Toolkit for a Systems Analysis Framework of the EU Bioeconomy (Report 2.4)

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SAT BBE

REPORT D 2.4

Toolkit for a Systems Analysis Framework of the EU Bioeconomy

Overview of WP2 in the EU FP 7 SAT-BBE project:
Systems Analysis Tools Framework for the EU Bio-Based Economy Strategy

Report for public dissemination

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Preface

This document is based on the contribution of all project partners (see box below). It especially builds forward on the three interim project deliverables in Work Package 2. Myrna van Leeuwen, Hans van Meijl and Edward Smeets of LEI Wageningen UR are the editors of this report. Researchers who contributed are Peter Verburg and Marleen Schouten (VUA), Stefan Bringezu and Meghan O' Brien (WI), Hannes Böttcher and Hugo Valin (IIASA), Yannis Tsiropoulos (UU), Lauri Hetemäki, Marcus Lindner and Alexander Moiseyev (EFI), Franziska Junker and Ralf Döring (TI), and Siwa Msangi (IFPRI).

	Short name	Full name	Member State	Contributed to WP2
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
5	IIASA	International Institute for Applied Systems Analysis	Austria	X
6	VUA	Vrije Universiteit Amsterdam	Netherlands	X
7	TI	Thünen-Institut	Germany	X
8	IFPRI	International Food Policy Research Institute	USA	X

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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 five societal challenges relevant for the bioeconomy:

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 project (SAT-BBE) with the purpose to design an analysis tool useful to monitoring the evolution and impacts of the bioeconomy. Second, the EC started the Bioeconomy Information System Observatory project (BISO) with the objective to set up a Bioeconomy Observatory. That observatory must bring together relevant data sets and information sources, and use various models and tools to provide a coherent basis for establishing baselines, monitoring, and scenario modelling for the bioeconomy.

SAT-BBE and BISO are complementary projects. SAT-BBE develops a Systems Analysis Framework for the Bioeconomy to assess and address the short and long term challenges for an effective and sustainable EU strategy, and it develops a conceptual analysis tool for monitoring the evolution of the bioeconomy. Herewith SAT-BBE could advise the BISO project on the types and sources of data and tools that need to be taken into account. On its turn, BISO assembles and implements the data and tools that lie beyond the conceptual framework to be designed in SAT-BBE into an information system. These efforts to providing a comprehensive insight in the data and tools availability could help SAT-BBE with developing the conceptual analysis framework of the bioeconomy.

More precisely, the purpose of SAT-BBE is to develop a system analysis tool for monitoring and assessing the evolution of the bioeconomy, based on both quantitative and qualitative analytical tools. The toolbox enables to assess and address the impact of drives and various policies on the evolution of the bioeconomy and the implication on people, planet and profit indicators. The focus is on economic aspects, as well as on side effects such as land use, food security, biodiversity and greenhouse gas emissions. The systems analysis tools framework has the capacity to understand the functional requirements of a bioeconomy and to measure the necessary extent for transformation of the economy as a whole to a biobased foundation. Tools are modelling and non-modelling analytical methods, organised in evaluation (and, by extension, monitoring) methodologies. 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 this field. Further, many models and tools exist that can be used to evaluate certain aspects of the bioeconomy, although they were not specifically designed for this purpose. This shows the need to categorise and link these models and tools, and the complementary need is to 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 SAT-BBE project structures the development of the analysis tool for the EU bioeconomy strategy in three phases (Figure 1):

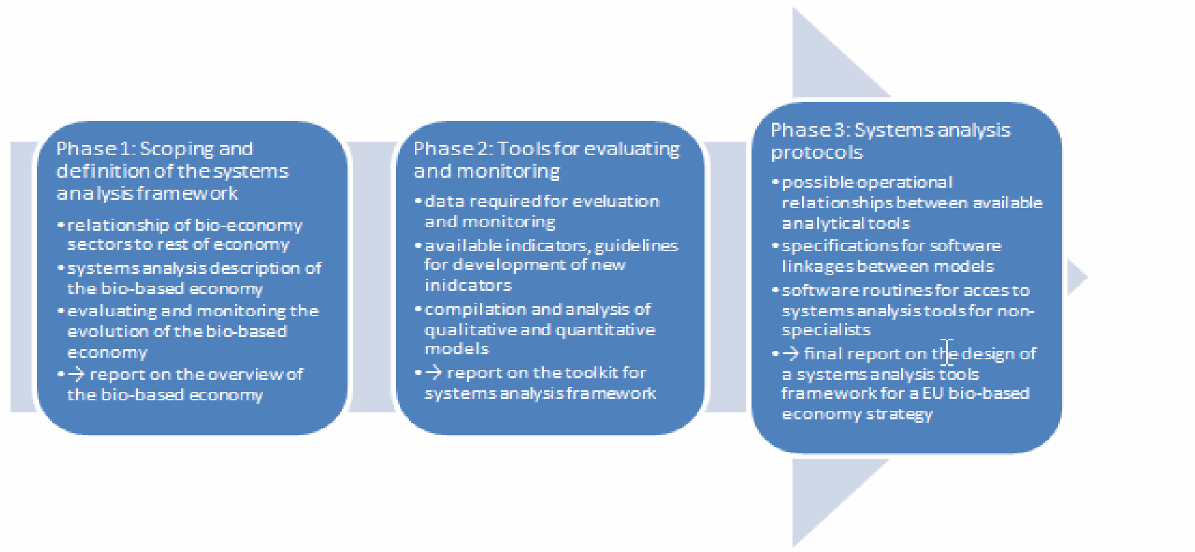
1. scoping and definition of the systems analysis framework (WP 1);

[1] Innovating for Sustainable Growth: a Bioeconomy for Europe (COM(2012)60).

