & IAMs | PE models | Bottom-up analysis |
|---|---|---|
| **IAM models**<br><br>***IMAGE*** *(combination of IMAGE+MAGNET+TIMER)*<br>*Regions:* 26 regions<br>*Sectors:* depends on model component; e.g. 11 crop sectors, 12 primary energy carriers, 14 land cover types,<br>*Focus:* climate change, land-use change, biodiversity loss, modified nutrient cycles, and water scarcity.<br><br>***GLOBIOM (*** *combination of* GLOBIOM+G4M+MESSAGE) | **GLOBIOM**<br>*Regions:* 28 EU MS (NUT2); 30 Rest of World regions<br>*Sectors:* 18 crops, vegetable oils and protein meals, DDGS, cereal straw, 7 livestock, 9 primary and processed wood products, 1st and 2nd G ethanol and biodiesel, biogas, bioelectricity, fuel wood<br>*Focus:* climate change mitigation, food security, deforestation, bioenergy and biofuels, biodiversity protection, food-energy-water nexus<br><br>**IMPACT**<br>*Regions:* 320 globally, EU relatively aggregated<br>*Sectors:* agriculture commodities<br>*Focus:* Ag tech growth, food security impacts, water-food linkages | **TIMER**<br>*Regions* : 26 regions<br>*Sectors*: 12 primary energy carriers (incl. biomass), conversion technologies (incl. bioenergy/chemicals<br>*Focus:* climate change, land-use change, biodiversity loss, modified nutrient cycles, water scarcity |

*Source: SAT-BBE consortium*

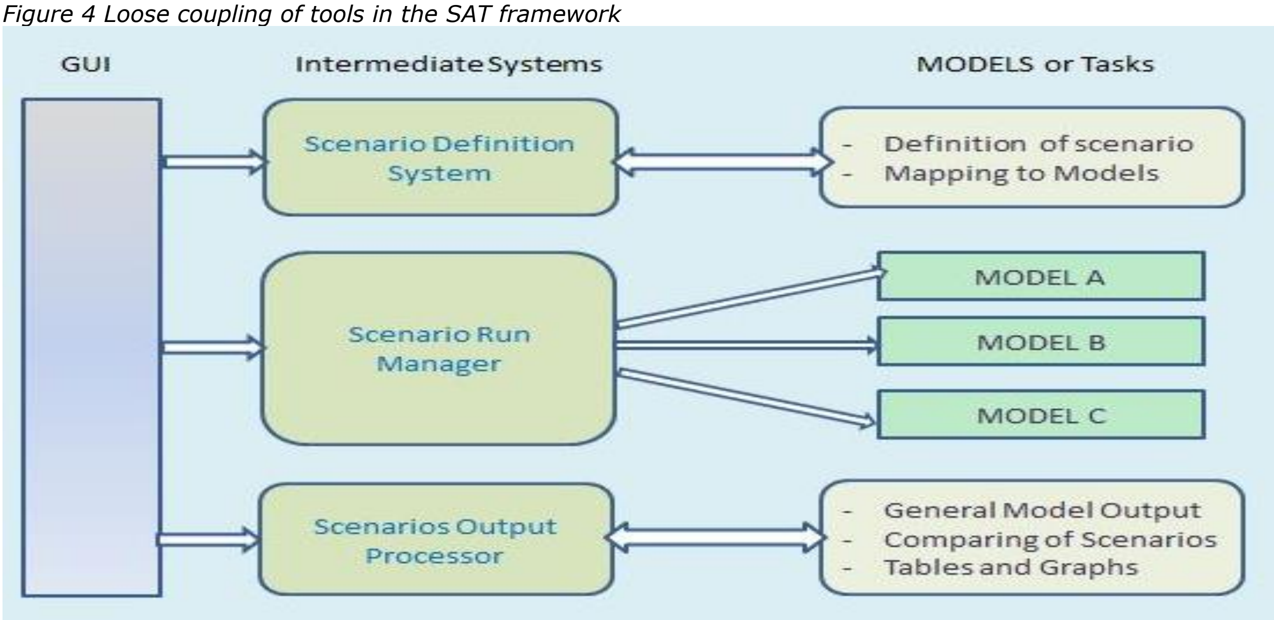
*Figure 3 Overview of model types and groups presented in systems analysis tools framework of the bioeconomy*




*Source: SAT-BBE consortium*

**Fourth,** it can be concluded that no 'super model' exists (nor should be designed) that covers all societal challenges and multi-dimensional relationships in the bioeconomy. Neither it is advisable to aim for such an all integrative model, as the system complexity is too high and such a fully integrative model may be overly complex and inaccessible. Instead, each model shown in Figure 3 has its specific strengths and weaknesses, which means that models needs to be linked in an operational, transparent and systematic way to monitor the evolution and impacts of the bioeconomy and to investigate impacts and potential trade-off and synergy effects, tailored to the specific aim of the analysis or policy question. For example, general equilibrium (GE) models and partial equilibrium (PE) models are essential components in the systems analysis tools framework, but are often not linked with bottom-up biophysical models and datasets (e.g. crop growth models, spatially explicit land use models, techno-economic feasibility studies). Linking of models through 'loose coupling', instead of integration of modules, is a suitable option to further operationalize the SAT-BBE framework and toolkit and provides the flexibility to include models based on the specific needs of the assessment (Figure 4). Graphical user interfaces (GUIs) can be used to facilitate loose coupling of models. GUIs also provide quality control and transparency to enable stakeholder participation in a targeted way.

*Figure 4 Loose coupling of tools in the SAT framework*




*Source: SAT-BBE consortium*

**Fifth**, Figure 5 shows for each of the five societal challenges of the EC Bioeconomy Strategy the required data and models, as well as the gaps in available and required data and models. In general it can be concluded that data, indicators and models are fairly well established for traditional sectors of the bioeconomy (agriculture, fishery, forestry, food, paper and pulp, textile), but less for the innovative sectors (e.g. bioenergy and biochemicals) and less for specific aspects, such as land use, employment, soil quality, etc..

*Recommendations for further research*
Research is required to test the applicability of the systems analysis tools framework and toolkit developed in SAT-BBE for various different research questions and policy assessments.
Gaps exist especially for 'new' and innovative sectors of the bioeconomy regarding the availability of socio-economic indicators such as cost structures, break-even prices, value added, employment, technological potential of economies of scale and technological learning effects.

Gaps exist for food security data regarding the availability of indicators such as consistent household income and expenditure data, nutrition intake data, own consumption and health data.

'Quality' aspects of natural resources like land and water must be captured in environmental models in order to assess how ecosystems impacts could result from alternative pathways driving towards a biobased economy. Feedbacks between environmental and economic models needs to be strengthened.

Model collaboration is required to get a better understanding of land resource availability, land use intensity and costs to take land into production, and to make optimal use of available data and empirical evidence to make assessments correspond more closely to reality.

Ecological limits and sustainable supply need to be better taken into account at the field/farm level up to the global level. This requires the formulation of sustainability criteria and guidelines on how sustainability criteria can be translated into targets, e.g. for land use, energy use and GHG emissions. The targets should become an integral aspect of a bioeconomy monitoring, whereby footprint indicators (like for land and emissions) could measure the distance-to-targets. Demands for other ecosystem services need to be better specified in scenarios to be able to value impacts on these.

Existing models cover already many aspects of the bioeconomy and are strong in the field of agriculture, forestry, energy or economy wide coverage. New biobased sectors are currently built in but data are limited available and weak. To cover the entire bioeconomy there is a trend in equilibrium models that GE models are extended with new and more detailed sectors and PE models are used in combination with one other.

Improved collaboration between model types is essential to evaluate the evolution and impacts of the bioeconomy across different levels of aggregation (Figure 3). The selected models for collaboration depend on the research question, which means that linking of models through 'loose coupling', instead of integration of modules, is a suitable option to further operationalize the SAT-BBE framework and toolkit as long as essential feedbacks are accounted for.

Scenarios and sensitivity analyses are needed in order to understand the impact range of uncertain factors such as technological progress, biomass availability, and fossil and biomass prices on the long term performance of the bioeconomy.

On top of private and scientific research initiatives, the development of coherent and integrated policies are needed to set incentives for the most efficient use of biomass, to strengthen the use of organic waste, to improve primary production practices, to mobilize domestic resources, and to support innovation to enable cost-effective deployment of biomass conversion technologies. It can be concluded that further data disaggregation and improved model collaboration are required to increase the usefulness of the designed systems analysis tools framework and toolkit developed in SAT-BBE for monitoring and evaluating the progress of the EU Bioeconomy Strategy.

*Figure 5 Models, indicators and data requirements per societal challenge of the EC Bioeconomy Strategy*

| Societal challenge | Main models | Key indicators | Data requirements | DATA GAPS | MODEL GAPS |
|---|---|---|---|---|---|
| **Ensuring food security** | • multi-sector, multi-region CGE and PE models<br>•household models | food prices, household income; jobs; nutrition intake; water, land, energy | Agro-food balances; food prices, wages; household income and expenditure data; demographic data | •Capture own-consumption of food for producing & consuming households<br>•Track changes in food purchasing power related to feedbacks on household income<br>•nutrition (macro and micro nutrients) & human health<br>•Detailed household info on food intakes | •Capture own-consumption of food for producing & consuming households<br>•Track changes in food purchasing power related to feedbacks on household income<br>•Link nutrition to human health aspects |
| **Managing natural resources sustainably** | PE resource availability models; biodiversity models | land use; management; soil, water, energy; ecosystem services; forestry | Remote sensing; soil fertility field observations; water/field/biodiversity inventory | •Low spatial resolution of species occurrence<br>•Lack of species abundance & time series data<br>•Consistency of land & residue potential estimates<br>•Land management intensity data, esp. of forests<br>•Recent groundwater data at high spatial resolution<br>•Soil quality data covering time series & spatial res.<br>•Supply & tippling points for ecosystem services | •Calibrate elasticities in PE and CGE models related to available land and trade-offs<br>•Improve biophysical simulations and ecosystem functioning |
| **Reducing dependence on non-renewable resources** | Bottom-up analyses, PE technological-economic models; CGE to add indirect effects | Cost-supply of energy and biobased substitution options; self sufficiency indices; fossil/renewable/bio-based energy use | Conversion data , breakeven points, agrofood versus byproducts; substitution potential; detailed cost-breakdowns; LCA data | •Process efficiencies & costs for "substitution" & new conversion technologies, esp. chemicals<br>•Tech change rate, learning rates, breakeven costs: more transparency needed at more regional levels.<br>•Diffusion rate of alternative products based on consumer preferences<br>•Logistics and trade data for innovative products | •Further develop PE models for "new" BE sectors and include new sectors in CGE<br>•Include end-of-life technologies in PE<br>•Improve cost-supply curves of PE<br>•Extend typical assessments from energy to other non-renewables, e.g. phosphorus<br>•Incorporate scenarios based on stakeholder input for technologies |
| **Mitigating and adapting to climate change** | Climate models; biophysical models; CGE\PE models; life-cycle assessments | GHG emissions; nutrients; temperature; ecosystem services; carbon price | Atmospheric concentration; nutrient depletion data; global erosion and GHG data | •Understanding of climate change patterns. Incl. atmosphere, ocean energy flux, LUC dynamics<br>•Crop responses to CC, incl. yields, pests, diseases<br>•Farmer/forest owner behaviors & options<br>•Accounting of C-storage in bio-based materials<br>•Costs of adaptation and mitigation | •Scale up process-based impact studies<br>•Better reflect high uncertainties<br>•Include potential inter-sectoral effects<br>•Improve robust econometric estimates of farmer and forest owner responses<br>•Include adaptation options and their costs |
| **Creating jobs and maintaining European competitiveness** | CGE, SAM, IO models; PE sector models; labour market models; education models | GDP; sectoral value added, jobs; trade balance ; fossil, biomass, food prices | National accounts; IO tables, prices; subsidies and taxes; labour statistics; RIS statistics | •Rate and quality of employment data<br>•Regionally specific social aspects of employment<br>•Detailed value added data at a sectoral level for 'new' bioeconmy sectors, e.g. bioplastics, bioenergy<br>•Returns and production costs structures for 'new' bioeconomy sector; breakeven points between oil and biomass prices. | •Broaden sectoral scope<br>•Revise parameterisation of models adjusted to new sectorial coverage<br>•Disaggregate sectors in CGE models, enable potential substitution possibilities<br>•Strengthen links with other PEs (agriculture vs. energy vs. chemical market PE models) |

*Source: SAT-BBE consortium*

# 1. Introduction

## 1.1 Motivation for SAT-BBE project

In 2012, the European Commission (EC) launched a new strategy on the Bioeconomy[1], consisting of a Bioeconomy Strategy and an Action Plan. Both have the objective to establish a resource efficient and competitive society that reconciles food security with the sustainable use of renewable resources. The focus of the Action Plan is on 1) investing in research, innovation and skills; 2) reinforcing policy interaction and stakeholder engagement; and 3) enhancing markets and competitiveness in the bioeconomy. The Bioeconomy Strategy is aimed at tackling five societal challenges:

1. ensuring food security;
2. managing natural resources sustainably;
3. reducing dependence on non-renewable resources;
4. mitigating and adapting to climate change; and
5. creating jobs and maintaining European competitiveness.

To promote and monitor the development of the EU bioeconomy, the EC launched the "Systems Analysis Tools Framework for the EU Bio-Based Economy Strategy" (SAT-BBE) project with the purpose of designing an analysis framework for monitoring the evolution and impacts of the bioeconomy. Second, the EC started the 'Bioeconomy Information System Observatory' (BISO) project with the objective of bringing together the data, indicators and tools needed to monitor the progress, assess the impacts, and model future scenarios of the bioeconomy. SAT-BBE and BISO were established as complementary projects, and interactions among researchers have strengthened the knowledge basis for developing a systemic bioeconomy monitoring framework.

More precisely, the purpose of SAT-BBE has been to develop a system analysis toolbox for monitoring and assessing the evolution of the bioeconomy, based on both quantitative and qualitative analytical tools. The toolbox should enable the assessment of drivers, including various policies, on the evolution of the bioeconomy and the assessment of impacts, on people, planet and profit, related to different pathways of bioeconomy development. The focus is on economic aspects, as well as on impacts such as land use change, food security, biodiversity and greenhouse gas emissions. The systems analysis tools framework should have the capacity to understand the functional requirements of the bioeconomy and to assess the sustainability of a biobased transformation. Tools include modelling and non-modelling analytical methods, organised in evaluation (and, by extension, monitoring) methodologies.

The SAT-BBE project structures the development of the analysis tool for the EU bioeconomy strategy in three phases:

1. scoping and definition of the systems analysis framework (WP 1);
2. tools for evaluating and monitoring (WP 2);
3. systems analysis protocols (WP 3).

This report describes the key findings of WP 3 on 'Systems analysis protocols', but above all, it presents the key findings and conclusions of the overall SAT-BBE project.

## 1.2 Definition of the bioeconomy

Until 2005 the term *bioeconomy* has mainly been used in relation to economic activities derived from scientific and research activities focused on biotechnology, i.e. on understanding mechanisms and processes at the genetic and molecular levels and its application to industrial process. Since 2005 several broader and overlapping definitions of the bioeconomy, have been used that vary with respect to scope and issues covered. In total seven definitions were found in the literature, each with specific advantages and disadvantages (see further SAT-BBE Deliverable 1.1). One of the definitions is the result

[1] Innovating for Sustainable Growth: a Bioeconomy for Europe (EC, 2012).

of an on-line consultation of the European Commission on the bioeconomy, held from February 2011 to May 2011. Stakeholders mentioned that the definition of the bioeconomy should be broad enough to capture the concept of *sustainable development*, taking into account environmental, social and economic issues, including the *ecosystem* dimension of the bioeconomy. Also the drivers of the bioeconomy have specifically been addressed. In response to this consultation, the EC formulated the following definition that was published in the 'Communication on Innovating for Sustainable Growth: A Bioeconomy for Europe' (EC, 2012):

> *'The bioeconomy encompasses the production of renewable biological resources and their conversion into food, feed, bio-based products and bioenergy. It includes agriculture, forestry, fisheries, food and pulp and paper production, as well as parts of chemical, biotechnological and energy industries. Its sectors have a strong innovation potential due to their use of a wide range of sciences (life sciences, agronomy, ecology, food science and social sciences), enabling and industrial technologies (biotechnology, nanotechnology, information and communication technologies (ICT), and engineering), and local and tacit knowledge.'*

The SAT-BBE project has adopted this relatively broad and generic definition also, considering the broad scope and goal of the project, the wide scope of quantitative and qualitative research studies, the emphasis on a sustainable development, and the diverse driving forces of the bioeconomy. Despite not explicitly mentioned in the definition we want to stress that it takes account of:

- the concept of a circular economy, which relates to both the production and consumption side of the bioeconomy, especially when it comes to use types of waste for innovative bioeconomy processes, including cascading;

- the role of ecosystem services.

For example, the definition takes into account the important process of moving from a linear towards a *circular economy* by using agricultural waste streams at farm (e.g. manure), post-harvest (e.g. straw, plant residuals) and retail levels (e.g. food wastage). Instead of looking at waste as a cost factor linked to currently existing bans on dumping waste, organic or biodegradable waste could be treated as a by-product or return factor of agrofood and fishery.

Moreover, the definition allows for an *ecosystem-driven* green economic and industrial vision on the bioeconomy, i.e. in which fossil fuels are replaced by biobased substitutes, not only for energy, but also for material, clothing, plastic, and chemical applications and *non-market services.* The transition towards a bioeconomy thus implicitly embeds a transition towards a circular economy, ensuring the sustainable use of agricultural, maritime and forest-based biomass, waste and by-products, contributing to new competitive opportunities of the concerned sectors, reducing the potential harm to the environment and taking into account the value of non-marketed ecosystem services.

## 1.3 Aims and organization of this report

This report is the last and final deliverable of the SAT-BBE project. The objective is to combine different specialist knowledge in both developing and using data, indicators and models into one systemic framework for monitoring the development and impacts of the bioeconomy. During the full SAT-BBE project period, data sources, indicators, methods and models have been collected, compared and assessed toward developing a comprehensive systems analysis framework. This deliverable builds on the results of all three work packages.

The target audience of this report is policy makers, but the report is also relevant for researchers and businesses. It aims to provide a sound, concise and informative overview of available tools, key gaps and suggestions for the future developments. As it is not an academic paper, citations and references are kept to a minimum. Further detail can be found in the prior deliverables of this project.

This report is organised into 5 chapters:

- Chapter 2 presents the conceptual systems analysis framework for monitoring and evaluating the bioeconomy that has been developed in the SAT-BBE project. The overview of the framework contains the ingredients to comply with the policy topics highlighted in the Bioeconomy Strategy and Action Plans. More specifically, it covers the overall complementarities and trade-offs of the bioeconomy that deal with the five societal challenges of the Bioeconomy Strategy;
- Chapter 3 looks at the theoretical and operational linkages of required data and indicators, models and tools that account for the description and analyses of the bioeconomy related to each of the societal challenges;
- Chapter 4 links these required data and models (the tools) into the conceptual framework of Chapter 2, which generates the **Systems Analysis Tools (SAT-BBE) framework**. This SAT framework must be capable of answering the main policy questions related to the bioeconomy and its societal challenges;
- Chapter 5 ends with a summary of key messages and recommendations for further research in order to close gaps between required and available data, indicators and tools in the SAT framework.

## 2. Conceptual framework for assessing the bioeconomy

A systemic framework is needed for assessing the bioeconomy. In particular it must be possible to monitor, model and assess the following (more information, see SAT-BBE Deliverable 1.2 and Deliverable 1.3):

- **multiple scales:** comprising the analysis of specific products, the wide array of sectors and processes at the level of entire economies;
- **local to global level impacts:** considering that impacts manifest differently at different scales of analysis, and taking in particular care to distinguish between impacts within the EU and impacts abroad in a systemic way that avoids leakage effects, i.e. problem shifting from one sector or region to another;
- **interlinkages between the economy, society and environment:** in particular taking into account how changes in demand and production affect food security or natural ecosystems, and vice versa;
- **possible futures in light of mega trends:** including consideration of factors outside the scope of modelling, like population growth, and how such trends and factors affect possible bioeconomy development pathways;
- **innovation:** in particular taking into account technological change in production and manufacturing (such as genetically modified organisms and advanced bioenergy and biochemical production systems), but also considering social innovation and changed behaviours in the context of the bioeconomy, like reducing food waste, and distinguishing between incremental and radical changes;
- **sustainability:** considering how the bioeconomy and processes within the bioeconomy contribute to reaching sustainability targets, like the sustainable development goals, and also developing indicators and targets to benchmark sustainability in a quantifiable way at different levels of analysis. Important thereby are (potential) trade-off effects and complementarities of different sustainability targets;
- **policy relevant questions:** keeping in mind the key research questions and political relevance, in particular to help maintain focus and avoid becoming lost in the complexity of the system.

At a conceptual level, a systems analysis implies the capacity to understand relations between parts, and the nature of both the parts and their relationships. Given this systemic complexity, evaluating, monitoring and modelling the evolution and impacts of the bioeconomy are not straightforward. In particular, capturing the wide array of sectors (from primary sectors like agriculture and forestry to industrial sectors like food processing and chemicals to service sectors like energy supply and retail), the broad and rapidly evolving research and development activities, as well as environmental and social impacts both domestically and abroad in one framework is a challenge. For this reason, we suggest using the DPSIR Framework as a conceptual framework to structure and underpin the analysis.

The DPSIR concept is a framework for describing the description of the interactions between society and the environment. It represents a systems analysis view: social and economic developments within the economy (*drivers*) exert *pressure* on the environment and, as a consequence, the *state* of the environment changes with *impacts* on the environment. Policy *responses* attempt to intervene to drive the system toward more sustainable development.

SAT-BBE uses this framework as a basis, and has simplified it somewhat to reduce complexity and reflect the specific aims of analysis in SAT-BBE. The adjusted framework consists of three elements: Drivers (and pressures), Impacts (and mechanisms) and Responses (and other policy issues) and is referred to as Driver-Impact-Response (DIR). The DIR framework can be presented as a linear chain or a circle, but in reality resembles a complex web of many interacting factors, some of which may represent highly non-linear dynamics. It is used by SAT-BBE to help determine what dimensions should be taken into account in a systemic modelling of the bioeconomy (more information is available in Deliverable 1.2).

**Drivers** and **constraints** identified by the SAT-BBE consortium can be grouped into the following categories:

Drivers:

- demographics, which includes, among others, population growth, which is dependent on birth, mortality and migration rates;
- consumer preferences, such as consumer behaviour and public attitudes toward genetically modified organisms and bioenergy;
- economic development, which includes not only income growth, but also relates to consumption, investments, poverty, development of infrastructure, etc.
- climate change, which affects, among others, the availability and productivity of agricultural areas, forests and fresh and salt water systems;
- innovation and technical change, which provide the options to improve the efficiency of the use of natural and human resources and the economic competitiveness of different sectors in the bioeconomy.

Constraints:

- availability of three categories of natural resources; land, water and non-renewable natural resources (nutrients and fossil energy resources);
- availability of labour resources or human capital, which is dependent on education and experience.

**Impacts** have been assessed related to the societal challenges and the three pillars of sustainability and across multiple scales of analysis. Particular attention has been given to both economic impacts (like economic growth and job creation) and certain environmental impacts (related to e.g. land and water use) and possible conflicts between them. On the environmental side, impacts are not only related to the how land and water are used (production practices), but also how much land and water are used. See also Deliverable 1.3 and Deliverable 2.2. Both aspects relate to constraints of the sustainable bioeconomy. Impacts have to be measured with regard to the societal challenges: food security; managing natural resources sustainably; dependence on non-renewable resources; mitigating and adapting to climate change; and creating jobs and maintaining European competitiveness.

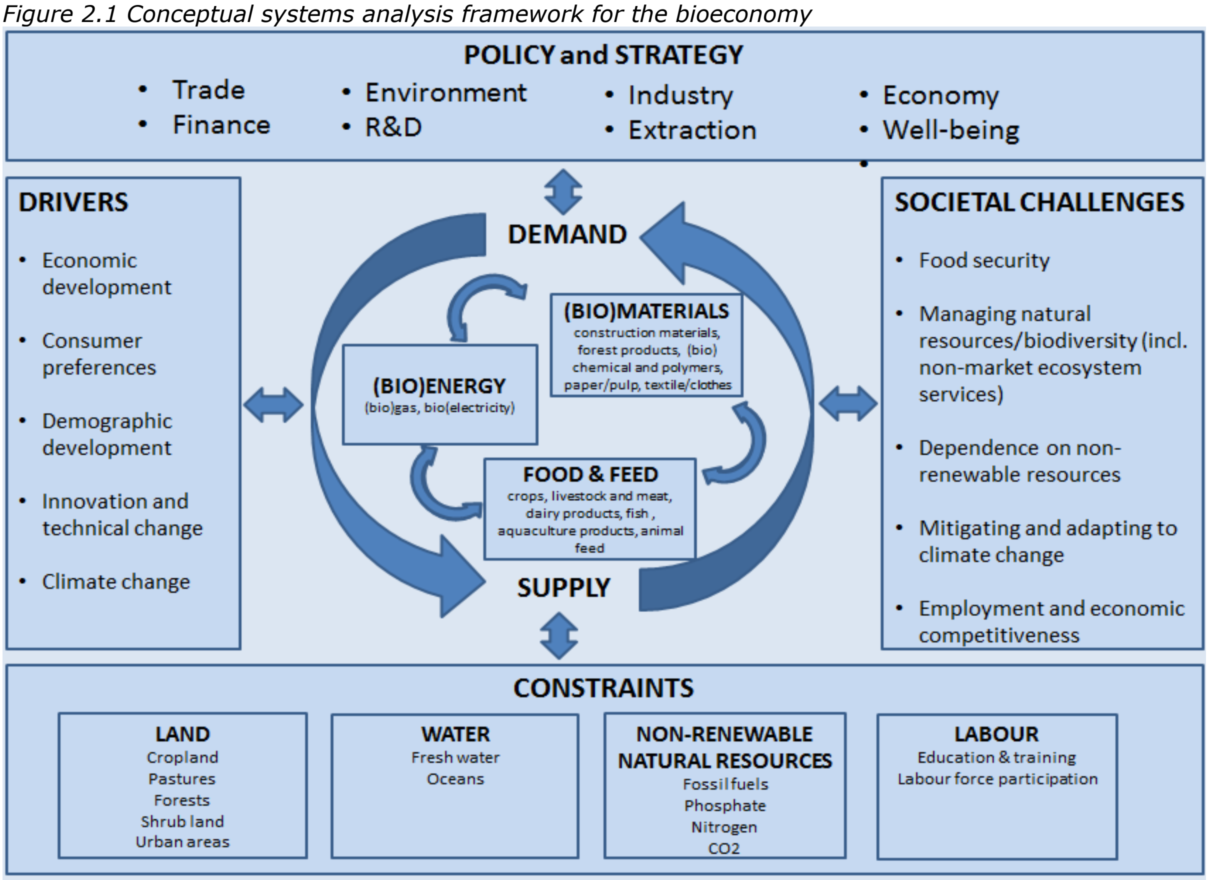
**Responses** demonstrate the efforts of the society, i.e. from politicians, decision-makers, and private stakeholders, to solve problems when realising the objectives of the bioeconomy (policy and strategy). Policy responses refer both to (1) specific policy areas and interventions, like in the context of biofuel policies, the renewable energy directive, agricultural policies, trade policies, climate change policies, environmental policies, and science and innovation policies, as well as (2) pathways that stimulate the sustainable development of the bioeconomy. Coherence among policy areas is critical for the development of a knowledge-based and sustainable bioeconomy.

Building on these concepts, this report has developed a **supply-demand framework** for putting the supply and demand relationships within the bioeconomy into the wider perspective of drivers & constraints, impacts (societal challenges) and responses (policy and strategy). Figure 2.1 illustrates this framework, noting that it is difficult to depict all components of the bioeconomy in one diagram. It should also be noted that these categories are not meant to be exclusive, e.g. mitigating and adapting to climate change is both a societal challenge and a key driver of the bioeconomy due to policy targets. Instead, the figure is meant to illustrate the overarching systems framework that must be taken into consideration in modelling specific research questions.

Figure 2.1 is based on the premise that the transition from the current fossil based economy towards a sustainable bioeconomy (including food, energy and materials) is influenced by system and policy drivers and barriers. A linked system of food, energy, and material markets with competing demands for both biobased and fossil based inputs. On the other side, the availability of biomass and fossil supplies is constrained by land, water, other natural resources and human capital. In a nutshell, for describing and assessing the bioeconomy in the EU, and to analyse its trade-offs with the fossil-based economy, the systems analysis framework is structured as a linkage of five blocks:

- drivers (left box in Figure 2.1);
- constraints of natural resources and labour (bottom box); and
- mechanisms and correlations of demand and supply of biomass (centre);
- societal challenges related to the bioeconomy (right box);
- policy, management and strategy responses (top box).

*Figure 2.1 Conceptual systems analysis framework for the bioeconomy*




*Source: SAT-BBE consortium*

The system drivers of the bioeconomy (left box in Figure 2.1) relate to both supply and demand side elements. Demographic growth, consumer preferences and economic growth are driving the demand for biomass, while technological and climate change influence the supply of biomass. In addition, the availability of resources (land, water, non-renewable natural resources, human capital) constrains the supply of biomass (bottom box). Regarding the natural resources land and water, not only availability but also the impacts of use, like pollution, constrain the supply of biomass and fish available for the bioeconomy. The third block (right box) mentions the five key societal challenges of the bioeconomy. These challenges, in turn stimulate policy and management targets, e.g. the reduction of CO2 emissions (in case of adapting to climate change) or the increase of green jobs (in case of employment and economic competitiveness). Changes in drivers and resource constraints affect the challenges and the extent to which their targets are met. If indicators are not in line with policy and management targets the fourth block (top box) includes policy and management initiatives and responses that are implemented in order to achieve the policy targets set by the geographic region. These policies and strategies will influence the interaction of demand and supply through several (simple and complex) mechanisms that result in impacts on the societal challenges of the bioeconomy.

In essence, the systems analysis framework depicts the interrelationships between the bioeconomy with the fossil-based economy. Moreover, it addresses the potential trade-offs and synergies that become relevant when monitoring and evaluating the impacts of the bioeconomy. When it comes to achieving the objectives of the five societal challenges, possible conflicts or dilemmas – due to trade-off effects – may occur (e.g. economic growth versus environmental protection). On the other hand, synergies could also become important, for example across technical change, economic growth and food security. As the transition toward the bioeconomy is a complex systems change, there is a need for a systems analysis perspective to capture all relevant correlations.

# 3. Societal challenges relevant for the bioeconomy

This section discusses the five societal challenges that are addressed in the European Bioeconomy Strategy. First, each challenge is briefly explained in terms of its background and importance for EU bioeconomy policy. Second, data requirements and monitoring tools appropriate for the specific societal challenge are analysed. The focus here is on the types of methods and models and not on specific models themselves (for an extended description of specific models, see Deliverable 2.3). Third, not only gaps in the systems analysis framework are addressed, but also what the requirements for future research are in order to close these gaps. In all cases, the operational relationships between analytical tools available and needed in the framework and potential synergies and trade-offs with the other societal challenges of the Bioeconomy Strategy are important.

## 3.1 Ensuring food security

### 3.1.1 Background and importance of issue

The sharp increases in food prices that occurred in global and national markets over the 2006-2008 and 2010-2011 periods have sharpened the awareness of policy makers and agricultural economic analysts to the stresses facing global food systems and the ecosystems that support them. A number of factors have been suggested to explain the rapid increase in food prices, such as the rapid increase in first-generation, food-based production of biofuels, the increase of cereal and meat demand from East and South Asia, crop failures due to extreme climate circumstances, export restrictions, energy price increases, and the increase in speculative activity in food markets. The steady decline in the level of cereal stocks, globally, as a result of the private sector taking over the operation of cereals stocks from government, has also been cited as a factor that has reduced the ability of national governments to stabilize consumer and producer prices. Most analysts, however, do not isolate a single cause as being to blame for the current world food situation, but cite a complex interaction between several coincident factors.

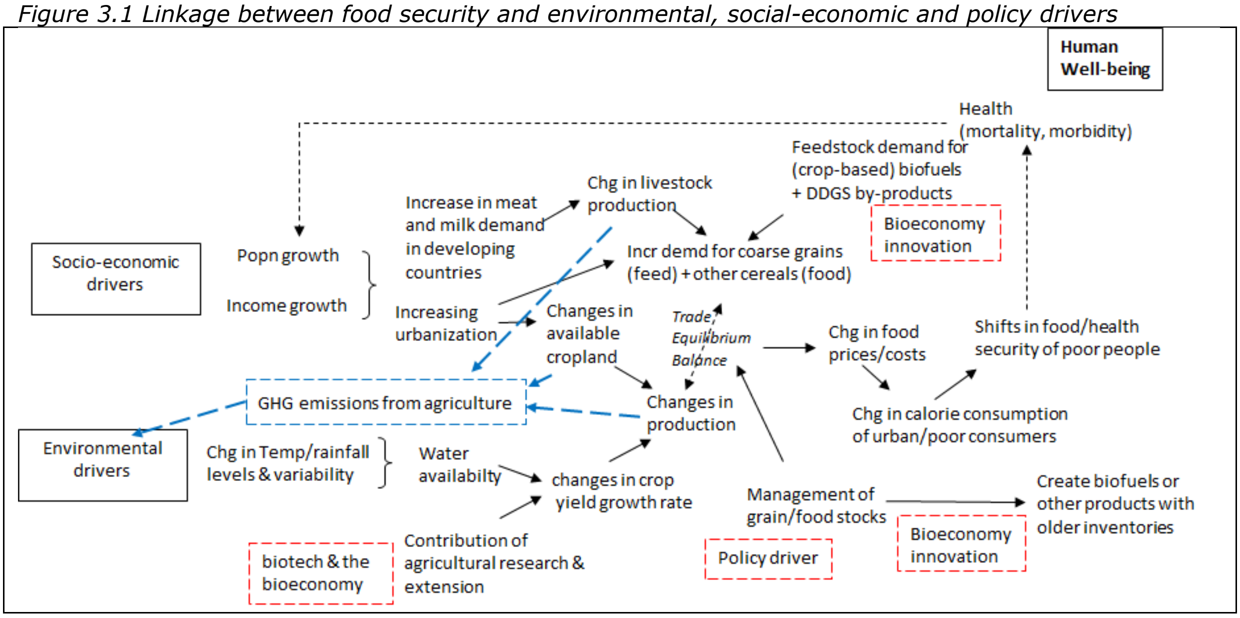
The challenges and increased stresses that face global food production and distribution systems are particularly acute and pressing for Sub-Saharan Africa. Also South Asia sees very high levels of food insecurity, even despite considerable gains in household income levels and reductions in poverty. Though the worst food insecurity is suffered in counties under conflict or unreliable governance, in other countries this is due to the persistent lack of adequate access to clean water and sanitation (or the persistence of poor sanitary practices) that causes the nutrients in available food not to be absorbed by the body. This illustrates the importance of considering *all* aspects of food security, and not just availability. The FAO definition of food security embodies four key pillars or components that all must be fulfilled if food security is to be realized:

1) *availability*: quantity that is available for consumption (on markets or within households);
2) *accessibility*: relates to the affordability or other aspects of securing available food;
3) *stability*: relates to how volatile the levels of availability are & the market environment; and
4) *utilization*: how nutrients can be retained within available and accessed food and used by the body to sustain health and well-being.

Figure 3.1 below illustrates (in a simplified manner) how a number of factors can interact in order to affect food security outcomes. Not all the interactions shown in this schematic are happening at the same rate of change, given that some socio-economic trends are gradual (i.e. urbanization), while weather changes (i.e. rainfall/droughts) can occur more quickly. The figure also illustrates the linkages to other societal challenges such as mitigating and adapting to climate change, natural resource sustainability (i.e. the availability of water and land), while the dependence on non-renewable resources and the ability to switch to alternative sources of energy (such as biofuels) is also captured here – which may, themselves, be innovations that come from a vibrant bio-economy. Also relevant is the emergence of new bio-based applications and the impact of technological change, such as for example the development of Genetically Modified Organisms (GMOs) and the production of first and second generation biofuels and biochemicals[2].

On the other hand, the importance of preventing and reducing food waste in the food chain has to be mentioned. Over 100 million tonnes of food are wasted annually in the EU, and without actions it is expected to rise to about 126 million tons by 2020 (EC website). Wasting food is not only an ethical and economic issue, but it also depletes the environment of limited natural resources. Due to limited space in Figure 3.1, this has not been explicitly included in the schematic below.

*Figure 3.1 Linkage between food security and environmental, social-economic and policy drivers*




### 3.1.2 Tools framework for analysing food security related to bioeconomy

In SAT-BBE a range of economic models are included that are well-suited towards capturing the socio-economic dimensions of food security – particularly with respect to the way that market-mediated forces guide the consumption decisions of households and determine the availability of dietary energy and nutrients that determine food security status. On a macro-scale food security status is influenced by a number of market-level linkages:

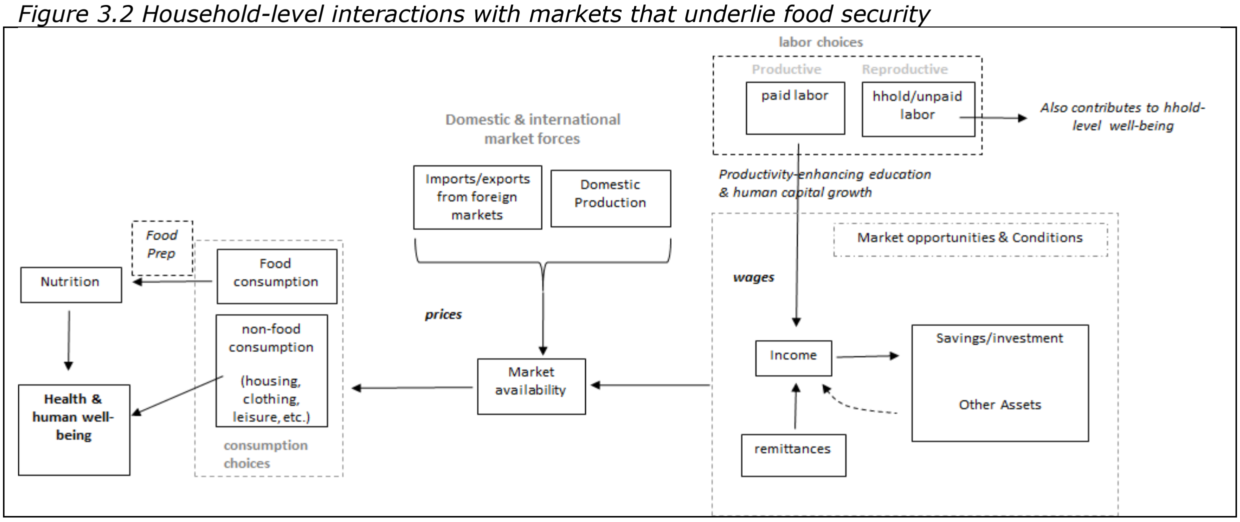
- the forces of economic development are key drivers that determine consumption growth – along with consumer preferences (and how they evolve with income growth), as well as demographic growth (i.e. population size and age structure);
- the key factors such as land and water underlie the supply side of agriculture;
- the interaction of other natural resources, such as oil, is on the one hand an important cost factor within agriculture and on the other a driver in the energy sector, which determines the evolution of bioenergy production and its interactions with agriculture;
- agriculture R&D is an explicit driver of yield growth – along with overall innovation and technical change that adjusts crop and livestock productivity. This can also apply to the energy sector, and how conversion technologies and efficiencies might evolve to affect the demand for energy;
- trade is a key component of market-mediated price formation, for both the agricultural and bioenergy sector;

[2] Msangi, S. and M.W. Rosegrant. 2011. "World Agriculture in a Dynamically-changing Environment: IFPRI's Long-term Outlook for Food and Agriculture". In *Global Agriculture in the Long-run: Opportunities and Challenges* (P.Conforti, ed.), Food and Agriculture Organization of the United Nations (FAO), Rome.