2. tools for evaluating and monitoring (WP 2);
3. systems analysis protocols (WP 3).

This report D2.4 describes the key findings of WP2 on 'Tools for evaluating and monitoring', as further explained in the next section.

Figure 1. Work programme of SAT-BBE project



1.2 Systems analysis description of the bioeconomy

The bioeconomy is multidimensional concept, because of the wide array of product sectors (such as fuels, consumer products, chemicals), research and development activities, making evaluating and monitoring the evolution and impacts of the bioeconomy not straightforward. The SAT-BBE consortium has adopted the following broad definition of the bioeconomy (Deliverable 1.4, 2013):

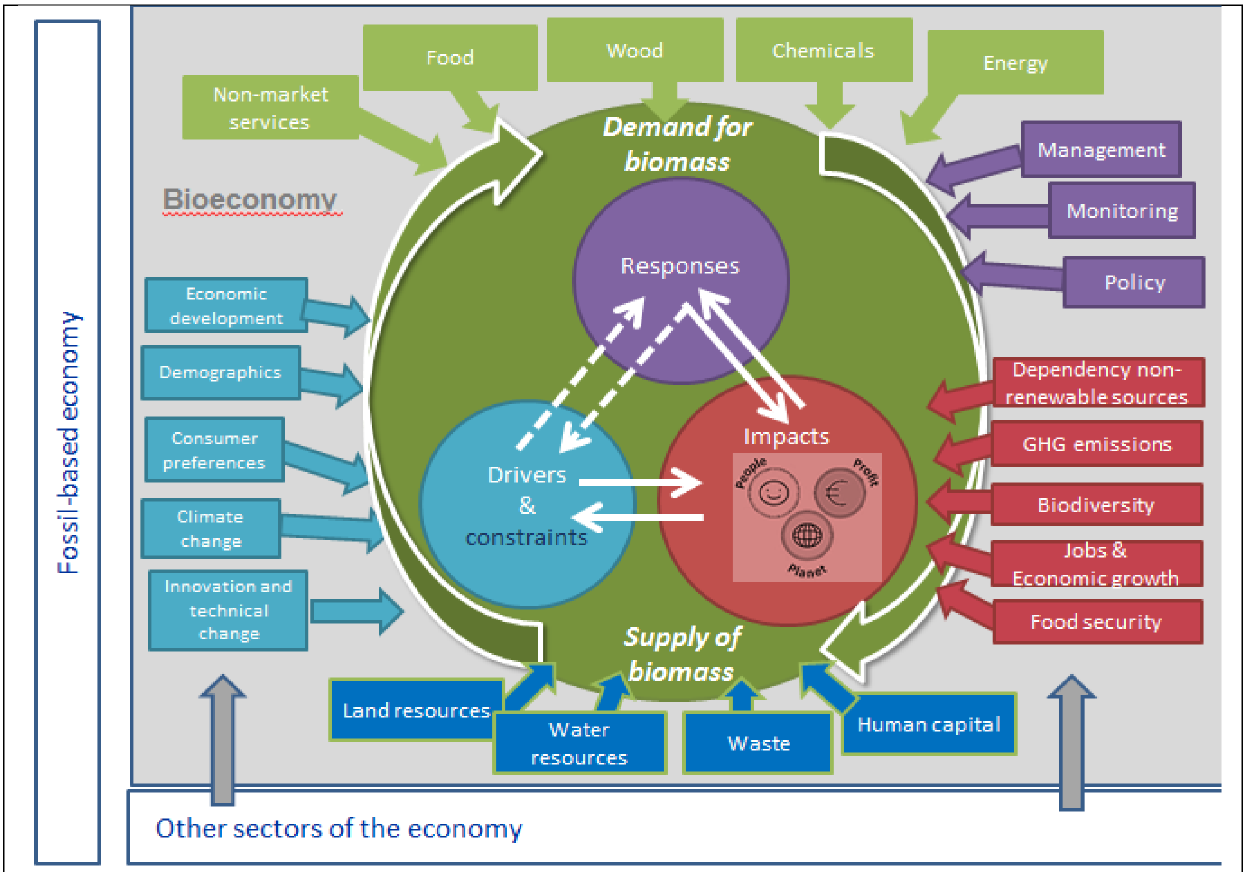
> *'The bioeconomy encompasses the production of renewable biological resources and their conversion into food, feed, bio-based products and bioenergy. It includes agriculture, forestry, fisheries, food and pulp and paper production, as well as parts of chemical, biotechnological and energy industries. 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 broad scope and goal of the SAT-BBE project, also emphasizing the many diverse drivers and sustainable development of the bioeconomy, requires a broad definition. Work package 1 has developed a Driver-Impact-Response (DIR) conceptual framework for the bioeconomy (Figure 2), that captures all these aspects. This DIR framework is the base for streamlining the activities conducted in Work Package 2 aimed at a comprehensive overview of the data, indicators and model requirements for evaluating and monitoring the evolution of the bioeconomy.

For the complex economic analyses of the bioeconomy in general and bioenergy specifically, we use a supply-demand framework that connects the building blocks (drivers, impact, response) for our analyses (see, Figure 2). The current fossil-based economy is the starting point, whereby the pathway of transition to a sustainable bioeconomy (including bioenergy) is influenced by system and policy drivers. The demand for the bioeconomy is coming from a linked system of food, wood, energy, chemicals and non-market services. To supply biomass, land, water, waste and human capital resources are used, which are linked to the demand system. The DIR framework consists of three elements to describe and assess the bioeconomy in the EU,: Drivers and pressures, Impacts and mechanisms, and Responses and other policy issues. The structure is organized along the three pillars of sustainability: economic, social and environmental sustainability. In the framework the relevance and importance of various drivers and pressures are emphasized, as can been seen in Figure 2 (Hockings *et al. 2006*). Further, it ensures that various types of drivers and pressures are taken into account in a comprehensive manner, i.e. within each of the three sustainability dimensions. The SAT-BBE consortium identified six categories of key drivers and constraints of the bioeconomy:

1. demographics (e.g. population growth, education, human capital);
2. consumer Preferences (consumer behaviour);
3. economic development;
4. global environmental change;
5. resource availability (e.g. land, where is the biomass available?);
6. innovation and technical change.

Figure 2. Proposed systems analysis framework for the bioeconomy



(dark blue)	Natural and human capital resources
(light blue)	Key drivers
(green)	Sectors
(purple)	Responses
(red)	Mechanisms that result in impacts

Source: Van Leeuwen, van Meijl, Smeets and Tabeau (2013)

The system drivers of the bioeconomy (blue boxes) are related to the supply and demand side of the bioeconomy. Demographic growth, consumer preferences and economic growth are identified as key drivers for the demand side and technological and climate change for the supply side of biomass (left light blue boxes). For the supply side also the natural and human capital resources are important (bottom dark blue boxes). The third block includes policy and management initiative and responses to achieve the policy targets by influencing the demand and supply system drivers. The system drivers and the management and policy responses change the system's state through several (simple and complex) mechanisms that result in impacts (red boxes) that can be monitored and responded to. Responses (purple boxes) are indirectly affected by the drivers as well, but may also affect drivers or impacts in a direct way.

1.3 Challenges of Work Package 2

The objective of WP2 in the SAT-BBE project is the inventory of tools for evaluation and monitoring the EU bioeconomy. Three Deliverables describe in depth the data required for evaluating and monitoring the evolution of the bio-based economy (Deliverable 2.1), the availability of indicators and lacunae for monitoring the bioeconomy indicators (Deliverable 2.2), and the quantitative and qualitative models currently used or under development for analysing the bioeconomy (Deliverable 2.3).
The conceptual DIR framework, as developed in WP1 of the project, structures and harmonizes the research programs associated with:

- monitoring the bioeconomy;
- evaluating the impacts of the bioeconomy (e.g. technology assessments);
- assessing the future prospects (e.g. forecasts, foresight studies) for a sustainability bioeconomy analyses.

Annex 1 includes a summary table with indicators and modelling tools qualifications related to monitoring the evolution of the EU bioeconomy, based on Deliverable Report 2.1, Deliverable Report 2.2 and Deliverable Report 2.3 as delivered under this WP2.

The overview in this report is aligned with the Bioeconomy Strategy and Action Plan, by taking account of two of the five societal challenges mentioned in the Bioeconomy Strategy. There are cross-references to the types of impact covered and to the territorial scale of analysis. Also, gaps have been analysed and responsibilities have been assigned to fill these gaps.

The WP2 synthesis report aims to contribute to the bioeconomy discussion in the EC. It was therefore agreed on to take some bioeconomy related issues or questions as starting point, to highlight the key problems, and to discuss how to tackle these issues, questions and problems. Chapter 2 and Chapter 3 respectively focus on the questions:

- What is the socio-economic competitiveness of the EU bioeconomy?
- What is the impact of the biobased economy on food security?

These questions are interesting as they are not only bioeconomy linked, but are at the same time closely related to some of the societal challenges of the Bioeconomy Strategy as established by the EC (2012). The questions link up with the objectives 1) to ensure food security; 2) to create jobs and maintaining European competitiveness; and 3) to manage natural resources sustainably. Each question is addressed in a similar way: first the challenges that need to be tackled are discussed; then the data and model requirements are specified; and finally the data and model gaps are identified. When possible, these aspects are highlighted from the three sustainability dimensions: economy, social and environment.

Chapter 4 describes the key findings of this WP2 project. The activities in WP3 of the SAT-BBE might build further on these analysed issues.

2. What is the socio-economic competitiveness of the EU bioeconomy?

The first bioeconomy related question that is addressed in this synergy report D2.4 is:

- *What is the socio-economic competitiveness of the EU bioeconomy*?

Section 2.1 describes the background and importance of this bioeconomy question. Section 2.2 discusses the data and model tools required to provide empirical based answers to the identified question. Data and model gaps that need to be solved in order to ensure a proper analysis are described in section 2.3.

2.1 Background and importance of issue

In the context of the addressed question, '*competitiveness*' pertains to the ability and performance of the (regional) bioeconomy sector to generate income and employment, in relation to the ability and performance of other sectors in the same country or region. Therefore, the question '*What is the socio-economic competitiveness of the EU regional Bioeconomy?'* fits to one of the objectives of the strategy and action plan for a sustainable bioeconomy in Europe, i.e., the development of markets and competitiveness in bioeconomy sectors (EC 2012). The Commission considers the Bioeconomy as a key component for smart and green growth, and identified access to energy and raw materials at affordable prices as one of the priorities that should be pursued to support the competitiveness of European industry and the Bioeconomy. Green growth, including green jobs, can be enhanced by 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 biobased production system is mostly determined by 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, companies need insight in the long-term competiveness of such new technologies. This requires a comparison of the contribution of sustainable versus common practice – fossil based – production methods to turnover and value added within a sector. First, companies need to know the factors that determine the competitiveness and/or profitability of new and/or existing technologies in the long run. Second, they need to know 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 region or country has regional employment and economic growth (value added) implications.

It is therefore important to conduct studies that help companies in making strategic decisions on the use and type of production methods and the production location. Studies might also provide insight for national, regional and local governments to outline and implement strategic plans targeted to achieve national, regional and local development of the bioeconomy. So far, several studies attempted or are attempting to tackle the questions on the possible economic size of the bioeconomy, and whether it will become competitive with the fossil based economy. Box 1 and Table 1 illustrate examples of such studies (Smeets *et al*, 2014). The study of Smeets *et al.* shows the macro-economic effects of biobased applications in the EU. The results show that these effects are determined by the difference in production costs, but also by indirect economic effects, mostly from changes in the use of production factors (labour and capital) and intermediate inputs for bio-based production and changes in prices, production, consumption and trade.