- climate enters into the picture, in terms of its impact on crop yields and is in turn influenced by agricultural and land use change emissions.

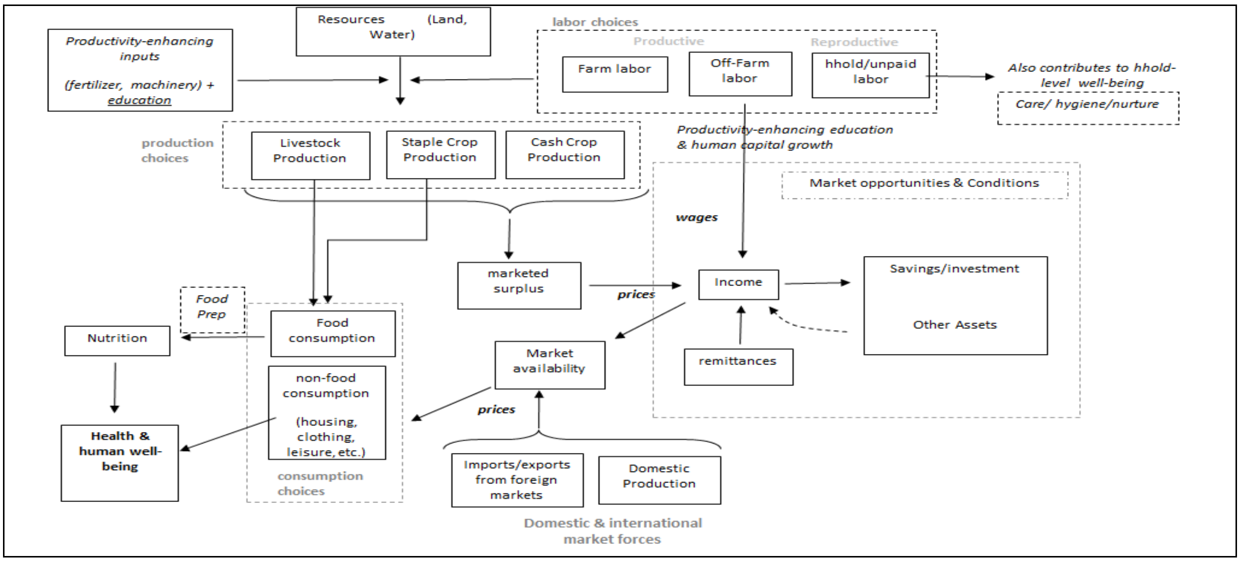
If we were to focus more on the household-level where food insecurity outcomes actually occur, we could describe the key market-mediated interactions that occur in the way shown in Figure 3.2 on the next page. In this figure we show a household that does not produce its own food (as is typically the case in our modelling tools), but which faces market forces that determine the consumption choices that ultimately lead towards food availability and nutritional status. This would be true for both partial and general equilibrium models. However this figure brings in more of the feedbacks between labour choices and household level income than we would get in a broader economy-wide modelling perspective. The wages are made explicit, and determine the labour supply decisions at the household level (which can also choose to engage in unpaid activities) and the income from those wages determine the level of income that the household receives, and upon which expenditure decisions can be made. Consumption choices also include non-food items, which are essential for overall well-being. This provides a full-income perspective to the overall household budget, and is typically the approach used in general-equilibrium modelling. The market forces that determine trade and domestic supply are directly linked to market-level availability of food and non-food goods, which is typically done in both partial- and general-equilibrium models.

*Figure 3.2 Household-level interactions with markets that underlie food security*




In a more generalized case where the households, themselves, produce food (Figure 3.3) shows the farm household-level food production contributing both to the availability of food (for the households own consumption or as marketed surplus to others), as well as the revenue from farm-production contributing towards the overall budget constraint.

*Figure 3.3 Interaction of household-level food production and consumption with markets*




The addition of household level production to that of consumption behaviour, creates a framework for household decision-making, which is the hallmark of small-holder agriculture, where both production and consumption decisions are taken simultaneously, and are linked to the total household budget constraint. Cash crops contribute directly towards household income, whereas staple production tends to supplement household food availability directly. Decisions about labour (off-farm or on-farm) are also linked to overall household earning potential, and determines the household's ability to purchase goods from the market, either for consumption or as inputs into production. This type of non-separable framework is typically missing in economic models of agriculture (either PE or CGE in nature), which tend to separate the production and consumption decisions as if they're undertaken by completely separate agents in the economy. In developing countries, smallholders are both producers facing the market for their products, as well as consumers who can decide to supplement purchased consumption goods with own-production of essential staple items. This type of a closely-linked economic decision-making is a key feature of agent behaviour within the rural economy. In order to address important questions of food security among rural households who both produce and consume agricultural goods, economic models have to take this kind of a framework into account.

An important aspect of food security that a number of models have tried to address is that of human health and well-being outcomes that are key indicators of malnutrition status, and which go beyond just the quantities of food that are demanded in the market. Some modelling methods have gone beyond the indicators of market demand that normally come from PE and CGE economic multi-market models, and infer the levels of "dietary energy" that are implied in the per-capita consumption levels of the households or agents on the demand side. This entails converting the quantities of food consumed per capita into kilocalories per capita of dietary energy that is (potentially) available. This is typically a population average, rather than being specific to a particular sub-stratum of the general population, and conveys an approximate status of food security in a region. Some models try and use the levels of dietary energy to infer the likely levels of hunger and under-nourishment in the population, based demographic information that might indicate the number of children under 5, which is a particularly vulnerable demographic class.

### 3.1.3 Gaps and further needs

In terms of data needs, one of the key gaps that analysts and researchers currently face in the estimation of food security status is that of actual per capita intake of foods at the household level, in sufficient detail to infer the availability of potential micro- and macro-nutrients. If household level surveys are available, then these indicators can be calculated for households covered in the surveys. Obtaining this at sufficient scale to be nationally-representative requires a concentrated empirical effort, but has been done for a number of countries of particular interest to FAO, IFPRI, LEI and other organizations focused on food security and agricultural development. Coverage of both urban and rural households is important for determining the overall status of food (in)security within a country, and is also needed for detailed estimation of the household demand parameters needed for the modelling. The estimation of small children and other demographic groups in the population is done by making use of the UN population projections, which are available to 2050 and beyond for different socio-economic scenarios. Endogenising population growth (especially birth and mortality) as way of capturing the feedbacks between food security, human productivity and future growth potential has yet to be done in a systematic way, and would represent a significant methodological advancement.

Whereas there is a strong tradition of micro-simulation analysis to look at the poverty impacts of various policy shocks simulated within economy-wide models, the extension to hunger and over/under-nourishment has not been developed, at this stage. There is information on the incidence of malnutrition in rural and urban populations, as has been carried out by FAO, the UN World Food Programme and the World Bank, as a way of estimating the need for disaster relief and food aid. This has yet to be linked to an epidemiological-type of analysis in which the increase in the incidence of hunger or malnutrition can be directly inferred to change in other determinants and socio-economic or environmental variables that can be directly linked to modelling outputs. This is a needed step to improving the state-of-the-art in how the status of food security can be better assessed and forecasted as a function of changing socio-economic or environmental conditions.

From the gaps that we have enumerated, the critical ones for moving forward in the analysis of the food security challenges arising from socio-economic change and the evolution of the bioeconomy are the following:

- obtaining good coverage of food consumption and intake data for key food groups, that can allow for disaggregation of key socio-economic (e.g. urban/rural, poor/wealth) and demographic groups;
- capturing own-consumption of food for those households that are both producers and consumers of important staple foods;
- capturing feedback effects on household income, through an economy-wide framework, in order to track changes in food purchasing power (i.e. the ability of the household to *access* food);
- developing better ways to link the human health aspects of nutrition and food security to the outputs of economic modelling (income & changes in demand), so as to create a clearer picture of food securing impacts;
- developing better ways to link the human health aspects of nutrition and food security to biodiversity and sustainability aspects, so as to create a clearer picture of food securing impacts.

## 3.2 Managing natural resources sustainability

### 3.2.1 Background and importance of issue

As natural resources are the basis of the (bio)economy, sustainable management of natural resources is one of the key societal challenges. Pressures on *land resources* are considerable, and results in soil degradation and deforestation, biodiversity loss and associated loss of ecosystem services. These pressures are increasing due to growing population, rising consumption of meat and dairy products in emerging economies, increasing use of biomass for energy and other industrial purposes, and climate change. The fact that land is now - through the development of international trade - a resource on a global market, increases opportunities for better land use efficiency on the one hand, through a more effective and sustainable allocation of land. On the other hand, it increases the risks of detrimental impacts associated with unsustainable land-use decisions, inequalities in access to land as well as the complexity of monitoring the land use effects of EU consumption and production patterns and policies.

The global capacity to produce agricultural products is controlled by the cultivated land area and the production technology. Increasing demand for products can thus be met by expanding the area of cultivated land and/or increasing the efficiency of production. Whether production capacity can be increased depends to a large degree on the amount of land that is available and suitable for cultivation. Estimates of globally available cropland vary between 1600 and 5000 million hectares of which almost 1500 million hectares are currently in use. The rest (about 3500 million hectare) most probably is rough grazing or forestry land, so it could be wondered whether this area is useful for intensive agricultural production.

Apart from the biophysical and land use constraints, the availability of land for agricultural expansion is also limited by trade-offs with other uses, such as housing, hunting and other extensive uses of land, recreation and various ecosystem services, such as providing habitat critical for maintaining biological diversity. There is universal agreement that converging forest, grass or wetlands into agricultural land is more costly than intensifying the use of existing area. So, the behavioural aspect of farmers beyond the land availability for cultivation must not be neglected. The use of additional land or – on the other hand – even the abandonment of land will depend on economic and environmental incentives to land owners.

*Ecosystem services* provide the basis on which the bioeconomy is based, such as food and fibre provision, and underpin the production of several other goods and services, through e.g. protecting against erosion and floods, regulation of climate and providing services such as pollination and soil fertility. Natural land cover types including wetlands and forests provide numerous ecosystem services in high quantities. However, habitats important for ecosystem service provisioning continue to be lost and degraded at a global scale. Also extensively managed farmlands offer a reasonable degree of multi-functionality which often decreases upon further intensification of production practices. Abandonment of farmland on the other hand can enable a significant "passive restoration" of habitats important for ecosystem service provision. In general, polarization of land use activities is seen with intensification on the most productive areas, while productivity of agriculture in the more marginal areas will remain limited. Biomass potentials on marginal lands are restricted, simply because these lands are very low productive and therefore not taken into production until nowadays. This also leads to a spatial segregation of the provisioning of different ecosystems services. For some services this is not an issue. However, not all services can easily be transported and a supply near the locations of societal demand is essential. Worth mentioning is that while food and fibre usually have a marketable economic value, many ecosystem services are public goods with no direct economic benefit to the land owner or manager. Examples are regulation of climate and provision of ground water. Though considerable efforts are being made in the US and EU to find ways to pay for certain conservations services, payments for ecosystem services are still very rare and are generally lacking on a larger scale to influence natural resource management decisions.

The Convention on Biological Diversity (CBD) summarises the state of *biodiversity* globally in relation to meeting the 2020 Aichi Biodiversity targets in the Biodiversity Outlook 4[3] and concludes that: '*while targets like conserving at least 17% of terrestrial and inland water areas are on track to be met, habitat loss, degradation (e.g. from pollution, eutrophication, intensification) and fragmentation are still widespread across all habitat types and natural resources use is far beyond what is considered within safe ecological limits*'. This poses a potentially serious constraint for extending the bioeconomy. Ecosystems that provide essential services, including services related to water, and contribute to health, livelihoods and well-being, such as wetlands and coral reefs, are still in decline. This is despite the fact that many response indicators are positive in terms of target-setting, reducing pressures, and restoring habitats. The reasons why positive outcomes have not been realised may be due to time lags in ecosystem responses, but on the other hand the measures taken may be insufficient in terms of quantity and effectiveness.

Many of the resources discussed here reflect a global scale of analysis. This implies that the societal challenge "managing natural resources sustainably" requires two levels of reflection. The first is the supply side perspective, which is about the need to manage natural resources within the EU in a sustainable way (e.g. sustainable forestry, agriculture and fishing as well as conservation of biodiversity,

[3] CBD (2014). Global Biodiversity Outlook 4. Montreal, Quebec, Canada, Secretariat of the Convention on Biological Diversity.

etc.). Continuous monitoring of criteria and indicators of sustainable forest management already points to several improvements, such as increasing shares of protected forests, more diverse forest species composition, and higher deadwood volumes in managed forests. But while the natural resource condition in Europe has improved, at least regarding forest biodiversity, global deforestation and forest degradation have continued at high rates. This underlines that the EU must take into account the impacts it induces on natural systems beyond its territory. This reflects efforts both toward sustainably produced bioproducts and toward reducing the EU's global footprint of resources like land and water. In this sense, the societal challenge requires both responsible production and consumption. While methods, tools and monitoring systems regarding the former seem to be more advanced, the latter is crucial to avoiding problem shifting through the development of the bioeconomy (for example triggering deforestation abroad). Research on indicators to monitor national consumption levels, like land footprint accounting, as well as targets to benchmark sustainability, have been suggested in research, but are so far absent from policy.

In EU fisheries policy, the focus is now to manage all stocks aiming for the Maximum Sustainable Yield (Council Regulation. No later than 2020 all stocks shall be managed accordingly at the knowledge that the biomass of all stocks may not be at the biomass level for MSY in all cases. The new discard ban will most likely also increase the amount of landed fish. Both aforementioned developments shall substitute for some of the currently fish imports (which is significant in some countries, e.g. up to 80% in Germany).

At the EU level a series of relevant policy developments related to managing natural resources are taking place (Table 3.1). Despite many ongoing efforts, there is still insufficient cohesion of natural resource policies in the EU. Several of the policies listed in Table 3.1 have at least partially conflicting objectives. An illustration of this is the increased demand for biomass from agriculture and forestry, which resulted in a modification of the set-aside policy, which was originally introduced in the 80s to control the unaffordable cereals surpluses. The revised policy allows the production of biomass crops on areas that were formerly set-aside for several years. Consequently a large challenge for sustainable natural resource management is the question how to balance and integrate different, partially conflicting policy objectives.

*Table 3.1 Relevant policy developments related to managing natural resources*

| Policy (and start date) | Objective |
|---|---|
| Seventh Environment Action Programme (2014) | Sustainable land management in 2020 |
| Policy on soil protection (2006) | To ensure sustainable use of soils; protecting their various functions in a coherent way |
| Land Communication (2015) | To limit land consumption, soil sealing and degradation, as well as ensuring multi-functionality of land |
| Maritime Spatial planning (2013) | Efficient management of maritime space; avoid potential conflict and create synergies between different activities |
| Common Agricultural Policy (2014-2020) | "Greening"; non-contractual actions relating to crop diversification, maintaining sensitive permanent grasslands and ensuring that permanent grassland ratio does not decrease by more than 5% |
| Common Fisheries Policy (2014-2020) | Maximum Sustainable Yield (MSY) by 2020 for all stocks, Ban of discards, Multi-Species long-term management plans, Aquaculture strategic plans |
| EU No Net Loss initiative | To ensure there is no net loss of ecosystems and their services (e.g. through compensation or offsetting schemes) |
| Roadmap to a Resource Efficient Europe (2011) | Gives ways to increase resource productivity and decouple economic growth from resource use and its environmental impact; illustrates how policies interrelate |
| Renewable Energy Directive | Set rules to achieve the EU target of 20% renewable energy by 2020; non-binding recommendations on sustainability criteria for biomass for electricity generation, heating, and fuel production; the *indirect land use change* amendment sets stricter standards |

| | |
|---|---|
| | on efficiency of biofuels and sets rules on reporting of emissions due to indirect land use change |

Sustainable management of natural resources directly interacts with the challenges on 'Ensuring food security' and 'reducing dependence on non-renewable resources' in terms of:

- competing claims on land (safeguarding biodiversity versus food production versus biofuel production);
- trade-offs between yield and pressures from eutrophication and pollution (intensity).

Synergy effects can only be realised by decreasing the demand for resources (e.g. through dietary changes, energy-efficiency, and efficient use of biomass within the economy, e.g. through cascades) or in exceptional cases where increased utilization of biomass may reduce the risk of natural disturbances, particularly wild fires (through reduced fuel loads). Mitigating and adapting to climate change interacts with all three societal challenges through additional land claims, both for mitigation (more land needed as carbon stocks, biofuel production) as for adaptation (more extreme weather patterns require more robust ecosystem networks to support population of species, and more frequent harvest failures require more use of worldwide agricultural land[4]. In terms of the challenge 'Creating jobs and maintaining European competitiveness', there are interactions with sustainable natural resource management.

### 3.2.2 Tools framework for analysing resource sustainability related to bioeconomy

Key constraints with respect to the sustainable management of natural resources are the availability of the resources, in terms of quantity and quality. To understand these constraints in relation to the demand drivers, there is a need for monitoring and evaluating land use and land cover, biodiversity, water availability, soil quality, and other ecosystem services.

*Land use and land cover change* is regularly monitored using *Remote Sensing data* (CORINE land cover), field observations, including the EU scale LUCAS project, agricultural census data and forest inventory data. While Remote Sensing data only provide information on land cover, the other data and indicator sources provide information on the land use and land use intensity as well. All mentioned data sources provide (more or less) regular time series at EU and global scales. Within a bioeconomy perspective the analysis often starts with macro-economic modelling mostly in the form of CGE or PE models that account roughly for constraints in land availability. Focus of CGE and PE models is on the role of trade and changing societal demand as drivers of changing use of land resources, often at the level of world regions or administrative units. A high-sensitivity of these models towards assumptions on available lands and allowed trade-offs in service provision is common while choices between intensification on existing agricultural land or expansion into previously uncultivated areas is based on assumed or calibrated elasticities due to limited data availability. On the other hand, in the most commonly applied tools framework such regional level results are downscaled to pixels of various spatial resolutions to allow assessment of environmental impacts including biodiversity and ecosystem services. This can be done in *integrated assessment models* as well as in specialized *land allocation models*. These approaches account for variations in the biophysical and socio-economic conditions that enable changes in the agricultural sector in more detail. However, simulation is often done in a top-down manner with little feedbacks on the macro-economic system. Therefore, both the local constraints in terms of land resources as well as the anticipated environmental impacts (affecting the economy) are not fed back to the macro-economic assessments. Global scale models used in major assessments differ substantially in outcomes in terms of land use and its environmental impacts. This is to a large extent a result of different operationalization of land resources and its availability in the models used as well as different assumptions towards allocation preferences. There is an urgent need to improve the model coupling and tools to better account for land resource availability as well as land use intensity and make optimal use of the available data and empirical evidence to make the assessments correspond more closely to reality.

[4] Note that the EU agricultural area has been steadily diminishing for the last 40 years.

*Status of fish stocks* is regularly assessed and we have sufficient information on stock sizes for nearly all commercially viable species. The framework for this is the European Union Data Collection Framework (Commission Regulation 665/2008).