Box 1. Evaluating the macro-economic impacts of biobased applications in the EU

The macro-economic effects of biobased applications are not only determined by production costs, but also by indirect economic effects due to input and product price changes. These indirect economic effects are caused by the use of production factors (labour, capital, land), the use of intermediate inputs for biobased production, and by changes in prices, production, consumption and trade. Such effects can only be evaluated with economic equilibrium models, such as the MAGNET (Modular Applied GeNeral Equilibrium Tool) global CGE model used in this study.

The objective of this study is to evaluate the total net macro-economic effects of using 1 EJ biomass for biobased applications in 2030 based on a set of assumptions on oil price, biomass price and efficiency of biobased conversion technologies. Four biobased applications are considered in MAGNET, namely bioelectricity, biofuels (2nd generation), biochemicals and biogas (synthetic natural gas).

Table B1. The impact of the use of 1 EJ biomass for the production of fuel, gas, electricity, chemicals on the production value and GDP (billion US$)

	-------- Cost calculations (spreadsheet) --------			Model based (MAGNET)	
	Change of value of biobased production	**Change of value of conventional production**	**Net change of value of production = Net GDP effect**	**Net GDP effect MAGNET**	**Multiplier effect**
1 Biofuel	10.7	-13.7	3.0	5.1	1.7
2 Biogas	10.7	-6.2	-4.5	-5.1	1.1
3 Bioelectricity	10.2	-7.7	-2.5	-3.0	1.2
4 Biochemicals	11.8	-22.4	10.6	6.0	0.6

Results (Table B1) show that the net GDP effect of biofuels is 5.1 billion US$ based on the MAGNET model, which is 1.7 times the GDP effect that has been calculated from the change in value of production taking into account only the differing production costs between conventional and biobased applications (and no indirect economic effects). This factor 1.7 is a kind of multiplier effect. A substantial part of the increase in GDP comes from the increase in wages, which is partly the effect of the labour intensive collection, pre-treatment and transport of biomass that replaces more expensive oil intensive imports. The increase in wages is transmitted to the other sectors in the economy and partially explains the (positive) multiplier effect. Another important effect comes from the lower oil price due to the substitution of oil based fuel production by biobased fuel production. The lower oil price is beneficial for the entire economy and in case of the EU it also improves the terms of trade effect as the EU is a large net importer.

The same mechanisms applies to the calculation of macro-economic impacts of the production of chemicals, electricity and gas. The production of chemicals results in the highest net GDP effect compared to the other biobased applications, namely 6 billion US$. The GDP calculated from the change in value of production costs is however 10.6 billion US$. The lower multiplier (0.6) is mainly the result of reduced competitiveness of the services sector and the other industries sector. These sectors are relatively labour intensive and compete for labour with the domestic chemical industry. The GDP effect of biogas and bioelectricity is negative as these technologies are not competitive with their fossil based equivalent.

Source: Smeets *et al* (2014b)

An important focus of the EC Strategy is to evaluate the progress and impact of the EU Bioeconomy related sectors. In order to address these issues, two EC funded project have been launched. First, the conceptual DIR framework, developed under SAT-BBE (Deliverable Report D1.4), helps to structure and harmonize the research programs associated with 1) monitoring the bioeconomy; 2) evaluating the impacts of the bioeconomy (e.g. technology assessments); and 3) assessing the future prospects (e.g. forecasts, foresight studies) for a competitiveness bioeconomy analyses. Second, the BISO project has to provide regular analysis and data that will help policy makers and stakeholders to monitor the development of the bioeconomy. By identifying the required and available data on indicators and the models needed to analyse the bioeconomy, this report D2.4 is meant to support the activities of the BISO project.

The **data and tools gap** analysis conducted in this chapter has the aim to identify which part of the question '*What is the socio-economic competitiveness of the EU bioeconomy*?' may be answered based on current availability of data and tools, and which part cannot be answered yet. The type of analysis should cover the monitoring, evaluating and assessing of impacts, which means that the competitiveness of the bioeconomy should be looked at from ex-post, real time and ex-ante perspectives.

Table 1. Examples of studies that conduct the socio-economic importance of regional bioeconomies

Title and key focus	Key focus and comments
***"The Knowledge Based Bioeconomy (KBBE) in Europe: Achievements and Challenges"*; Clever Consult (2010)**	Rough estimates on turnover, employment of EU bioeconomy sectors in 2009. No updates.
"*An approach to describe the agri-food and other bio-based sectors in the European Union. Focus on Spain*"; Cardenete, M. A., P. Boulanger *et al* (2012), JRC-IPTS.	Use of Agro-SAMs, based on 2000. Forward and backward linkages of biobased sectors; value added and employment in EU27 and Spain. Shock analysis. Base year (2000) is outdated. No updates of SAMs.
***"Analysis of the economic impact of large-scale deployment of biomass resources for energy and materials in the Netherlands "*; Hoefnagels and Banse (2009). Utrecht University and LEI Wageningen UR.**	Integration of technical bottom up analyses and a socio-economic model (MAGNET CGE). Effects of bioeconomy for Dutch employment and value added in 2008 and 2030. Biobased technology pathways in chemical and energy sectors have not been detailed in terms of cost and return structures (data constraints).
***"Analysis of the economic impact of large-scale deployment of the bioeconomy in the Netherlands"*; Study being conducted in 2014 and 2015 by LEI Wageningen UR, Utrecht University, DSM, Essent, Corbion, Brouwer Advies.**	Follow-up study of previous macro-economic study, conducted by Hoefnagels and Banse et al (2009). Improvement of methodology. Bottom-Up calculation (MARKAL economic-technical model) and Top-Down calculation (ORANGE/MAGNET socio-economic model) of biomass use in energy, chemical and transport sectors. Scenario study; effects for 2010 (reference) and 2030, in Netherlands and regions. Implementation of a) biobased technologies in chemical sector, and b) biobased, fossil based and renewable technologies in energy sectors. Based on experience and knowledge of company partners in consortium and literature.

2.2 Data and model requirements

Biobased feedstock is used in three main industrial sectors of the bioeconomy: 1) food and feed sectors; 2) energy sector; and 3) industrial material use sectors. Food and feed sectors include established industries and therefore market data are available from different sources. On the other hand, the biobased feedstock use in the production of industrial materials and products represents an emerging industry, whose economic and technical data is still difficult to retrieve. This is in particular the case with official data on the shares that biobased products adopt in industry branches like the plastics industry. Precisely these numbers and indicators are needed to get insight in the competiveness of the bioeconomy in comparison to the fossil based economy. Table 2 depicts the most recent available estimates of turnover and employment according to the broad definition of the EU bioeconomy (Clever Consult, 2010); these figures are often quoted by other studies.

In 2009, the new biobased industries had a relatively low turnover (about 57 billion euro) compared to the more than 2,000 billion euro generated by the whole bioeconomy. It should be mentioned that the quantitative information is based on expert estimations, and is thus of limited reliability. Also, note that bioenergy production is not explicitly shown in the table, although the use of biomass for energy is quickly becoming more important. Further, the true potential of the bioeconomy in the EU is much larger than the values shown in the table. 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 2. Turnover and employment of bioeconomy sectors in Europe, 2009

	Turnover (billion euro)	Employment (1,000 fte)
Food	965	4,400
Agriculture	381	12,000
Paper/pulp	375	1,800
Forestry/wood incl.	269	3,000
Fisheries and aquaculture	32	500
Biobased industries		
*- Bio-chemicals and plastics**	*50*	*150*
*- Enzymes**	*0.8*	*5*
*- Biofuels**	*6*	*150*
Total	2,078	22,005

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

From an analytical point of view, there is a need to indicate the main indicators and model requirements that enable a quantitative description of the socio-economic competitiveness of the EC bioeconomy. Deliverable Report 2.1 and Deliverable Report 2.2 mention the **value added** as key indicator for monitoring and measuring the economic impacts of the bioeconomy, whereas the **people employed** in the production of bioeconomy products is mentioned as the key indicator for monitoring and measuring the social impacts of the bioeconomy. Figures 3 and 4 summarize the statistical sources and modelling tools that respectively capture numbers on value added and people employed (step 1 in Figure 2 and Figure 3). For sectoral and regional dimensions, however, the data and model are insufficiently detailed, hindering the measurement of the competitiveness of the bioeconomy according to the broad definition as adopted in the SAT-BBE study (step 2 in Figure 2 and Figure 3). Information about prices, production and trade volumes are available from existing statistics, such as Prodcom, UN Comtrade, Eurostat, Farm Structure Survey database and other databases. However, data are typically only available for agricultural commodities, but not always for wood based products, by-products, wastes and residues and for new biobased products. Further, data on employment and value added are only partially, or on an ad-hoc basis, available in existing statistics and the same applies to information on R&D investments (in public and private sectors), R&D personnel and human resources skills, patents and research, innovation programmes, policies at regional, national and international level. See further Table 3, Deliverable Report 2.1 and Deliverable Report 2.2 for a more complete overview of the quality and gaps in data about biobased products and also the results of the Bioeconomy Observatory.

According to Wicke *et al* (2014), existing approaches for assessing biomass supply and impacts may be broadly categorized in a) computable general equilibrium (CGE) models (including IO and SAM analyses), b) partial equilibrium (PE) models, c) bottom-up models and analyses, and d) integrated assessment models (IAM). Table 4 provides a better understanding of these approaches, by discussing their main applications, and their strengths and limitations with respect to the assessment of biomass supply and impacts.

Table 3. Overview of data availability and quality

Indicators	Data requirements	Data availability	Data quality	Relevant sources
Economic				
Change in biomass end-product turnover and values added		1	1	EUROSTAT
Change in cropland-based biomass net trade		4	4	UN COMTRADE, EUROSTAT, FAOSTAT
Change in cropland-based biomass end-product net trade		3	3	UN COMTRADE, EUROSTAT
Change in animal-based and fish based product net trade		4	4	UN COMTRADE, EUROSTAT, FAOSTAT
Change in wood net trade	Exports /Imports of wood and wood biomass	4	4	UN COMTRADE, EUROSTAT, FAOSTAT
Change in forest products net trade	Exports /Imports of forest products	3	2	UN COMTRADE, EUROSTAT
Change in real wood prices and forest products prices	Round wood prices; prices for solid wood	3	4	Finnish Forest Research Institute

	products, paper & boards, wood pulp			MetINFO service, consultancy reports (RISI, etc.)
Change in forest products prices		3	4	Consultancy reports (RISI, etc.)
Change in wood (fibre) demand for forest products	Wood fibre use for wood based products (including use of recycled materials)	1	3	Wood resource balance
Change in wood biomass demand for energy use	Wood biomass use for energy (heat, electricity, liquid biofuels)	1	2	Wood resource balance
Change in cropland-based biomass demand for products	Biomass used for biomaterials and bio-based products	1	1	Sources needed
Change in cropland-based biomass demand for energy	Biomass used for energy	4	4	Eurostat, REN21 EurObserv'ER, IEA
Social				
Number of Full Time Equivalent jobs	Full time equivalent jobs per sector per year	5	5	OECD, ILOSTAT, EUROSTAT
Job creation in (un)skilled labour	Data on employment (creation) in skilled, low skilled, manual, elementary occupation labour	4	4	EUROSTAT, ILOSTAT
Average income of employees in the bioeconomy sectors	Data on average annual income of workers per sector	2	4	ILOSTAT, EUROSTAT
Average number of work days lost per worker per year	Data on average number of work days lost per worker per year, per sector	2	4	ILOSTAT, EUROSTAT
Quality of life	Data on level of life satisfaction, ability to meet needs, , rights, social, health interaction, at national level	2	2	Eurostat