*Biodiversity* is most prominently monitored through *species and habitats monitoring programmes* (e.g. Article 17 in EU Habitats). At global level a significant amount of endangered species is monitored through the IUCN red lists, requiring trend data of species ranges and abundances. The IUCN Red List has been assessing the conservation status of species for the past 50 years and is updated at least once a year, thus providing a solid monitoring basis. However, data are mostly at country level, thus providing little spatial detail, and there is both spatial and taxonomic bias in survey intensity. Many other indicators for biodiversity exist, including the size and connectedness of natural habitats, pressure-related indicators such as eutrophication and response-related indicators such as the area protected (see e.g. Biodiversity Outlook 4, EU SEBI indicators). Beside indicators, modelling tools most importantly include species distribution modelling, vegetation dynamic modelling and meta-population modelling, which link the performance (predicted presence, abundance, or viability of species or ecosystem types) to biotic or abiotic conditions of the environment including land use/cover, climate, elevation, water and nutrient availability. These models can be used in ex-post, but primarily ex-ante evaluations of environmental change. Within the tools framework these models are at the end of the modelling chain: they assess the implications of predicted land change on biodiversity parameters. The only alternative use are applications in which scenarios are constructed in which biodiversity parameters are considered in limiting the availability of land resources due to optimal allocation of protected areas.

Indicators for *water availability* include the surface area of freshwater ecosystems, and several statistics on water quantities available in Europe's lakes, rivers, and groundwater bodies. Additionally, water recharge is monitored. On the water demand and use side, there is regular monitoring of water extraction rates by country and by sector. A final category of indicators describes the ratio between water provision and water abstraction. Such water budget, water use efficiency and water footprint calculations are regularly used in future integrated assessment modelling and consider changes in water demand due to changing population and changing agricultural practices, as well as changes in water provision due to climate change and land use change. While often water availability is seen as an impact analysis resulting at the end of the model chain several models also include water availability as a constraint in land allocation and available land area for agriculture, thus having important impacts on the assessed outcomes of scenarios.

For *soil* resources, there are EU scale and some global scale spatially explicit data on several quality parameters: organic matter content, nutrient depletion, erosion risk, pH, susceptibility to compaction, and several chemical parameters. Also several datasets about soil degradation are available, both at EU level and for the world. For organic matter content, a few maps are available, allowing assessing changes. For organic matter content also models are available with which the impacts of land use change, management change (e.g. crop type or harvest intensity) and climate change on development of organic matter content can be assessed.

Mapping and modelling of other *ecosystem services* is an active research field. Over the past years, many European and global scale maps and indicators of ecosystem service supply and demand have been developed. As many ecosystem services are difficult to measure directly, these indicators are often model based, building on spatial data on land cover and land use, biophysical characteristics of the landscape, and socio economic data. Hence, the models used for mapping can generally be applied easily for modelling temporal developments as well. In principle, monetary valuation of ecosystem service changes could provide feedbacks to the economic modelling and ensure a more integrated treatment of environmental impacts on the macro-economic effects of the bioeconomy. However, at the same time the use of monetary valuation of ecosystem services is heavily debated and there is consensus that many services cannot easily be expressed in monetary terms, thus limiting such integrated analysis.

### 3.2.3 Gaps and further needs

Gaps in data on *land resources* firstly refer to inconsistency among different estimates. As indicated before, land availability estimates vary widely as a consequence of different definitions, data sources, and judgments considering what constitutes a safe operating space for different types of land use. Such inconsistency can hamper accurate monitoring. It also points to an absence of benchmarks for monitoring sustainability. Answers to questions like "what is a sustainable level of global land use to supply the European bioeconomy" could e.g. be provided by global land use targets. Such targets not only need to be based on solid scientific evidence, but also reflect normative judgements based on societal consensus (e.g. comparable to the target to halt climate change at 2 degree Celsius). Research is needed on both fronts. At the European scale, temporal resolution of land cover monitoring has so far been very low, limiting the possibility of reacting quickly on adverse changes. New remote sensing products are promising to improve the situation in the near future (e.g. Copernicus satellite data). A main gap in *land use* modelling related to natural resource availability is the focus on agricultural production. Commonly, land use change demands are based on the need for agricultural crops. Land however provides many more resources, including timber and ecosystem services. Including these demands as drivers for land use change is strongly needed but is still under development. In terms of land cover data, there is also bias towards the agricultural land covers, with natural vegetation types being mapped in coarse classes. Moreover, the treatment of land use in CGE and PE models is a simplification of many land change processes and the results are therefore quite uncertain. A better integration of land use models within the bioeconomy tools suite provides the potential to better account for land resources. Uncertainty in available land resources calls for sensitivity analysis of outcomes as related to the uncertainties in land resource availability. Another major limitation is the lack or scarcity of information on management intensity. Information from the LUCAS survey is poorly integrated with other information layers. Management intensity in forests is difficult to derive from remote sensing data, and the information from national forest inventories cannot be linked to local or regional conditions because of the low sample density and the fact that individual plot data are not publically available.

For *biodiversity***,** a gap regards the low spatial resolution of species occurrence data. Additionally, data are mostly on occurrence only and do not include species abundance, nor time series capturing population dynamics. Population dynamic modelling is hampered by high data demands (data on life history traits, like recruitment capacity, survival rates, dispersal capacity; or time series high resolution presence-absence data). While species distribution modelling can be performed using single snap-shot presence-only data, better data (higher spatial resolution, presence-absence or abundance, multiple time frames), in combination with high-quality land use (but see gap in vegetation mapping), climate and topographic data (incl. soil and hydrology) allows the use of more advanced techniques and subsequently more accurate predictions of species' responses to change.

A main gap for *water availability* data and indicators is the lack of recent data on groundwater resources. In Europe, most recent data is from the 1980s and only covers Western Europe. Data on water extraction are generally summarized at country scale, while recharge of water bodies and aquifers takes place at a basin scale. Thus, there is a mismatch between recharge and extraction data in water indicators that calculate a balance between demand and supply. Monitoring at basin scale would be an improvement. These data issues also hamper modelling changes of water budgets.

Collection of *soil resources* data is often a one-time effort. Only for organic matter contents time series exist. These are however inconsistent. As carbon stocks are very large relative to annual changes and are highly spatially variable, monitoring is difficult. Also data about soil degradation are incomplete and inaccurate, especially at a global scale and for certain regions.

For *ecosystem services***,** although a wide range of indicators is available, the quality of the indicators is an issue. The provisioning ecosystem services can be properly measured, but the non-provisioning (supporting, regulating and cultural) services are difficult to measure directly. There is a lack of proper validation data and consequently there is a lack of insight in the accuracy of the indicators. Secondly, while a few ecosystem services (e.g. pollination) are frequently mapped, other ecosystem services receive little attention. Thus, there is an unbalanced picture of the supply and demand of ecosystem services, though this is not just a data collection problem because the concepts of supply and demand for non-market services are so difficult. A gap in modelling is the lack of insight in how ecosystem services respond to temporal changes in the drivers.

At a more conceptual level, a challenge lies in the increasing need to quantify ecosystem services and ecosystem functions, but there is still limited understanding of how biodiversity and ecosystem functioning link to the supply of ecosystem services, including some of the societal challenges such as food production (for which supporting services such as pollination and regulating services such as erosion control are important).

## 3.3 Reducing dependence on non-renewable resources

### 3.3.1 Background and importance of issue

The most critical dependencies on non-renewable resources are phosphorus and fossil fuels. Phosphorus is essential for all biological processes, non-substitutable and based on finite mineral rock deposits found in a very narrow range of countries. On its turn, fossil resources are currently used as essential inputs to production, distribution and consumption processes. Due to a series of problems that face the current world (growing population, increasing demand for food and energy consumption, changing climate and endangering of biodiversity), the bioeconomy is seen as solution for green growth. The main focus of this section is on the challenge to reduce the dependency of the world on of fossil resources.

Supply and demand for solid fuels, oil and gas are unevenly distributed among geographic regions:

- almost half of proven natural gas reserves are located in Russia, Iran and Qatar;
- 70% of proven oil reserves are available in OPEC (Organization of the Petroleum Exporting Countries) countries.

Such distribution creates economic and political dependencies between import (demand) and export (supply) regions, and it increases the influence of both import and export regions on market volatility and fluctuations of energy prices. Also, it raises concerns about secure and uninterrupted energy supply, which may result in geopolitical conflicts among regions. Furthermore, reliance on non-renewable resources is also constrained by their long-term availability. Given today's consumption patterns, global proven reserves were once thought likely to last around 50 years and extraction of remaining available resources will come at costs, which may hamper further economic growth. However, recent developments in shale gas production in the US suggest the opposite. Nevertheless, this exacerbates the vulnerability of importing regions. In addition, it is expected that economic share of BRIICS (Brazil, Russia, India, Indonesia, China, South Africa) countries to the global economy will increase, which will intensify the demand for fossil energy leading to faster resource depletion and higher commodity prices. At the EU-28 level, Europe imports more fossil energy than it produces; a trend that has been increasing over the years. This suggests that the EU is strongly subjected to impacts of fossil resource dependency and may progressively be exposed even further as proven fossil fuel reserves of EU member states are gradually depleting (e.g., natural gas reserves of the Netherlands).

Against this background, it is imperative for the EU to reduce its dependency on non-renewable resources without, however, compromising the competitiveness of industrial, transport and household activities or its supply of high value products to markets. Developing bioeconomy sectors under a coherent policy framework is often seen as one of the ways to address this challenge. This can be achieved by means of reducing energy demand (e.g. by improving resource and energy efficiency), by diversifying the mix of energy supply and by substituting an appropriate part of the demand for fossil-based products with functionally equivalent biobased alternatives, or renewable options such as wind, solar, hydro and nuclear. Biomass conversion technologies are situated as a key renewable source that can supply all sectors with materials and energy (chemicals cannot be produced by other sources, although $CO_2$ is being researched as a potential feedstock). Moreover, bioeconomy development leads to feedstock diversification in the EU's material and energy production systems. By increasing the activity of the bioeconomy accompanied by a parallel reduction of non-renewable energy sectors, the dependency on non-EU energy suppliers can be partly alleviated. This might provide longer-term stability and a secure investment environment, both of which enable opportunities for growth within the EU. However, the increased demand for bioenergy (solid and liquid) due to existing policies has already positioned the EU as the main biomass importer. The EU is expected to remain a net importer, at least in the short term, due to more stringent energy targets and its limited domestic supply potential. Although the distribution of biomass suppliers is more diverse than that of fossil resource suppliers, caution should be raised about reaching a position of import dependency for biomass resources. Like it is for fossil resources, Europe depends on imports of pellets from Canada, of soybeans from Brazil, or rapeoil from Malaysia. Another issue to consider is the sustainability of biomass supply, as the EU's policy framework does not guarantee extra-EU production practices. Furthermore, increase in biomass supply with the aim to reduce non-renewable resource use may create competition for land use and induce land use change and thereby exacerbate impacts related with food security and natural resource use.

The EC policy portfolio already includes measures to reduce the EU's reliance on energy imports and improve its security of supply. Most prominent examples are the Renewable Energy Directive (RED) and the Energy Efficiency Directive (EED). The former aims to increase shares of renewable energy in the energy mix to reduce dependency on imported fossil resources. Biofuels are addressed separately due to their potential to replace transport fuels from fossil resources, but there is controversy amongst the interests groups and branches of the EU institutions regarding what a sustainable level of biofuel use would constitute. The post-2020 framework for the EU's energy and climate policies suggests at least 27% of renewable energy and energy savings by 2030, which will reduce the dependency on non-renewable resources even further. The EED directive helps the EU to meet its 20% primary energy consumption target. However, having as goals a low-carbon economy and energy system, a secure and efficient transport system and to decouple growth from resource use the policy framework needs to be expanded to a more coherent set securing bioeconomy. For example, focus areas can seek to: set incentives for the most efficient use of biomass in different end-use sectors, seek opportunities for cascading uses, strengthen the use of organic waste, improve primary production practices, mobilize domestic resources, and support innovation to enable cost-effective deployment of biomass conversion technologies. Furthermore, attention should be paid to biobased products, which could replace a significant part of non-renewable energy currently used as feedstock. This may occur either by providing renewable feedstock or by supporting the development of manufacturing processes and market demand for innovative materials (e.g., biobased plastics). Biobased materials are not covered by existing policy frameworks and should be addressed by an inclusive and coherent EU bioeconomy policy. Due to the cross-cutting nature of bioeconomy, other policies are also linked with the societal challenge discussed in this section. For example, the reform of the Common Agricultural Policy (CAP) removes the EU's sugar production quota after 2017. Sugar production is expected to shift to more efficient producing areas with subsequent increase in EU sugar production volumes. The EU sugar price is expected to converge more to world prices, which might create opportunities for fermentation industries, especially in the chemical sector.

### 3.3.2 Tools framework for analysing fossil-based resource dependency and bioeconomy

A modelling framework that assesses independence from fossil fuels should account for the primary bioeconomy sectors (e.g., agriculture, forestry), which supply biomass that substitutes non-renewable resources in the rest of economy including an explicit representation of biomass conversion sectors (multi-sector models). Substitution of non-renewable resources with biomass, either at the supply side (i.e., as energy source) and/or at the demand side (e.g., as alternative biobased materials), requires optimized biomass supply and deployment of resource efficient conversion technologies. The deployment of technologies depends on production costs of alternative options, in which feedstock costs (biomass, fossil-fuels, etc.) are a key determinant. Such relationships can be captured when primary bioeconomy and biomass deployment (and conversion) sectors are explicitly incorporated. The model(s) equipped to describe the former sectors, like CGE models, should be able to describe with adequate regional resolution a wide variety of feedstock, including mobilization and supply of residues (agricultural, forestry), different production/management practices (also in other sectors such as livestock), land uses and land-use substitution. Cost-supply curves can then be used by key conversion sectors such as energy and industry, which are main users of non-renewable energy and provide key resources to the rest of the economy such as energy and fertilizers for intensive agriculture or construction materials (e.g., for housing). The desired description level of such technologies includes process efficiencies and costs which when compared across all technologies determine the level of savings in non-renewable energy as they compete with biomass-based alternatives by substituting resources or products.

This is a typical application area of sophisticated multi-sectoral PE system models, which have adequate representation of biomass supply and energy conversion technologies (fossil-, biobased or other renewables; as opposed to single-sector PE models limited to food market or energy systems). A relevant modelling technique that PE models follow is linear optimization which calculates the optimal uses of resources and conversion technologies combined based on system costs. Apart from savings on primary energy, these models are used to estimate among others GHG savings and abatement costs. In this manner GHG emission mitigation pathways can be determined taking into account developments on the supply and the conversion side. Also, optimisation models can account for co-production, a typical characteristic of biorefineries, which are typically not yet fully incorporated in broader economic models. Furthermore, since technologies are explicitly described, these models can take material properties into account when assessing their technical substitution with conventional products. This may prove to be particularly relevant for prospective and innovative biobased chemicals and other products. This way a significant level of detail can be brought to the analysis, which provides more transparency and insights as to which applications or routes reduce dependency on fossil fuels from a systems perspective. With respect to the SAT-BBE framework, however, these models fail to account for interactions with the rest of the economy. For example, it will remain unknown to what extent bioeconomy sectors deployment can affect macroeconomic indicators such as GDP and household income, and then indirectly impact economic welfare and overall employment. Other issues that PE models would fail to account are leakage or rebound effects of EU policies also outside the boundaries of the EU. These issues can be partly addressed by collaboration of PE models with GE models by means of soft linking. The models are connected by exchanging model outputs as discussed in report WP3.2.

### 3.3.3 Gaps and further needs

Key questions when assessing impacts of reducing dependency on non-renewable energy use in the EU through bioeconomy relate to model types, data quality and availability, and limitations of existing policy frameworks. PE system models that include the energy market have sufficient representation of energy sectors (electricity, heat, fuels) with alternatives to fossil technologies. However, representation of industrial sectors –especially those relevant for bioeconomy– is under- or not represented. Efforts should focus on including these sectors by also extending the synergies of the systems by including various end-of-life options (e.g., municipal waste incineration with energy recovery, recycling) and other technologies (e.g., bioenergy with carbon capture and storage (CCS)). For biomass production and availability (including residues), of critical importance are the cost-supply curves used as inputs in PE models. These are exogenously determined as a result of technical assessments and outputs of biophysical or integrated assessment models. This is a typical area where model collaboration will be required in order to improve the representation of biomass potentials in PE models. Another issue, inherent to the partial representation of the economy in PE models, is that they do not account for interactions with the rest of the economy, as they only reflect one (or some) specific sector (e.g. agriculture and fishery); thereby introduce a bias as to which sectors are most important for the economy. In addition, synergies across the complete chain are not identified as PE system models work with exogenous inputs on the supply of resources (e.g., costs, potentials, energy). Another aspect that is relevant to all societal challenges is the mobilization of cheap and sustainable biomass resources. Logistics and trade which are not endogenous in the PE system models are also an important gap. Soft-linking of models may provide answers on the above and also offer insights on the trade-offs between societal challenges. Closer model collaboration would be required to assess synergies in sectors that are not within the boundaries of the PE models, (e.g., potential reduction of non-renewable energy use of intercropping food and energy crops). This entails that drivers, key input parameters (e.g., prices) or other parameters (e.g., elasticities) would need to be streamlined across the different models.

Data gaps are typically an issue faced by, among others, models that require explicit representation of technologies. Data on industrial technologies and especially on innovative biobased conversion technologies to chemicals is typically not publically available; mainly due to proprietary reasons or highly uncertain due to level of technology readiness (e.g., lab scale technologies). This limits the possibility to include alternative technologies in the models. It is important to improve data quality and dissemination of information on innovative biobased material technologies so that their potential can be properly assessed. In addition, life cycle assessment (LCA) studies can provide information regarding non-renewable resource use beyond the direct use of feedstocks for conversion to energy or materials. LCAs can serve as input data for the framework's models; however, they are also limited by data availability. Another fundamental uncertainty related with data is that of the rate of technical change. Various drivers (e.g., innovation and technical change of the SAT-BBE framework) or policies (e.g., R&D support) may be used to influence the rate at which different technologies emerge. The rate of technical change can prove to be significant as delayed rates might lead to lock-in situations or accelerated rates may overestimate potentials of innovative technologies. This can be dealt with incorporation of scenarios, which, need to be composed based on technology stakeholder input. Another uncertainty variable is the diffusion rate of alternative products based on consumer preferences, especially on those that are not identical (e.g., a fossil and a biobased chemical) or even future, currently non-existing, products. Currently there is limited knowledge whether end-consumers can stimulate or pose barriers to bioeconomy products. Given that consumer preference is one of the key demand drivers in the SAT-BBE framework this can also be captured by scenarios.

## 3.4 Mitigating and adapting to climate change

### 3.4.1 Background and importance of issue

Climate change is likely to deeply transform the bioeconomy, by impacting directly agricultural, forestry and marine resource stocks produced and consumed in the EU. Most recent projections anticipate that keeping global temperature increase below a 2°C target compared to the historical baseline is hardly attainable under the current negotiation development; therefore more dramatic climate developments are now envisaged. An increase of the GHG concentration in the atmosphere will lead to climatic change in most regions of the world, with transformation of current temperature and precipitation patterns. These changes will directly impact crop productivity in these regions, as plant growing conditions are heavily dependent on temperature and water availability. Additionally, $CO_2$ concentration in the atmosphere affects photosynthesis and tends to increase crop biomass production, whereas tropospheric ozone has adverse impact on yields. Crop production is however not the only sector exposed to climate change. Livestock is also threatened by climatic change, as ruminant feeding relies on productivity of grassland and availability of forage crops. Livestock is also exposed to water scarcity and heat waves which makes this sector more vulnerable. Also crops, livestock and forests are expected to be exposed to more disease. Forest productivity is likely to change under dryer or wetter climate and by the $CO_2$ fertilisation effect. In addition tree species distribution patterns will be affected, influencing species suitability and silvicultural management options. All these changes will take place in a context where climate variations might increase, according to many authors, worsening the impacts on the bioeconomy sectors of regions negatively affected. Even marine resources are exposed to climate change as increase of $CO_2$ concentration in the atmosphere endanger marine trophic chains due to acidification of the oceans. Without action, this will endanger the overall ecosystem (people, animals, biodiversity, etc.) that is dependent on the quality of the earth system.

In the EU, the impact of climate change on agriculture has started to become visible. For example, average annual temperature is already more than 1°C above pre-industrial values, while since the 1980s winters and summers are warmer in Northern and Southern Europe, respectively. This latitudinal gradient is also visible in annual precipitation changes, with observed increases in Northern and decreases in Southern Europe. The frequency of extreme temperatures has shifted towards more high-end and fewer low-end events. There is evidence that these climate changes contributed to slow down and accelerate recent yield growth of crops in respectively Southern and parts of Northern Europe. While clear evidence of such impacts is still relatively scarce for managed ecosystems due to the difficulty to separate climate and human influences, there is a much larger evidence for impacts of recent changes in climate on natural ecosystems in the EU. Impacts on forests have been both positive and negative. While growing season and productivity has increased especially in northern latitudes and higher elevations, there is also increasing evidence of adverse effects of increased drought stress and more severe disturbances (particularly disease, storm and fire). Species distribution ranges have been affected particularly at the warm and dry boundaries.

EU farmers must adapt their production methods to the new environment. Adaptation channels are manifold, though there are temperature and other limits beyond which viable crop production becomes impossible (especially as it is uncertain that temperature rise contain below 2 degrees). They range from field level options, such as shifting planting dates, using different varieties, using more input or diversifying rotations to minimize risks of losses, to more large scale approaches, for example water management investment, storage capacities, trade infrastructure. More drastic changes can also include change in consumption patterns towards products that are easier to cultivate domestically, if traditionally consumed food becomes more difficult to produce under new climatic conditions. In forestry the adaptive management includes species or provenance changes as well as a wide range of other measures to mitigate drought effects, reduce disturbance risks, or to adjust management schedules to the changed growth dynamics. These adaptation mechanisms will be crucial to ensure that the bioeconomy can keep delivering the levels of food, feed, fibre, fuels and all forms of new uses (biomaterials, biochemicals) demanded by our society in the near future. Note that studies suggest that the EU could be suffering from climate change relatively less than some other regions of the world.

The EU bioeconomy can also contribute to the mitigation of these impacts by participating more directly to the reduction of GHG emissions. With 9%, EU agriculture and forestry sectors are relatively high contributors to overall EU emissions (while their contribution to GDP is 3%), but they are the only sectors which can offer sequestration potentials, through afforestation, enhanced forest growth rates at least in some regions, improved grassland and cropland management, and can provide energy substitution through biomass, biofuels and material substitution from biomaterials. Promotion of use of renewable energy in the transport and the energy sector already led in the EU to ambitious deployment of biofuel production and biomass supply chains. However, the efficiency of these mitigation measures is considerably debated, and some other uses of bioproducts (e.g. biomaterials, biochemistry) could, and probably should, in the future have to face more rigorous sustainability requirements. Increase of biofuel production has led to reduction of land set-aside, intensification of pesticide uses, increased feedstock imports and associated land use leakages, and increase of food and feed prices. The use of less intensive production methods is also a path to reduce the use of mineral fertilizers and associated nitrous oxide emissions. However, a decrease in crop yields would also exacerbate the pressure on land, potentially leading to more land use change emissions. In forestry the assessment of mitigation strategies is rather complex, because there are different strategies available with conflicting management implications. One strategy is maximizing the carbon stocks in existing forests, through reduced harvesting and accumulation of biomass in the forest. But the capacity to store more carbon on land is limited and this strategy is also increasing the risk for leakage and increased pressure on forests elsewhere. It also reduces the potential to use biomass and to sequester the carbon in harvested wood products or to substitute fossil fuels and fossil fuel intensive materials with renewable woody biomass.

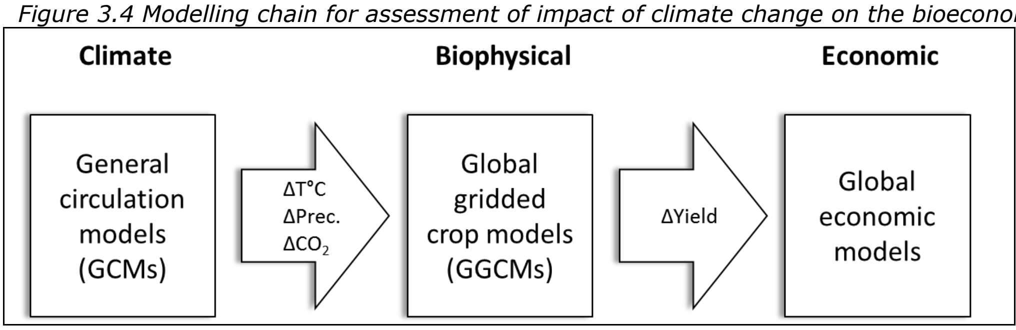
The different mitigation measures therefore require linked or integrated economic and environmental assessments, to assess their costs and benefits, and compare them with fossil-based mitigation technologies in the industrial and energy sectors (carbon sequestration, energy efficiency investments, and use of energy sources with lower emission intensity). Options based on changes in our consumption patterns (food - and indirectly feed, bioenergy) should also be studied, as they influence the overall footprint of the bioeconomy. Changing consumption behaviour could lead to significant emission abatements, not only in Europe but also in the rest of the world, by giving preference to bioproducts with lower emission impacts.

### 3.4.2 Tools framework for analysing climate change related to bioeconomy

Assessing impact and adaptation options in the EU bioeconomy requires a combination of both biophysical and economic tools, able to trace the climatic impact on productivity of the different sectors, but also the consequence for the food supply chain and other bioeconomy product markets in a global framework. When it comes to mitigation policy assessment, interactions with the energy and industry markets are also fundamental features requiring the use of multi-sectoral economic tools, because biomass prices versus fossil fuel prices determine the contribution of the bioeconomy to the overall mitigation efforts.

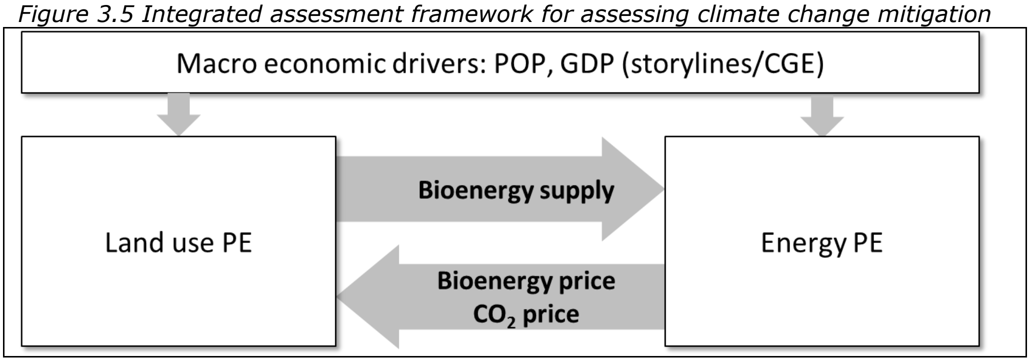
The framework applied in *the Agriculture Model Intercomparison and Improvement Project (AgMIP)* provides a good illustration of the integrated chain of tools that can be used for assessing impact and adaptation to climate change (see Figure 3.4). General circulation models form the first component of this chain: these models simulate, for a given level of GHG concentration, the changes to the current climate to be expected and provides variation in temperature, precipitation, wind patterns, etc. for typical seasons. They can represent the spectrum of probable weather faced by a given region, which can be used to derive impacts on the different bioeconomy sectors. These results, available at different levels of resolution on a global or regional grid, are used as input to a biophysical model estimating the impact on the productivity and other ecosystem services of crops or vegetation in each pixel of this grid. Crop models not only can inform on productivity but can also estimate the changes to plant water and nutrient requirements, the production in some biomass coproducts (e.g. straw). More interestingly, these models can be used to estimate productivity responses of alternative management and propose adaptation options in the face of the changing climate. Biophysical models can also help to look at impacts of climate on the livestock sector, through the effect of climate change on grassland productivity, in addition to change on the feed crop markets. All these results on sectoral productivities from various production technologies and regions can then be injected in a third model in the chain, representing the bioeconomy markets. Such a model is generally a global CGE or PE with a detailed representation of the bioeconomy sectors. The economic model can inform on the final impacts of climate change on production level, and consumption, including some parameters related to food security variables (amount of supply per capita of different nutrients). This latter part of the analysis, focusing on the market level, can also illustrate the extent of possible adaptation, as change in productivity is counter balanced by increase in harvested areas, trade flows and change in consumption patterns. However, not all adaptation mechanisms can be represented in the economic model, and field-level adaptation mechanisms are usually already tackled at the level of the vegetation model. The overall supply chains are therefore particularly adapted to estimate the raw impact of climate change on production, but also to study the overall outcome on the bioeconomy once agents have adapted.

*Figure 3.4 Modelling chain for assessment of impact of climate change on the bioeconomy*




Mitigation policies are more focused on the costs of production alternatives and are usually performed by economic models alone. However, to derive more accurately the exact GHG emissions implications of different production systems, it is usual to combine the economic tools with engineering models, life cycle assessments and biophysical models. Stylized representation of production structures usually rule out the use of macroeconomic or trade models for such analyses. Integrated assessment models are preferred, based on explicit representation of technologies on the supply side, relying on optimisation approaches to describe change in production patterns. Looking at mitigation options requires studying alternative systems in the bioeconomy, but it is also necessary to link the associated sectors to the energy and industry markets, that determine the profitability of the bioeconomy mitigation options. For instance, in the EU, public subsidies on Renewable Energy Sources (RES) play an important role under the climate mitigation policies, while $CO_2$ prices are very low and do not play any active role. These subsidies can interfere with other climate mitigation policies and their economic efficiency needs detailed bottom-up structure to study cross sector interactions. Models used by the Integrated Assessment Models Consortium, usually provide good illustrations of required linkages. PE models of agriculture and land use are operated through direct links with other PE models specialised in energy. Full-fledged CGE model approaches are also used to incorporate the two sectors simultaneously but they follow a top-down approach, losing the direct link to technology and GHG emissions present in PEs. The contribution of multiregional CGE models lies in the indirect effects on other sectors and countries by changes in energy prices and demand for biomass and land. Typical variables that need to be shared by the bioeconomy and the fossil fuel sectors are mainly carbon prices, which can influence land use availability, and energy prices. Figure 3.5 provides an example of exchange protocol between two PEs to study climate change mitigation scenarios. In that case, a land use model takes as an input the price of biomass and the level of $CO_2$ price for the mitigation in the agricultural sector. It then provides in return information about biomass supply for bioenergy and biofuels to the energy model. The two models are harmonised in their macro-economic assumptions through common storylines or additional inputs provided for instance by a CGE model.

*Figure 3.5 Integrated assessment framework for assessing climate change mitigation*




In the EU project VECTORS climate effects on marine ecosystems (especially the North Sea) were analysed and also social and economic impacts assessed (www.vectors.eu).

### 3.4.3 Gaps and further needs

Many uncertainties remain to be addressed to better assess the adaptation challenges for the EU bioeconomy in the face of climate change. The first ones are related to the understanding of climate change patterns. The first tools in the impact assessment chain, general circulation models, are very sensitive to assumptions on atmosphere and ocean energy flux dynamics, in particular with respect to the geographical distribution of climate change patterns. In addition, the magnitude of these changes also depends on the development of future GHG emissions over time, which depends on future scenarios of economic development and technology orientation. As a result, this initial uncertainty on future climate change patterns propagates all along the assessment chain and affects the precision on the final impact indicators. In addition, other components of the assessment chain increase this uncertainty. In particular, vegetation models add to the range of possible impacts, due to knowledge gaps in some of the crops responses to variation in environmental patterns. Time series can help to better understand how yields are affected by temperature and precipitation changes in different locations; however, effects of some other parameters such as $CO_2$ and tropospheric ozone concentration, or pest and propagation of diseases are still to be refined. In forestry there remains a challenge to scale up process-based impact studies at the local and regional level to larger scales. The models which are commonly used to assess large scale policy impacts do not include any mechanistic process understanding of more detailed impact studies and these can only be linked in with very simple response functions. Expected impacts will be highly variable in time and space and this does not easily translate into the market models operating on larger temporal and spatial scales.

Besides the representation of the biophysical impacts of climate change on the bioeconomy, a better description of farmer and forest owner behaviours and available technical options is also required to determine the adaptation capacity of the EU economy. This part is mainly tackled through economic models. Farm and sectoral bottom-up models usually provide a good description of different technological options for production of different products but usually overlook the potential synergies from intersectoral effects (crop rotations, organic fertilisation, intercropping, etc.). Additionally, models need more robust econometric estimates on farmer and forest owner’s responses to price changes and farm payments. For instance, in response to a productivity shock, farmers are likely to increase their production by planting more, using more inputs at a lower cost per unit of output. Increase in market prices can also lead to consumption decrease and reduce the incentives to produce. Data on farm supply and forest owner’s behaviours are then crucial, but available estimates in the economic literature are usually outdated. New estimations of these parameters in various locations in Europe would allow a better understand of the adaptation capacity of the EU bioeconomy. In particular, the potential contribution of Eastern Europe to the EU bioeconomy needs closer scrutiny.

In the field of mitigation, although powerful integrated assessment tools have been set up, they usually suffer:

- either from a lack of details in their representation of the land use, energy and industry sectors and the associated GHG emissions; this is in particular the case of CGEs that have difficulties to represent precise abatement curves based on bottom-up engineering approaches;
- or from a too limited scope as in bottom-up models.

These latter ones can provide more consistent representation of the supply side but usually do not combine a detailed description of the land and the energy sectors at the same time. To overcome these limitations, modellers usually link models together, CGEs with PEs, or sectoral PEs together. But these linkages can be heavy to operate and the modelling approaches to better represent in a single model the different sectors needs further exploration to lead to fully operational tools. In addition, some potential sectors of bioeconomy are still underrepresented in both PEs and CGEs (e.g., biobased chemicals). More efforts on inclusion of these sectors are crucial to explore potential of all mitigation pathways. Accounting of carbon storage in biobased materials in combination with end-of-life strategies/policies is still lacking in current assessments, which only focused on sectors covered by EU policies (e.g., the EU RED only accounts for electricity/heat and transport fuels). Moreover, in the forest sector there is still a need to balance and integrate alternative mitigation strategies of carbon sequestration in living biomass, biobased materials, and substitution of fossil carbon through renewable materials and energy, as these mitigation strategies depend on conflicting management regimes.

From a data perspective, more work is also needed to estimate the cost of different options of adaptation and mitigation. Transaction costs and institutional constraints are often overlooked, whereas they strongly determine the adaptation and mitigation potential. Costs need to be better assessed at a farm level, through data collection and use of detailed economic accounts. But non-economic information also needs to be gathered for different management options. Beside costs for the farmer, some other indicators matter for the EU bioeconomy as a whole, such as food security, protection of biodiversity, water resource protection, etc. These externalised costs need to be better integrated to the assessment of adaptation and mitigation options for the bioeconomy. This implies a better representation of these dimensions in economic models on the base of collected data, and a larger use of multi-criteria assessment techniques.

## 3.5 Creating jobs and maintaining European competitiveness

### 3.5.1 Background and importance of issue

Competitiveness pertains to the ability and performance of the (regional) bioeconomy sector to generate income and employment. Competitiveness is a relative concept and can be used to describe:

- the ability and performance of the bioeconomy compared to its fossil-based counterpart sectors in the same region and in other regions;
- the ability and performance of the bioeconomy compared to its international competitors
- its ability to take account of negative externalities such as $CO_2$ emissions, energy use, cultural landscape and biodiversity.

The competitiveness of the bioeconomy sector is thus a multi-criteria outcome. It is the combination of a smart set of criteria and indicators that determines whether the bioeconomy sector will enable to generate long-term income and jobs:

- cost and returns of the fossil based chemical sector versus the biobased chemical sector;
- cost and returns of the fossil based energy sector versus the biobased energy sector versus the renewable energy sector;
- cost and returns of traditional users of biomass: food processing, paper and pulp, textile;
- availability of sufficient sustainable biomass: domestically produced or imported;
- infrastructure such as location of the region: is their mainport with option to import raw materials? Have inland regions option to use own resources such as cheap land and labour?
- regulations and policy setting: certification, coherent policy, regional development policies;
- access to innovation: technology diffusion
- access to financial system: availability of private and public funds;

- quality of workforce: population with tertiary education.

The EC considers the bioeconomy as a key component for smart and green growth, and identified that access to energy and raw materials at affordable prices is one of the priorities that should be pursued to support the competitiveness of the industry and the bioeconomy in the EU. The number of green jobs and rate of green growth can be increased by, for example, stimulating the sustainable intensification of primary production, the conversion of waste streams into value-added products, and the mutual learning mechanisms for improved production and resource efficiency.

On the (regional) industry level, the willingness of companies to move from a linear (fossil based) to a more circular and biobased production system mostly depends on the cost efficiency of biobased technologies relative to their fossil counterparts. Before deciding to adopt a sustainable strategy and to innovate and investment in green production technologies, sectors need insight in the long-term competiveness of those new technologies. This requires a comparison of the contribution of sustainable versus their conventional (fossil based) production methods to sectoral turnover and value added. First, industries need insight into factors that determine the competitiveness and/or profitability of new and existing technologies in the long run. Second, they need insight which location (in own region, elsewhere in country or abroad) is most profitable, taking into account the availability and prices of biomass and resources like land, (skilled) labour and capital. The decision of a company to build a new plant in another country, instead of in the own region, has regional employment and economic growth (value added) implications.

So far, several studies attempted or are attempting to determine the size of the bioeconomy, to identify relevant economic mechanisms, and whether new technologies will become competitive with the fossil based economy. The availability of sufficient data about the biobased side of the economy is an important requirement for a meaningful competitiveness analysis, for now and for the future. In 2009, the new biobased industries had a relatively low turnover (about 57 billion euro) compared to the more than 2000 billion euro generated by the whole bioeconomy. It should be mentioned that the quantitative information is only based on expert estimations, and is thus of limited reliability. These qualifications of the numbers emphasize the need for introducing a data and modelling framework that enables the monitoring and evaluating the competitiveness of the EU bioeconomy on the short, mid and longer terms.