Legenda:	1 (weak)	2	3	4	5 (strong)

Socio-economic economy-wide models, like **CGE models, agro-IOs** and **agro-SAMs**, may be applied to monitor and analyse the competitiveness of (a group of) sectors for the total (regional) economy. Good examples are the MAGNET (Woltjer and Kuiper, 2014) and MIRAGE (Laborde, 2011) global computable general equilibrium models. Also very useful are the EU member state based agro-SAMs. **PE models**, such as CAPRI, AGMEMOD and RAUMIS are especially useful for more detailed sectoral analyses. **Bottom-up analyses** are especially useful to provide detailed technical and economic inputs (e.g. cost structures) to the PE and CGE models of new bioeconomy sectors, whereas **IA models** provide the longer run picture and interaction with biophysical processes (e.g. climate change). See Deliverable Report 2.3 for a more detailed overview of economic models and tools and also Chapter 3 on food security. The rate of technical change is important for the economic effects, and especially for new technologies, such as the use of genetically modified organisms (GMOs) and production of second generation biofuels. The inclusion of new biobased technologies in models requires additional assumptions with regard to technological change and preference shifts. The same applies to the use of alternative feedstock and land resources, such as production on degraded land or residues.

Some recent advances have been made in some GTAP based model versions by more broadly representing bioenergy: introducing ethanol, biodiesel and their by-products (Banse *et al,* 2011; Laborde, 2011), the agricultural residue corn stover, and the energy crops switch grass and miscanthus for second generation ethanol production (Taheripour and Tyner, 2013) and palm oil residues (Van Meijl *et al*, 2012). Smeets *et al* (2014) evaluate the impacts of the use of wheat straw in the bioeconomy in the EU on food prices, food production, consumption and trade in the EU and globally using MAGNET. At the time of writing this report, the MAGNET CGE model is being expanded 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 pre-treats agricultural residues). The development of more efficient technologies is thereby explicitly considered and this update allows an evaluation of the impact of the development and implementation of new biobased conversion technologies.

Table 4. Overview of four modelling approaches for assessing biomass supply, demand and impacts: their applications, typical timeframes, key strengths, and limitations

	CGE model	PE model	Bottom-up analysis	IAM
Application	Economy-wide impacts of biomass and bioenergy policies, including subsequent effects on land-use change and GHG emissions induced by these policies. 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. 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). Possible contribution of bioenergy to long-term climate policy. Impacts of bioenergy policies on global land use, water and biodiversity.
Typical timeframe	**Short to medium term**	**Short to long term**	**Short to long term**	**Long term**
Strengths	Comprehensive coverage of economic sectors and regions to account for inter-linkages. Explicit modeling of limited economic resources. 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. Explicit representation of biophysical flows and absolute prices. 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 modeling framework. Possibility to analyse feedbacks between human and nature systems, and trade-offs and synergies of policy strategies. Built around long-term dynamics.
Limitations	Level of aggregation that may mask the variation in the underlying constituent elements. 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. Often no or little explicit representation of quantities for biophysical flows.	Optimization of agent welfare, but only the sectors represented in the model. No consideration of macroeconomic balances and impacts on not-represented sectors. Need large number of assumptions for long-term projections	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. Unsuitable for short-term assessments. Large number of assumptions (and the communication of these to the public).

Source: Wicke *et al* (2014).

2.3 Gaps and further needs

The exercise in this chapter has identified the data and model shortcoming with respect to measuring the competitiveness of the broad version of the EU bioeconomy. Also, the need to fill the gaps in order to better understand the current and future size and contribution of the bioeconomy in the overall EU economy have been indicated (step 3 in Figure 2 and Figure 3). That would require the development and use of specific statistical data and models that are sufficiently disaggregated towards with respect to their sectoral and regional scopes.

To close the **value added indicator gap** of the (new) biobased chemical and energy industries, the underlying indicators need to be quantified, such as **turnover, production costs, input and output prices** and **production volumes**. Also, quantitative information on the origin of the raw - fossil based and biobased - materials and the industrial production is necessary. Data about the availability and prices of agricultural, forestry, and industrial biomass residues is also critical. Information on fossil-based industrial products is important, because it enables a comparison between fossil and biobased products. To compare the competitiveness of the bioeconomy sectors across countries or in regions within countries, sufficiently detailed geographically explicit data are required as well. **Industrial surveys** and the use of additional models (like PE energy models such as Markal and Poles) are helpful to solve the problem of lack of detailed sectoral and regional information, although global models that do not have this detailed information are sometimes essential to capture the impact of developments outside the EU and impact on other parts of the world.

Summarizing, we conclude that data on the biomass based sector is available only to a very limited degree in the economic accounts of European countries, which are necessary to generate Input-Output tables. Especially information related to biobased oriented plantations, residues, new biobased chemical and energy sectors is scarce. As Input-Output tables are the base of economy-wide socio-economic models, their extension with observed biobased sector data will improve the reliability of the results from these models regarding the current and future monitoring of the bioeconomy. These updated input-output tables reflect the new organisational structures established in the bioeconomy, such as the linkages between agrofood sectors with the bioenergy and biochemistry. Also, with a broader database, sector models will be better suited to analyse the competition between biobased and fossil based sectors.