*Table 3.2 Turnover and employment of bioeconomy sectors in Europe, 2009*

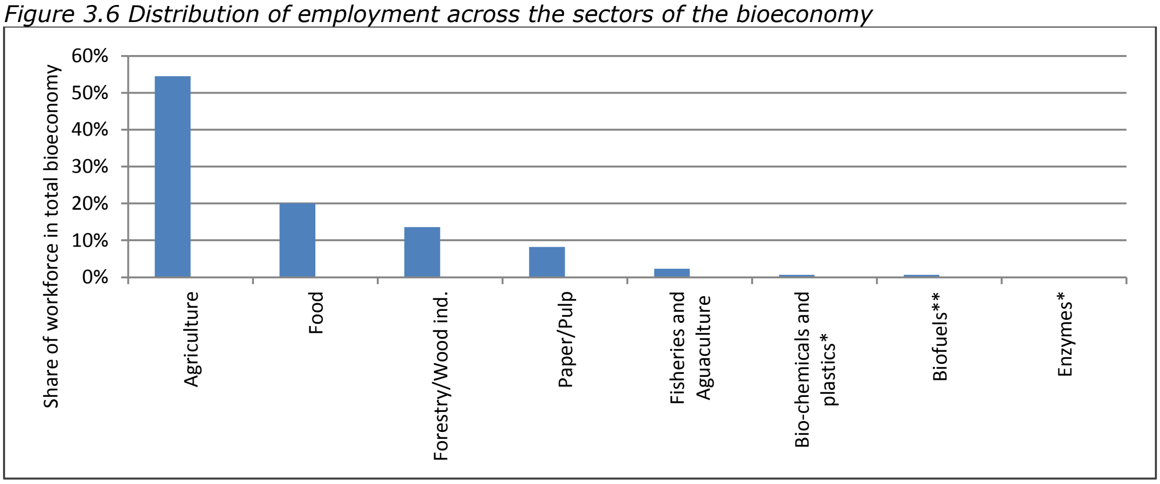
| | Turnover (billion euro) | Employment (1000 fte) |
|---|---|---|
| Food | 965 | 4400 |
| Agriculture | 381 | 12000 |
| Paper/pulp | 375 | 1800 |
| Forestry/wood incl. | 269 | 3000 |
| Fisheries and aquaculture | 32 | 500 |
| Biobased industries | | |

| | | |
|---|---|---|
| - Bio-chemicals and plastics* | 50 | 150 |
| - Enzymes* | 0.8 | 5.0 |
| - Biofuels* | 6.0 | 150 |
| Total | 2078 | 22005 |

Source: Clever Consult, 2010; *estimates for Europe for 2009.

The bioeconomy is an important source of employment in the EU. The bioeconomy sectors in the EU cover about 22 million people employed, which amounts to 9% of the EU´s workforce. Quite some variation can be found across the sectors that belong to the bioeconomy, as can be seen in Figure 3.6, mostly when it comes to make a distinction between the contribution of traditional biobased sectors (agriculture, fishery, forestry, food and feed processing, paper and pulp) compared to the new biobased sectors, like chemistry, transport and energy). Over half of the number of employees of the total bioeconomy in the EU can be attributed to the agricultural sector. The food, forestry and the wood industries cover shares roughly between 15% and 20%. Fisheries and aquaculture, biochemicals and plastics and enzymes as well as the biofuel industry currently play a quite limited role in terms of employment within the bioeconomy.

*Figure 3.6 Distribution of employment across the sectors of the bioeconomy*




*Source: European Commission, 2012, Innovating for Sustainable Growth*

The bioeconomy is regarded as a focus area for boosting the regional development in Europe, in the sense of providing jobs and value added. In light of technical progress and the emergence of new players on global markets, structural change takes place in the sectors of the bioeconomy. In the agricultural sector for example, labour input in the EU has decreased by over 30% since 2002[5] and is expected to decrease further in the future (SCENAR2020 I and II). In the fishing sector there is no clear trend in employment. A small reduction was observed, but overall the sector depends more on the available fishing opportunities and there we see some improvement over the last five years.

Over the last 25 years, the Common Agricultural Policy (CAP) has changed fundamentally from market price support to income support, which implies fewer incentives to increase agricultural production. The

[5] How many people work in agriculture in the European Union? EU Agricultural Briefs No. 8, July 2013.

EU is a large biomass importer (e.g. tropical beverages, animal feed and increasingly wood chip for bio-energy). Our biobased exports are high value added products, like wine and specialty foods. The growing world population, global economic development and the accompanying increasing need for food and forest products provide opportunities for the bioeconomy sectors in the EU. International competitiveness is a requirement for a sector to provide job and income opportunities. At the same time, labour costs influence the competitiveness of a sector directly. Hence, to be competitive in economic terms and at the same time to create and maintain jobs will be the challenge for the European bioeconomy. Also, side effects on externalities, such as CO2 emissions and energy use (in PJs) must be taken into account.

### 3.5.2 Tools framework for analysing economic competitiveness related to bioeconomy

Variables and indicators that can be used to monitor competitiveness of a sector are for example changes in trade balances (exports of a commodity indicate competitiveness on international markets) or development of market shares. Also, the change in turnover and value added of (biobased) sectors relative to other (fossil-based) sectors can be used as an indicator for competitiveness (see Deliverable 2.1).

To evaluate and measure the impact of the bioeconomy on economic competitiveness, changes in value added, the employment rate, the number of jobs or job creation in skilled and unskilled labour, household income, wage rates and trade balances need to be considered (see Deliverable 2.2). Models allowing for the analysis of economic competitiveness and labour market developments need to cover the interplay between the drivers working in the same or opposite directions. The coverage of the models needs to be broad enough to capture inter-sectoral effects (e.g. the movement of labour from the agricultural into industrial sectors) as well as developments on international markets (e.g. increasing competitiveness of the emerging economies on agricultural market) and international trade.

CGE models are one class of models that can be used to assess the impact of the bioeconomy on competiveness and employment. The strength of CGE models is their comprehensiveness in terms of key economic relationships, including market price adjustments and associated changes in terms of trade, market balances as well as impacts on labour, land and capital markets. This comprehensiveness comes at the cost of the level of detail: CGE models typically represent the economy at a high level of aggregation. Many CGE models cover the ´traditional´ sectors of the bioeconomy quite well, i.e. in particular agriculture, forestry and fisheries, paper and pulp, and textiles. The possibility to analyse advanced options of the bioeconomy (e.g. modern biomaterials) or alternative feedstocks and resources (e.g. wheat straw, switch grass and palm oil residues) are rather recent developments in the research community and are not standard features of CGE models[6]. Aggregation is typically also quite high in the spatial dimension, confining the possibility to evaluate regional and local effects of the bioeconomy on competitiveness and employment with CGE models (see Deliverable 2.3). Typically, CGE models assume full employment of all factors of production, including labour. This assumption would have to be relaxed in order to full capture changes in the employment (and un-employment) levels, in response to a transition from a fossil-based to a bio-based economy.

PE models that cover only certain sectors of the economy are much more flexible in incorporating a large amount of detail in the representation of processes. PE models could be useful for all sectors that belong to the bioeconomy (from agriculture to energy to chemistry). They can be designed in a way that regional and even local effects are captured. This can be of interest when the impact of the bioeconomy on local wages and employment opportunities (e.g. in rural or coastal areas, in which other job opportunities are scarce) are an issue. The trade-off for providing this level of detail and at the same time ensuring manageability of both the database as well as the model itself is the more narrowly

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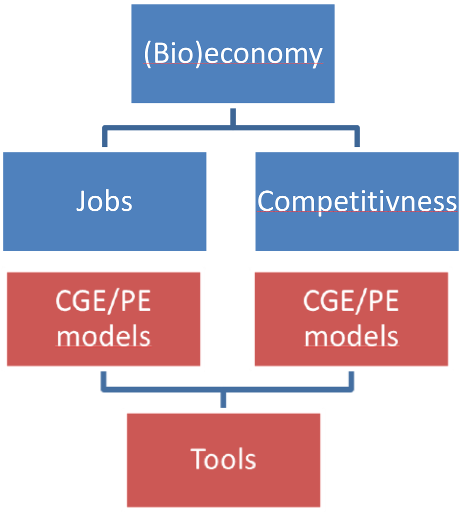
[6] Some recent advances have been made with regard to a broader representation of bioenergy in some GTAP model versions, introducing ethanol, biodiesel and their by-products (Banse *et al.* 2011, Laborde 2011), the agricultural residue corn stover, and the energy crops switchgrass and miscanthus for second generation ethanol production (Taheripour *et al.* 2013), palm oil residues (Van Meijl *et al.* 2012), wheat straw (Smeets *et al.* 2015). At this moment the MAGNET CGE model is being expanded in collaboration with the EC JRC with several new biobased sectors (second generation biofuels, bioelectricity, biochemicals) and biomass supply sectors (sector that collects agricultural residues, sector that collects forestry residues and a sector that pretreats agricultural residues).

defined sectorial scope of PE models or the lack of the representation of factor markets. Especially the latter is a severe constraint when job creation and maintenance are in the centre of interest (see Deliverable 2.3).

For both PE and CGE models the modelling of land use is a crucial aspect for the competitiveness and sustainability of the bioeconomy. If a land abundant country is able to extend its land easily it can produce more biomass without increasing the production costs. In a land scarce country additional production of biomass, and therefore additional demand for land, leads to an increase of prices of land and agricultural products. Modelling land markets is however difficult, as good quality data for land prices and land quantities are scarce. Especially the potential amount of agricultural and forestry land, the quality and potential of that land, and the mechanisms that cause deforestation and other types of land use change are uncertain and difficult to model. Furthermore, institutional factors determine the functioning of the land market, which can be region specific.

Input-Output (I-O) analysis is another powerful tool that can be used to assess the impact of a change in the demand conditions for a given sector in a given economy, including the bioeconomy. It is useful for short term descriptive analysis and as an indicator of likely bottlenecks that may occur in a growing economy. However, the assumption of constant prices and the fact that I-O analysis does not allow for substitution between inputs are severe shortcomings that restrict their suitability for questions of competitiveness and employment creation and maintenance (see Deliverable 2.3).

*Figure 3.7 Tools for measuring jobs and competitiveness related to the bioeconomy*




### 3.5.3 Gaps and further needs

Evaluating the competitiveness, employment effects and other economic impacts using the tools in the SAT-BBE analyses framework requires further refinement of models and tools and also the use of specific data, which need to be sufficiently disaggregated into sectors and regions. Economic data about advanced and innovative biobased sectors and its potential economies of scale, such as modern biomaterials and bioenergy is scarce. This is also the case for data on employment, turnover, input and output prices, value added generated by these sectors, especially when it comes to regional and local level. Also, statistics must be extended with information about the prices and origin of especially new biobased feedstock, such as agricultural, forestry, and industrial biomass residues. Evaluating the impact of the bioeconomy on employment, wages and the movement of labour between sectors can only be assessed with sufficiently detailed quantitative models. Many other social aspects of employment are more region or site specific, such as child labour, minimum wages, labour rights, secondary employment benefits (e.g. health insurance, pension) and are not covered by official statistics and thus not well reflected in economic models and tools (Table 3.3). For example, regional bioenergy supply chain development based on currently under-utilized forest biomass could be limited by the availability of skilled labour, as the job requirements might not fit the skills and education level of the regional labour market. This could be especially problematic in rural areas that are characterized by an aging population. As mentioned before, the typical assumption of full employment of labour that is present in economy wide models would have to be relaxed in order to assess the impacts of bio-based industrial development on labour markets and the rate at which they create new (or lose existing) jobs.

*Table 3.3 Suitability of tools for evaluating the impact on employment and competitiveness and steps for improvement*

| Tool | Suitable to evaluate the bioeconomy´s impact on jobs and competitiveness? | Steps needed to improve the tools´ analytical ability |
|---|---|---|
| CGE models | Yes, with limitations | - Provision of more detailed data (e.g. input for bioplastics, bioenergy or renewable energy)<br>- Disaggregation of sectors |
| PE models | Yes, with limitations | - Provision of more detailed data (e.g. input from agriculture for bioplastics)<br>- Inclusion of further sectors (e.g. energy sector)<br>- Linkage with other PEs (e.g. agricultural sector models *versus* energy market models *versus* chemical market models) |

The steps needed to improve the analytical capabilities of existing models can be divided into two broad categories. First step deals with the data provision, and the second step regards the adjustment of existing tools to the new data. The first step involves new and more detailed collection of data, e.g. for biomass use for energy purposes and biomaterials, use of waste and residue materials as well as biological resources for industrial use. In a second step, the existing tools need to be enlarged and adjusted to the new data base. In case of CGE models, this may involve the disaggregation of existing sectors. For PE models, it may also involve the disaggregation of existing sectors, but also broadening the sectorial scope of the model to new sectors. This may be necessary for instance to better reflect the increasingly important link between energy and agricultural markets, or between energy and wood markets. In most cases, the parameterisation of the models needs to be revised and adjusted to the new sectorial coverage. For both PE and CGE models the modelling of land use remains a challenge but is very important for the competitiveness of the bioeconomy. Data on land quality, land availability, land prices and conversion costs are key next to detailed knowledge of institutional factors.

Summarizing it can be stated that data on biobased sectors is available only to a limited degree in the economic accounts of European countries, which in turn is the base for the generation of Input-Output tables that are used in PE and CGE models. Especially, information related to biobased oriented plantations, residues, new biobased chemical and bioenergy sectors is scarce. This is a quite crucial omission, as it is these sectors where the new bioeconomy is expected to take place. Extension of Input-Output tables with more detailed biobased sector data (similarly as it has been desaggregated to present the heterogeneity of agrofood sectors) will improve the usefulness and reliability of the results from these models regarding the current and future monitoring of the bioeconomy. Further, it will reflect the new organisational structures established in the bioeconomy, such as the linkages between agrofood sectors with the bio-energy and bio-chemistry.

# 4. Systems Analysis Tools framework of the EU bioeconomy

The focus in this section is on the linkages between the societal challenges and the tools needed to address these challenges in a systemic way. This is done based on the conceptual framework presented in Chapter 2 and on the sections about the societal challenges (Chapter 3). Section 4.1 begins with the policy perspectives behind the research questions linked to the bioeconomy in relation to the main societal challenges. Section 4.2 presents the data, indicators and models in the systems analysis tools framework that are helpful to measure the performance and progress of the bioeconomy, and that take account of environmental, economic and societal disciplines. Section 4.3 summarizes to what extent these tools are suitable for monitoring and evaluating the progress towards a sustainable bioeconomy in the EU, and where data and models need further development, improvement and/or extension.

## 4.1 Policy perspectives

In the previous sections the complex relationships within the bioeconomy and between biobased and non-biobased sectors in the economy, and within the integrated economic, social and environmental systems are discussed. The framework developed in the SAT-BBE project must have sufficient analytical capacity to capture these complex relationships that are required for answering a broad range of bioeconomy linked policy questions.

Below we address a series of policy relevant questions, which relate to analysing the progress of the aforementioned societal challenges in relation to the bioeconomy, and that are then used as basis when designing the SAT-BBE framework.

- *What is the impact of the biobased economy and bioeconomy supporting policies on food security?* Food security is an important dimension of human well-being, and should be included in any assessment of how societal benefits might change with the evolution of a knowledge-based bio-economy. Both the bioeconomy and food security are complex concepts. The SAT-BBE framework can be used to provide insight in food availability, but also in other aspects of food security, such as affordability (i.e. access), stability and utilization. Paying attention to all the four 'pillars' of food security (availability, accessibility, stability, utilization) is required to evaluate the net impact on food security. This also requires insight in how negative impacts on food security can be avoided and positive impacts can be stimulated, for e.g. the sub Saharan Africa region.

- *How could reducing food waste in the food chain contribute to depletion of limited natural resources*?

- *What are the impacts of the biobased economy on the use of natural resources, biodiversity and ecosystem services?* While also competing with food production, the impacts of the biobased economy also causes trade-offs on other societal demands for services based on scarce land and water resources. Trade-offs of developing the biobased economy on biodiversity and ecosystem services have to be evaluated in the context of demand and social values assigned to these. Only by evaluating these in the context of clear-cut targets set for minimum levels of the provisioning of such services a careful evaluation of model outputs is possible.

- *What are the impacts of post-2020 energy policies for the use of biomass by energy and chemical sectors?* Insight required on the role and contribution of synergies between energy and industry sectors, optimal uses of biomass and attainable savings in fossil energy. To date it is unclear if and to what extent biobased materials can contribute to reducing the system's fossil energy demands, despite the significant non-renewable energy use savings they demonstrate on life cycle assessment studies.

- While the bioeconomy offers substantial opportunities to contribute to climate change mitigation, it is at the same time directly affected by the impacts of climate change on the land and water resources. There are still substantial uncertainties linked with projecting climate change impacts and dealing with these uncertainties is a major challenge when guiding land resources management. Adaptation to climate change needs to be planned well, and particularly forestry with its long production cycles needs to account for future changes in the environmental conditions already today. The connections between the drivers and responses are complex and therefore necessitate a comprehensive systems analysis framework.

- *How can coherent policy contribute to the development of the bioeconomy*? Current policy schemes such as the RED exclude biobased materials from their provisions. This has created an uneven playing field between the different possible uses of biomass. It is important to move to the direction where all uses of biomass and their contribution to EU societal challenges can be simultaneously addressed.

- *What are the impacts of government regulations (e.g. on agriculture, food, energy and waste, on climate, on trade) on the composition and development of the bioeconomy?*

- *How can the bioeconomy boost regional development?* Must give insight in targeted innovation and financial schemes aimed to support the transmission from a fossil based to a bioeconomy in terms of green job creation, regional and sector competiveness, economic growth and improved quality of life and sustainable development.

- *What is the socio-economic competitiveness of the EU Bioeconomy?* Must provide insight in the gross and net employment and macro and sectoral value added effects of the bioeconomy? Can the number of green jobs and green growth be enhanced by stimulating the sustainable intensification of primary production, the conversion of waste streams into value-added products, the mutual learning mechanisms for improved production and resource efficiency? Taking into account rural employment potential of agro-tourism and rural recreation in order to foster non-provisioning ecosystem services such as water filtration, biodiversity and cultural landscape.

- *What are the impacts of the biobased economy on the use of natural resources, biodiversity and ecosystem services?* While also competing with food production, the impacts of the biobased economy also causes trade-offs on other societal demands for services based on scarce land and water resources. Trade-offs of developing the biobased economy on biodiversity and ecosystem services have to be evaluated in the context of demand and social values assigned to these. Only by evaluating these in the context of clear-cut targets set for minimum levels of the provisioning of such services a careful evaluation of model outputs is possible.

## 4.2 Models in the systems analysis tools framework

### 4.2.1 Models and indicators for analysing societal challenges

In general, models focus either on the socio-economic, technical or environmental system, or simplified representations of integrated systems, based on a combination of these rationales:

- Modelling focused on the socio-economic effects is generally based on demand and supply curves and is used for evaluating the impacts of policy interventions (e.g. tariffs or subsidies) and making market forecasts about the economy as whole or specific sectors. Tools include e.g. computable general equilibrium (CGE), partial equilibrium (PE) models, and other economic models spanning the micro level (e.g. firms, households) to the macro level (e.g. Input-Output). This modelling group also captures aspects that belong to the social domain, like depicting food security, household income, demands and supply of human capacity and jobs;
- Modelling focused on environment impacts generally aims to monitor natural ecosystems and run simulations to mimic or predict bio-physical processes and identify problems. Methods include e.g. biophysical modelling, land change modelling and impact assessment and can focus on the micro level (e.g. farms and forest stands with crop simulation models) to the global level (e.g. with Earth system models);
- bottom up analyses are especially useful to provide detailed technical and economic inputs (e.g. cost structures, breakeven points) to the PE, CGE and more complex Integrated Assessment

Models (IAMs) that consider the new bioeconomy sectors. This includes detailed life cycle analyses to assess GHG emissions. At the same time, bottom-up analysis is used to understand the local implications and responses to implementation of the biobased economy. Such local responses are often poorly represented in the large scale global assessments and are essential to understand the impacts in sufficient detail;

- Integrated Assessment Models (IAM) are used to link models built with socio-economic rationale to those built with environmental rationale and to link different scales of analysis. They provide the longer run picture and interaction with biophysical processes (e.g. climate change). Integrated impact assessments bridge furthermore across the economic, social and environmental dimensions of bioeconomy developments.

Table 4.1 provides a better understanding of these approaches, by discussing their main applications, insights, and their strengths and limitations with respect to the assessment of biomass supply and impacts.

*Table 4.1 Overview of four modelling approaches for assessing biomass supply, demand and impacts: Their applications, typical timeframes, key strengths, and limitations*

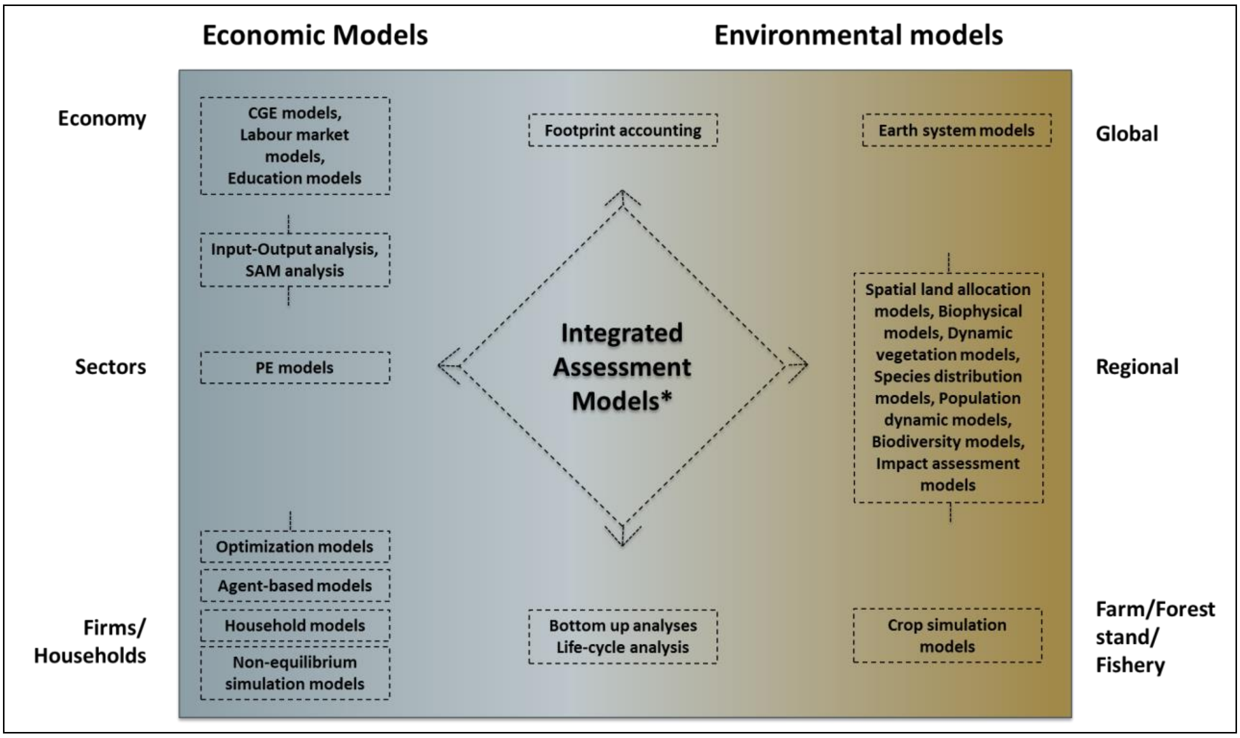
| | CGE models | PE models | Bottom-up analysis | IAMs |
|---|---|---|---|---|
| **Application** | Economy-wide impacts of biomass and bioenergy policies, including subsequent effects on land-use change and GHG emissions induced by these policies.<br>Indirect substitution, land use and rebound effects due to multiple sectors and production factors | Sectoral impacts of bioenergy policies on agriculture, forestry, land-use change, energy system and GHG emissions | Wide variety of specific (technical) aspects of biomass production, conversion and use.<br>Validation of other studies with a broader scope, such as PE and CGE models, and IAMs | Bioenergy resource potentials under different assumptions (incl. sustainability criteria).<br>Possible contribution of bioenergy to long-term climate policy.<br>Impacts of bioenergy policies on global land use, water and biodiversity |
| **Typical timeframe** | Short to long term | Short to medium term | Short to long term | Long term |
| **Strengths** | Comprehensive coverage of economic sectors and regions to account for interlinkages.<br>Explicit modelling of limited economic resources.<br>Measuring the total economy wide and global effects of bioenergy policies (including indirect and rebound effects) | Detailed coverage of sectors of interest with full market representation.<br>Explicit representation of biophysical flows and absolute prices.<br>Usually more details on regional aspects, policy measures and environmental indicators | Detailed insights into techno-economic, environmental and social characteristics and impacts of biobased systems | Integrating different relevant systems in one modelling framework.<br>Possibility to analyse feedbacks between human and nature systems, and trade-offs and synergies of policy strategies.<br>Built around long-term dynamics |
| **Limitations** | Level of aggregation that may mask the variation in the underlying constituent elements.<br>Scope of CGE models necessitates simplified, representation of agent choices, in particular favouring smooth mathematical forms and reduced number of parameters required to calibrate the models.<br>Often no or little explicit representation of quantities for biophysical flows | Optimization of agent welfare, but only the sectors represented in the model.<br>No consideration of macroeconomic balances and impacts on not-represented sectors.<br>Need large number of assumptions for long-term projections<br>Do not deal with | No inclusion of indirect and induced effects outside the boundaries of the study, i.e. often deliberately ignore interactions with other sectors | High level of aggregation or too complex systems.<br>Unsuitable for short-term assessments.<br>Large number of assumptions (and the communication of these to the public) |

| | | |
|---|---|---|
| | Do not deal with market failures wrt unemployment, price volatility, land management | market failures wrt unemployment, price volatility, land management |

Source: Wicke et al. (2014)

Figure 4.1 depicts the wide array of models, which are introduced earlier in this report, and that are needed to integrate multiple scales and dimensions of the bioeconomy into one systemic framework and it shows how the different model types introduced above can be used to monitor the impacts and evolution of the bioeconomy. Grouping models is difficult as there are many overlaps among model types and categories and many models address multiple scales of analysis. As such, Figure 4.1 should be interpreted for illustrative purposes only. A more detailed description of models is available in Deliverable 2.3. Note that Integrated Assessment Models (IAMs) not only link models built with socio-economic and environmental rationale and different scales of analysis, but also link models from different disciplines and fields of research (e.g. climate, energy and water related models). This schematic focuses on models related to land use and land change from e.g. agriculture and forestry disciplines.

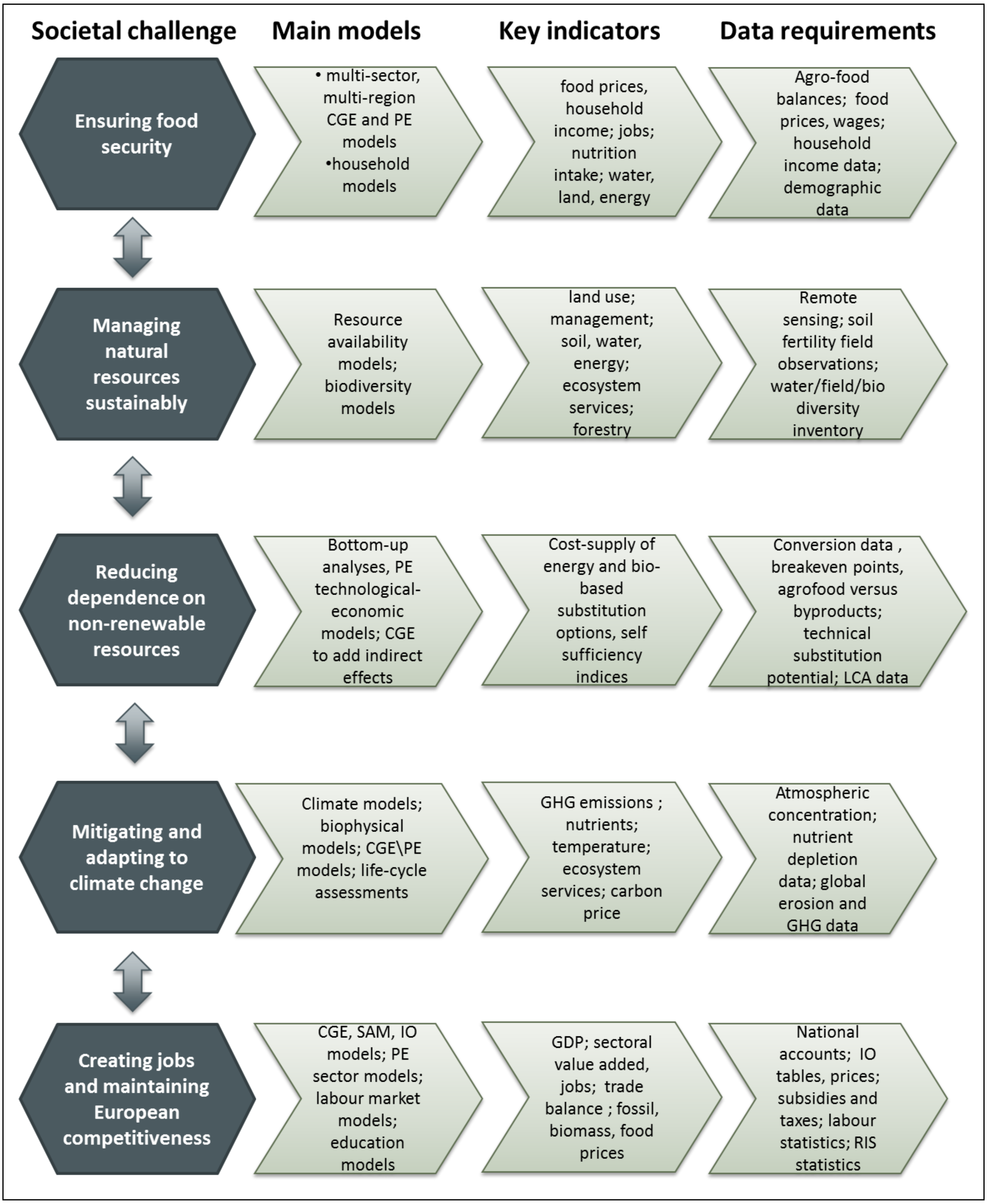
*Figure 4.1 Overview of model types and groups presented in this report*




*Source: SAT-BBE consortium*

Figure 4.2 provides an overview summary of the models, indicator and data requirements relating to the five societal challenges of the Bioeconomy Strategy. It is based on the extended descriptions provided in Chapter 3. One of the challenges is combining the different model types and indicators to assess the synergies and trade-offs between the societal challenges in one assessment framework. To this end the Driver Impact Response (DIR) framework is applied, as explained in Chapter 2.

*Figure 4.2 Models, indicators and data needs per societal challenge of the Bioeconomy Strategy*

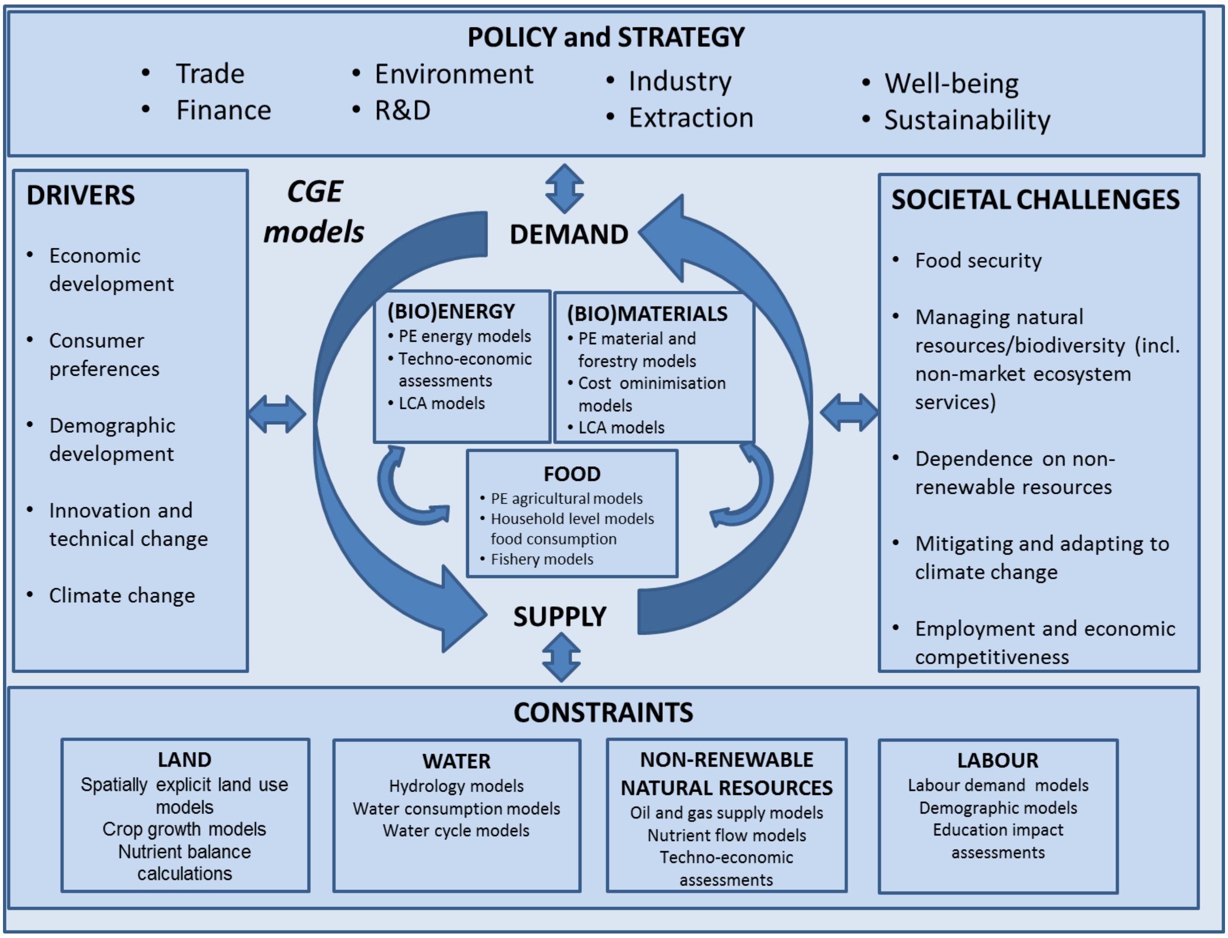



*Source: SAT-BBE consortium*

As the development of the bioeconomy is a complex systems change, the SAT-BBE framework must support stakeholders to identify all correlations that are relevant for understanding the progress and impacts of the bioeconomy. Figure 4.3 is an integration of the information from Figure 4.2 into the conceptual supply-demand systems analysis framework for the bioeconomy presented by Figure 2.1 (page 10). In a nutshell, for describing and assessing the bioeconomy in the EU, and to analyse its trade-offs and synergies with the fossil based economy, the data and models needed in the systems analysis framework is structured as a linkage of five blocks:

- *drivers* (left box in Figure 4.3): expressed by indicators, used as exogenous input for models; Input can be based, for example, on bottom-up analyses, demographic models or projections and climate change models or projections.
- *constraints of natural resources and labour* (bottom box); resource availability models and biophysical models addressing the state of natural ecosystems and tipping points;
- mechanisms and correlations of demand and supply of biomass (centre): multi-sector and multi-regional framework of CGE and PE models;
- *impacts on the societal challenges of the bioeconomy* (right box): expressed by indicators and targets, that measure the objectives of challenges; these indicators and targets are either the output of respectively CGE models, PE models, IAMs, resource models and (non-model) assessments and calculations or the basis for sustainability scenarios in e.g. back casting approaches;
- *policy, management and strategy responses* (top box): expressed by indicators, used as exogenous input for models.

*Figure 4.3 Systems Analysis Tools (SAT-BBE) framework for the bioeconomy*




*Source: SAT-BBE consortium*

On the economic side, the heart of the SAT-BBE tools framework consists of a combination of PE sector models, multi-sector, multi-regional CGE models (see Annex 1 for description) and other (non-model) assessments, capturing the interaction of regional markets of both the fossil based economy and the biobased economy. In general, PE models focus on the three main competing markets of the (bio)economy: food (agricultural), (bio)energy and (bio)materials. Implicitly, they consider the markets they depict as having no effects on the rest of the economy. This missing element (gap) is filled by linking the PE sector model results to multi-sector CGE models, that measure the impacts for the whole fossil based and biobased economy, while keeping the detailed representation of specific sectors in PE models.

The pathway of the transition from the current fossil based economy towards a sustainable bioeconomy (including energy and materials) is influenced by system and policy drivers, which are expressed by indicators (e.g. population growth, degree of technology, sugar quota policy). These indicators will drive the models, and their values are used as exogenous input values for the CGE and PE sector models in the centre of the SAT-BBE framework. A linked system of food, energy, and material markets (including forestry) operated by the models in place - competes for the demand for both biobased and fossil based resources, taking into account the status of drivers and policy instruments. On the other side, the availability of biomass and fossil supplies is constrained through endowments (production factors), such as land, water, non-renewable natural resources and human capital. The availability of these resources is measured by, respectively, land models, water models, energy models, and labour market models.

### 4.2.2 Operational relationships among models

Currently, there is no aggregate 'super model' that provides a meaningful description of the functioning of the bioeconomy in relation to the rest of the economy. Even if such a super model would exist it probably would be insufficiently detailed and have insufficient flexibility and legitimacy across the disciplines to address the rapidly evolving questions in the field of the bioeconomy.

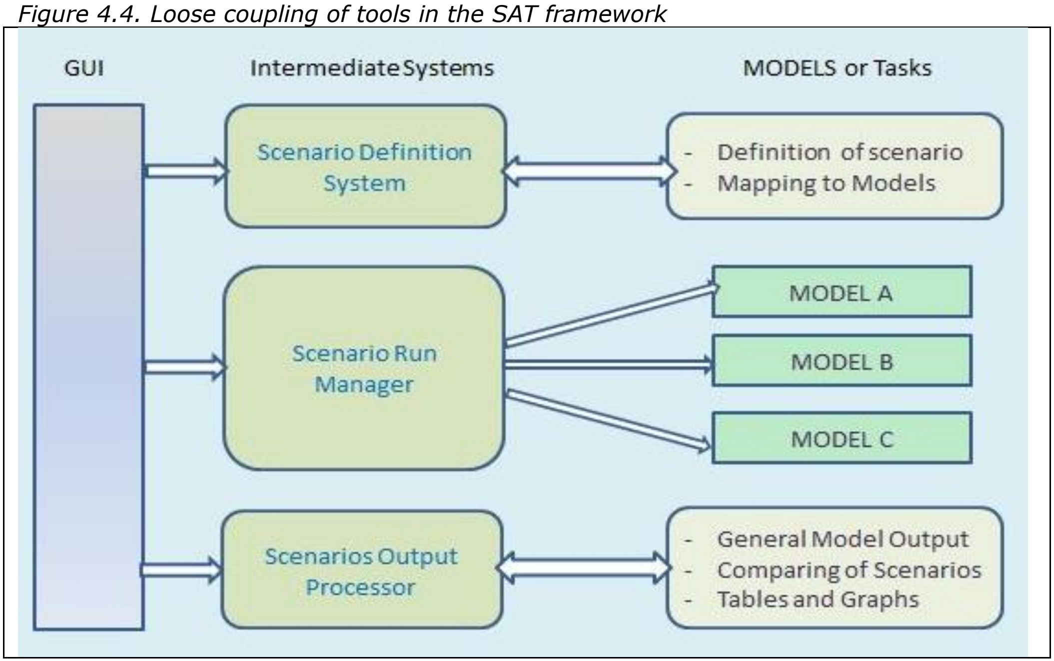
Therefore, the SAT-BBE framework (Figure 4.3) consists of a range of models, indicators and other (non-model) assessment methods (tools) in the environmental, economic and social domains. To make its linkages operational, certain levels of user interfaces are helpful (see Deliverable 3.2). Normally, user interfaces are designed to facilitate access to data and models, and hereby bear potential to increase the efficiency and transparency during the research and dissemination activities. This is also relevant for the SAT-BBE framework, which includes different tools. These roughly correspond to three groups of user interfaces:

- interfaces to get access to statistical databases (e.g. Bioeconomy Observatory, Geo-wiki platform, Data M), with a relative broad user group;
- interfaces that give access to individual model analyses and its outcomes: e.g., for CGE economic models (e.g. Magnet and Mirage), PE models for agrofood sector (e.g. Globiom, Agmemod, Capri). Its user group is mostly focused to a specific group of researchers;
- interfaces to make integrated model results accessible for policy analysts and other non-specialist users (e.g., Eururalis, Seamless, Agmemod, Image and Impact).