The standard, uniform way of generating Economic Accounts (UN Handbook, 1999) and balance sheets (Eurostat) should be applied to the new biobased sectors and commodities (including waste and by-products), with at least the same time horizon, frequency and geographic detail of collection. The aforementioned additional data needs may close the indicator gaps with respect to the sectoral and regional levels. Important is also that data are collected on a frequent (annual) basis. This will ensure the possibility to measure quantitatively the socio-economic competitiveness of the EU bioeconomy, including its past and future evolution.

In addition to the data gaps, there are also various gaps and uncertainties in economic models that focus on competitiveness. CGE models cover the whole economy but this comes often at a price of a high level of sector aggregation. This might mask variation in underlying elements and limit the degree that bottom-up information can be integrated. The representation of technology and technological change is often limited. Especially advanced options of the bioeconomy (e.g. modern biorefinery and biomaterials), or alternative feedstock (residues, dedicated plantations such as miscanthus) and land resources (production on degraded lands) have hardly been assessed in CGE models. The previous section explained that first steps are being taken to add bioeconomy sectors and to disaggregate agricultural, forestry, energy and chemical sectors (Banse *et al,* 2011; Laborde, 2011; Tahepour and Tyner, 2013; Van Meijl *et al,* 2012; Smeets *et al*, 2014; Wicke *et al*, 2014). Wicket et al. (2014) point out that it is possible to add new sectors and more complex relationships, but that in practice, mathematical relationships remain highly aggregated and simplistic.

PE models address questions related to a specific sector. PE models are more flexible to incorporate large amount of information on the representation of specific technologies as rebalancing of the database is less cumbersome than in CGE models (e.g. Havlik *et al*, 2011). This comes at a price of having no linkages with other sectors in the economy. This drawback can partially be circumvented by connected various PE models (e.g. agricultural, forestry and energy PE models), although this raises many model linkage and consistency problems. Msangi *et al* (2014) made a first step by connecting two PE models (agriculture and fossil fuel PE models). Another disadvantage of PE models is that there is no macro-economic closure which is a problem if sectors have a large impact on the economy. In case of a full bioeconomy this might be expected to be the case.

For both PE and CGE models, the modelling of land use is difficult but very important for the competitiveness of the bioeconomy. If a land abundant country is able to extend its land easily, it can produce more biomass without increasing its production costs. In a land scarce country, additional production of biomass and therefore additional demand for land leads to an increase in the land and therefore agricultural product prices. Modelling the land market is difficult as good quality data for land prices and land quantities are scarce. Especially the potential amount of agricultural and forestry land is surrounded with uncertainty. Furthermore, institutional factors determine the functioning of the land market and they can be very region specific.

Figure 3. Data and Model requirements and gaps to be filled, for answering the question 'What is the economic competitiveness of the EU bioeconomy'?