The last two types of interfaces are relevant in order to make the SAT framework operational for researchers from different disciplines, as well as end-users of the tools output such as policy makers or other (non-researchers) stakeholders.

When it comes to the architectural design of an integrated group of tools, the software concept of loose coupling or soft linking of modules is a way to operationalize the SAT-BBE framework. Soft links imply that models are connected exogenously by transferring the outcomes of scenario model runs from one component or model to another and hard links mean that models exchange information and are solved iteratively, meaning that the solutions are internally consistent between models. A graphical user interface (GUI) can be used as a 'translation module' among the various model types in the framework. This GUI is model independent, and can be linked to intermediate operation systems such as a scenario definition system, the scenario run manager and the scenario output processor (Figure 4.4). This is a feature which makes researchers and/or modellers independent of respectively the GUI, and all other modules and models in the system. Loosely coupled systems have the additional advantage that they tend to build more quickly and also can be maintained, reused and scaled more easily (Krause 2006)[7].

*Figure 4.4. Loose coupling of tools in the SAT framework*




*Source: SAT-BBE consortium*

The interfaces between the GUI and the model(s) are controlled by meta-information files, batch files and intermediate managers to process the run-off of the models. The GUI can run on top of any (set of) model(s). It allows defining new scenarios, inheriting from previous ones, running those scenarios, and if needed run all defined scenarios in a row. Furthermore, tables, graphs and maps can be generated with the GUI, or could be connected to more specialized visualization software. Tables and graphs are presented by a multidimensional graphical interface, which allows exporting results towards a variety of formats like Word, Excel, Gdx. All the dimensions of the research questions to be analysed (sectoral, geographical, temporal, scenarios) with the SAT-BBE framework outcomes are captured by this combination of interfaces. More information on GUI and linking of models can be found in Deliverable 3.1 and Deliverable 3.2.

## 4.3 Gaps and further research needs

Figure 4.5 highlights the data gaps and model needs for better understanding how the bioeconomy contributes to each of the societal challenges. It presents key messages from the descriptions in Chapter 3 and points in particular to the need for more detailed data regarding technologies, prices, employment, actors and spatial resolutions. It is also evident that one of the key challenges is linking the models in an operational, transparent and systemic way.

[7] Krause, A. (2006). *Einführung eines GIS für die Landwirtschaftsverwaltungen der BRD auf Grundlage EU-rechtlicher und nationaler Verordnungen*. Stuttgart: Ibidem

In the case of **model collaboration,** the collaboration can take many different forms[8]:

- the mere alignment and harmonization of models related to input data and scenario definitions;
- a close comparison of models in order to make systematic studies of methods, sensitivities, assumptions and results; and
- a linkage or integration of models, where models are either loosely or tightly-coupled together.

The latter has the highest level of computational intensity and research design complexity, making it also the most challenging and time-consuming. That said, it may also be one of the best ways to illustrate the critical feedbacks and interactions between the socio-economic and biophysical elements that characterize the wider bioeconomy and its evolution, depending on the research questions, e.g. hard linked model collaboration may not be ideal for all research or policy questions.

The main entry points for linkages between models are prices or quantities (see Deliverable 3.1). Prices allow the analytical tools to represent socio-economic welfare changes (or impacts) that a non-economic model would not be able to capture. The presence of prices also enables the flow of payments, revenues or transfers within the economic network of actors to be represented, and can provide useful points of comparison with which to judge the compatibility of the modelling tools, in terms of their economic, market-driven responses. Quantities refer to produced and consumed goods, as well as the factors of production that are required. Such quantities – production, consumption, trade, water volumes, and land areas – can also be used as 'shifters' that allow the endogenous results of one model to drive changes in the exogenous components of another model. Some important aspects of the bioeconomy, such as land and energy, can be linked either through the prices or the quantities that are simulated, whereas other aspects like water availability might be challenging to price directly, although the quantities can be more easily observed and measured.

The linkages between global and regional models is somewhat more straightforward, given that the global models can 'impose' the prices or quantities that are treated as exogenous or belonging to the 'rest-of-the-world' in the regional models – and thereby provide a direct linkage through endogenizing the changes of these factors. The linkage of one global model to another, on the other hand, is more challenging, because it involves the harmonization of key endogenous assumptions, such as population growth, global oil prices, climate conditions, assumptions of productivity growth and it involves the careful 'tuning' of behavioural parameters (i.e. elasticities) and other model components that would allow them to produce parallel results.

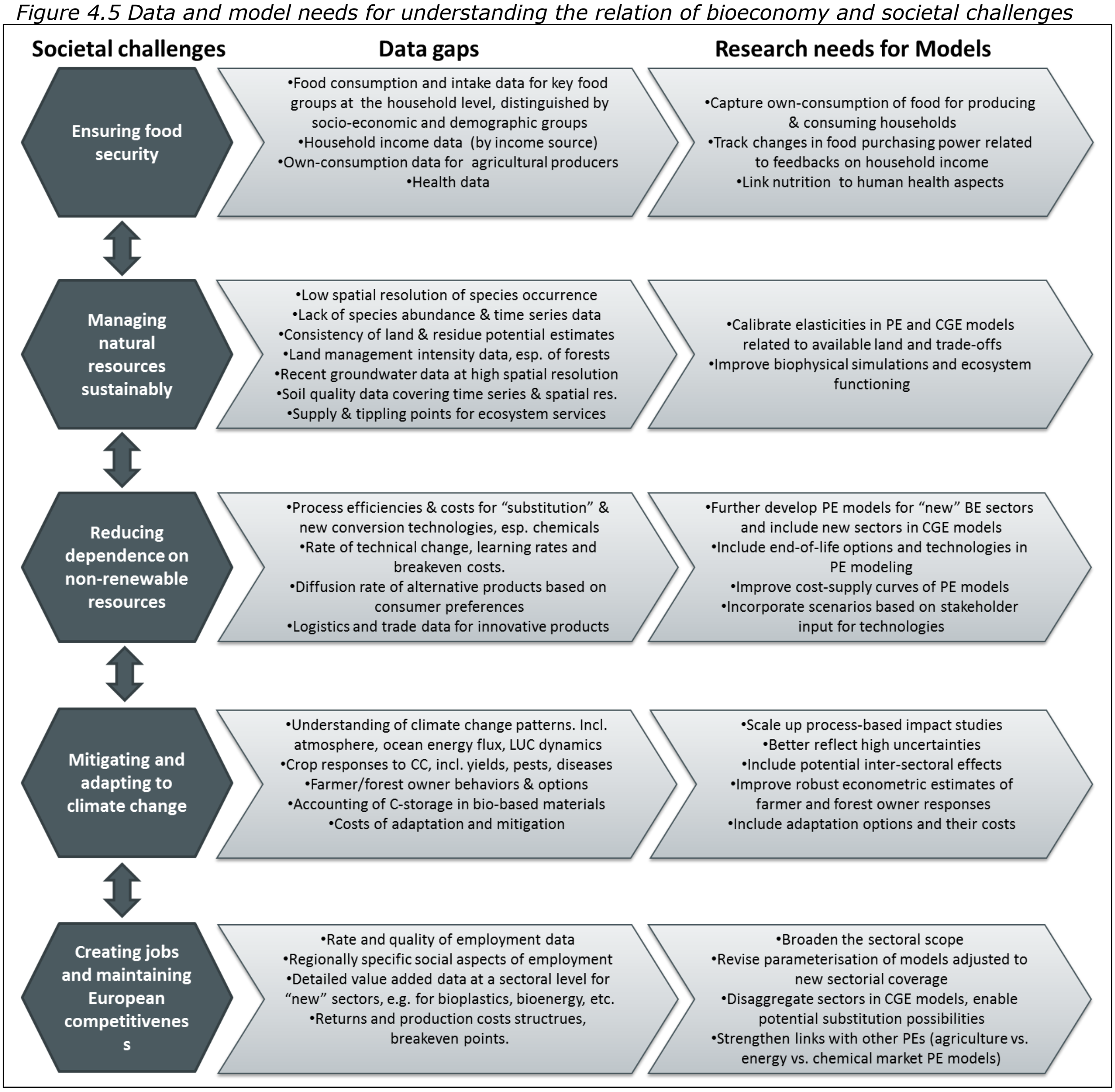
Given the complexity of the global economy and biosphere and the inherent uncertainties when modelling these, it would be unrealistic to expect that a total harmonization of models would be possible, since each component of the global economy or eco-sphere requires a certain degree of specialization in the models that are trying to capture it. In order to manage tension between capturing equilibrium and non-market equilibrium effects, modelling components within either model family would need to be simplified so that they would be able to have common indicators through which linkage and an (eventual) harmonization of model-based outcomes could be achieved.

One of the key gaps is the extent to which aspects of environmental quality can be captured with model collaborations of the sort available within the SAT-BBE Consortium. Without a better understanding of this it cannot be sure that the bioeconomy is (environmentally) preferable to the fossil based economy it is trying to replace. Although all of the models represent the quantities of goods and some environmental factors – such as land and water – the quality aspects of those natural resources, e.g. degradation of soil or water quality are neglected. Even if the initial conditions for these quality aspects could be captured – such as through the initialization of productivities in various agro-ecological zones –

[8] Wicke *et al* (2014) Model collaboration for the improved assessment of biomass supply, demand and impacts. *GCB Bioenergy*. doi: 10.1111/gcbb.12176.

it is very difficult to operationalize the feedbacks that future production or consumption behaviour have on the degradation of quality of land (for example), over time. This is a particularly challenging aspect that only very elaborates modelling exercises, such as that undertaken by the UNEP Global Environmental Outlook (GEO) 4 assessment, seem equipped to achieve at this time. Further research as to how some critical elements from a GEO-type framework could be brought to bear on a systemic modelling analysis of the knowledge-based bioeconomy are needed.

*Figure 4.5 Data and model needs for understanding the relation of bioeconomy and societal challenges*




*Source: SAT-BBE consortium*

# 5. Key findings and recommendations

This Chapter summarize the key messages and recommendations for further research in order to close gaps between required and available data, indicators and tools in the SAT framework.

- It is suggested using DPSIR as a structural framework for depicting the interlinkages between the economy, society and environment. This framework helps to organize, depict and portray the tools in the toolbox from a systemic perspective.

- Data, indicators and models are fairly well established for the traditional sectors of the bioeconomy (agriculture, fishery, forestry, food, paper and pulp, textile). Gaps exist for 'new' and innovative sectors of the bioeconomy (construction, chemistry, energy). For the new sectors or technologies, especially, value added, employment, cost structures, breakeven points, potential for scale economies, learning effects are missing. Further gaps relate to the interplay, problem shifting, and rebound effects between new bioeconomy sectors, traditional bioeconomy sectors and other industrial sectors. With regard to food security data gaps exist for consistent household income and expenditure data, nutrition intake, own consumption and health data.

- Agricultural PE models make use of commodity balances. E.g. for soft wheat, the balance is built from production, imports, exports, food use, feed use and seed use (in tonnes). From the bioeconomy perspective, and in order to regard competition for different use of wheat, more detail in the wheat balance is required. This could be done by including an additional indicator that measures the wheat (waste) that is used for chemical/material purposes. As Eurostat is responsible for providing agricultural commodity balances (at EU country level), this desaggregation of the domestic use options might be a task of Eurostat as well.

- There is a need to improve data availability and quality for addressing indicators (and metrics) that correspond to the three sustainability pillars of the bioeconomy. For a number of indicators, data are scarce, especially for social indicators. Also, as more disaggregated data are needed to answer questions about specific sectors (e.g. employment in bioeconomy sectors), the NACE levels[9] needs further disaggregation.

- One 'super model' does not seem appropriate to tackle the multi-dimensional systemic relationships within the bioeconomy. Instead, a variety of models and model types should be compared, combined and deployed as a toolbox for monitoring the bioeconomy. Integrated Assessment Models, with their systemic perspective focus, should play a central role to depict the interconnectivity, feedbacks and trade-offs between economic and environmental systems, supported by further analytical methods (such as LCA, MFA, multi-criteria analysis, etc.). To this end, further research is needed to categorise and link models and tools and find either mathematical algorithms or purely conceptual constructs that allow quantitative model outcomes to be interpreted relative to one another, in order to have more balanced outcomes in terms of forecasting, foresight elaboration or impact assessment.

- The software concept of loose coupling of modules is an option to operationalize the SAT-BBE framework. A graphical user interface (GUI) can be used as a 'translation module' among the various model types in the framework. It should also provide quality control and transparency to enable stakeholder participation in a targeted way.

- More needs to be done to capture the full impacts of the development of the bioeconomy on biodiversity and the non-provisioning, supporting, regulating and cultural ecosystem services, and thus on the state of natural capital. This requires fuller integration of 'quality' aspects of natural resources like land and water in environmental models (or sub-components of models)

[9] NACE is an acronym of Nomenclature statistique des activités économiques dans la Communauté européenne. NACE is a four-digit classification providing the framework for collecting and presenting a large range of statistical data according to economic activity in the fields of economic statistics (e.g. production, employment and national accounts) and in other statistical domains developed within the European statistical system (ESS).

in order to better assess how important ecosystem impacts could result from alternative pathways driving more towards a fossil-based economy – or towards a more biobased economy.

- Besides agriculture and forestry, the maritime bioeconomy should be better addressed in the PE and CGE models. There is a need to integrate the fishing sector in order to reflect better the whole food production, including food supply from marine ecosystems. Note that in the H2020 SUCCESS project (2015-2019) the fishery sector is implemented in the AGMEMOD model.

- There is an urgent need to improve model collaboration and tools to better account for land resource availability as well as land use intensity and make optimal use of the available data and empirical evidence to make the assessments correspond more closely to reality.

- The processes driving the biobased economy and its impact operate across multiple spatial and temporal scales. Local assessments need to be embedded in global assessments to contextualize the local drivers and impacts. At the same time, local assessments must include the larger context to understand trade-offs across spatial and temporal scales and displacement of (land use) impacts. To achieve this nested model structures and coupling of models must be achieved. This should not only be done in a top-down manner but also attempt to include the bottom-up responses in large scale assessments.

- New biobased technologies or sectors and the modelling of land and water use (agriculture, forestry, maritime) must be included in models to calculate the socio-economic aspects and or competitiveness of the bioeconomy. Extending the analyses to the food security impacts of the bioeconomy requires the explicit modelling of various households and the inclusion of the nutritional dimension.

- There is an absence of benchmarks for monitoring sustainability, especially the environmental dimension. Quantifiable sustainability targets are needed, which cover e.g. sustainable levels of land use, energy use and GHG emission. These targets should be derived from scientifically sound evidence and reflect normative judgments based on societal consensus. Footprint indicators (like land and emission footprints) can be used to measure the distance-to-targets.

- Research is needed on the concept of ecological limits and sustainable supply from the micro to global level (safe operating space) and how such sustainability criteria can be translated into targets. Such targets could become an integral aspect of a bioeconomy monitoring.

- Policies are needed to: set incentives for the most efficient use of biomass, strengthen the use of organic waste, improve primary production practices, mobilize domestic resources, and support innovation to enable cost-effective deployment of biomass conversion technologies.

- Synergies are only possible by decreasing the demand for resources (e.g. through dietary changes, energy-efficiency, and efficient use of biomass within the economy, e.g. through cascades) or in exceptional cases where increased utilization of biomass may reduce the risk of natural disturbances, particularly wild fires (through reduced fuel loads) or when the production efficiency of agricultural and forestry systems is increased, e.g. through using degraded areas with low biodiversity values and carbon stocks that are currently not used for other purposes.

- Further research is needed in particular to determine the sustainable supply capacity of wastes and residues from a systemic perspective as well as to further understanding of how different possible development pathways of the European bioeconomy will impact natural ecosystems across the planet. For example, consideration of how different harvesting techniques affect biodiversity or how the demand for different types of biomass (e.g. high-quality timber for cascades versus low-quality timber for fuel) influence (sustainable) resource management.

- Finally, there is a need to develop a baseline scenario that is able to describe the long-term development of the bioeconomy, taking account of driving factors (assumptions) and a smart set of environmental and socio-economic criteria and indicators.

# Annex 1. Characteristics of CGE and PE models

**Computable General Equilibrium (CGE) models**
The principle strength of CGE models is their comprehensiveness in terms of key economic relationships, including market price adjustments and associated changes in terms of trade, market balances and factor markets. This is important when considering the economic impacts, as well as the environmental impacts and social impacts. In recent years, several CGE assessments have been carried out to analyse the implications of biofuel policies and the bioeconomy. CGE models in the field of the bioeconomy are GTAP, MAGNET and Mirage, see further Deliverable 2.3.

CGE models are particularly useful for studying the impacts of significant bioenergy deployment in the short/medium term, especially when they are used and designed with a high level of disaggregation, and when sectoral and regional interlinkages are relevant. Similarly, they may also be used to study the medium/long term impacts of structural changes (policy- or market-driven), such as those of a biobased economy, but without detailed specifications for technologies. This requires additional assumptions with regard to technological change and preference shifts.

However, there are also many important uncertainties and limitations to CGE modelling analyses (Hertel, 1999). The price for their comprehensiveness is in general a high level of aggregation, which masks variation in and economic interactions between the underlying constituent elements, and limits the degree to which bottom-up information and data can be effectively integrated within the larger model (Hoefnagels et al., 2013). The same is true for temporal aggregation: CGE models provide a new equilibrium after a certain 'shock', and usually do not provide a temporal trend. Also the representation of technology and technological change is usually limited; especially advanced options of the biobased economy (e.g. modern biomaterials) or alternative feedstock and land resources (such as production on degraded land or residues) have hardly been assessed in CGE studies.

**Partial Equilibrium (PE) models**
PE models are often used to address sector specific questions (e.g. agriculture and energy) and for which interrelation with others parts of the economy are secondary. PE models have frequently been used to analyse first-order effects of policy intervention on a feedstock market when using biomass for bioenergy and materials. More sophisticated models however exist, such as the Common Agricultural Policy Regionalised Impact (CAPRI) model, encompassing a large number of sectors and regions, and providing a high level of detail in the supply and demand representation. Other examples of PE models that consider the agricultural sector are AGLINK, AGMEMOD, RAUMIS, IMPACT and GLOBIOM; examples of PE energy models are TIMER, MARKAL, TIMES, but many more PE models exist, see Deliverable 2.3.

The advantage of PE models comes from their high level of flexibility in incorporating a large amount of detail in process representation and input data. While CGE models also require a large quantity of information (in particular for the input-output tables), this information is only needed for sectors covered in the PE models, which removes the need for lengthy and distortive full rebalancing of the dataset. This allows a detailed representation of sectors and relevant economic mechanisms.

However, PE models also have limitations. The first one comes from the absent links with other sectors. Bioenergy being at the nexus between agricultural/forestry and energy sectors, models only focusing on one of the two groups of sectors miss feedbacks from the other group. There are attempts to circumvent this issue by incorporating two PE models and solving them simultaneously, by extending their model to a simplified representation of fossil fuel markets, or by establishing links between the various model approaches (see the section on integrated assessment models). Another issue is the absence of macro-economic closure, which can introduce some bias when sectors have a big role in an economy. For example, in developing countries, the link between agricultural income and the final consumer demand is generally missing because the supply and the demand side are not linked by the revenue cycling. PEs are therefore more limited to study food security benefits for smallholders to develop bioenergy projects.

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