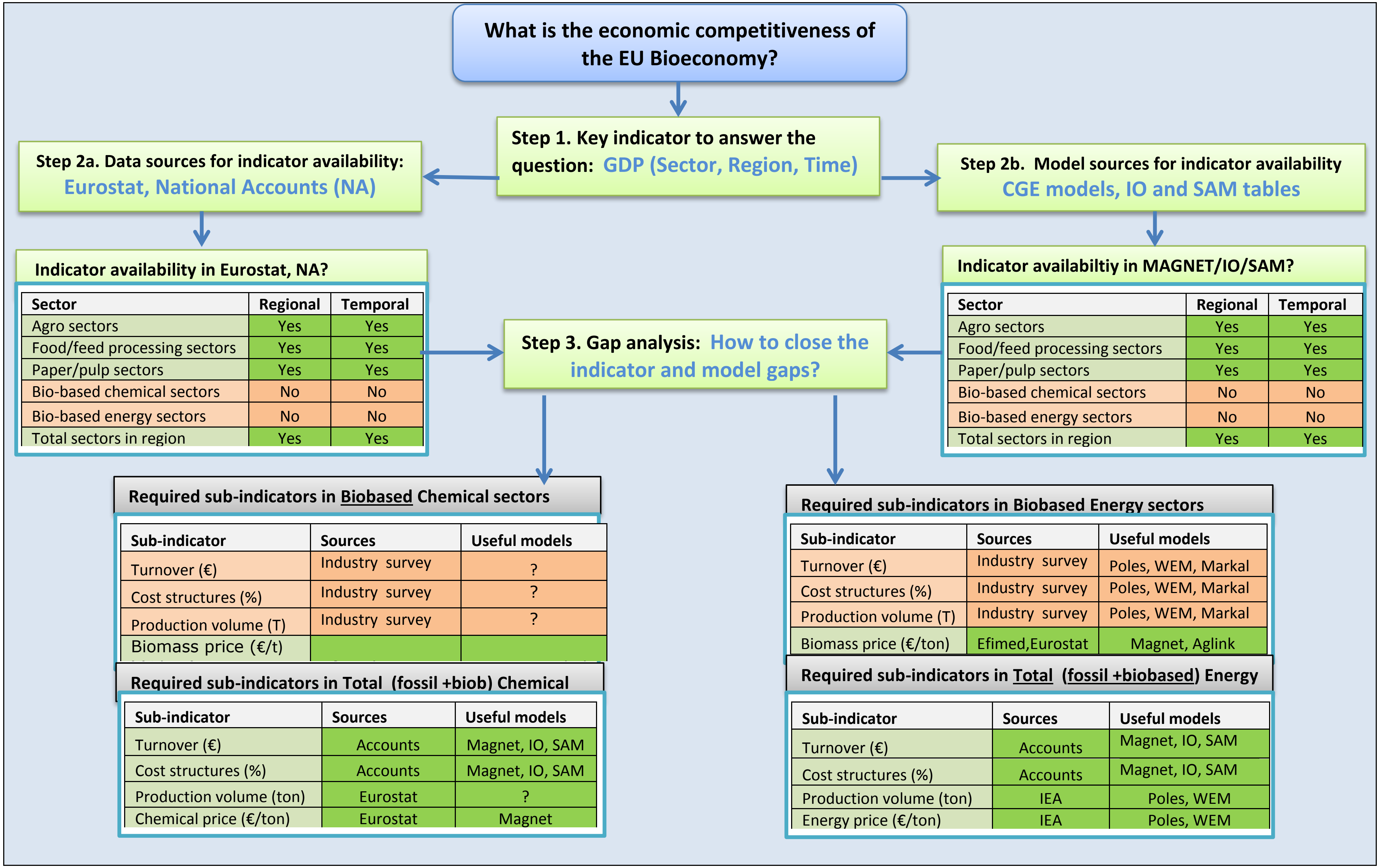
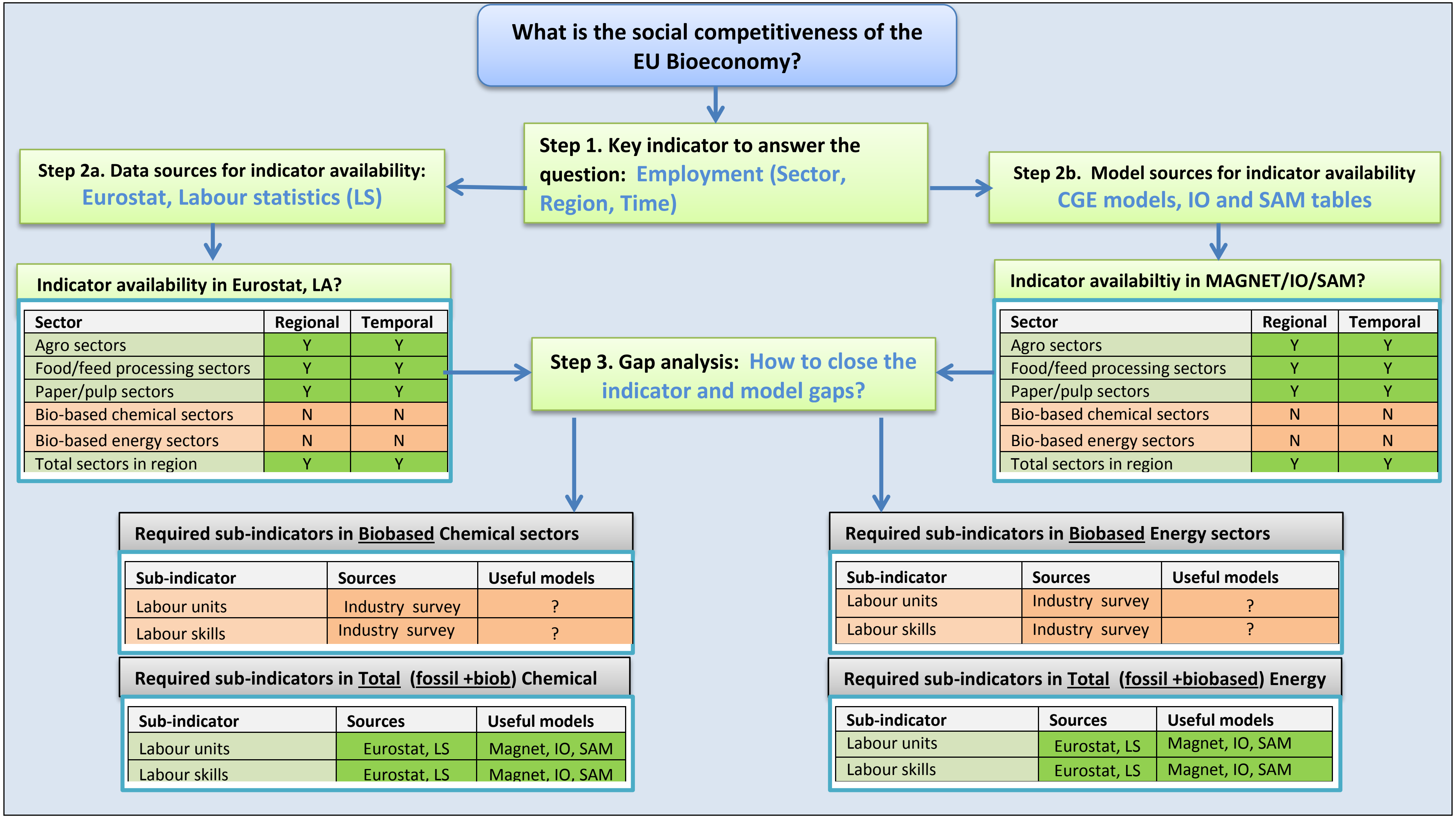


Figure 4. Data and Model requirements and gaps to be filled, for answering the question 'What is the social competitiveness of the EU bioeconomy'?



Indicator availability in Eurostat, LA?

Sector	Regional	Temporal
Agro sectors	Y	Y
Food/feed processing sectors	Y	Y
Paper/pulp sectors	Y	Y
Bio-based chemical sectors	N	N
Bio-based energy sectors	N	N
Total sectors in region	Y	Y

Indicator availabiltiy in MAGNET/IO/SAM?

Sector	Regional	Temporal
Agro sectors	Y	Y
Food/feed processing sectors	Y	Y
Paper/pulp sectors	Y	Y
Bio-based chemical sectors	N	N
Bio-based energy sectors	N	N
Total sectors in region	Y	Y

Required sub-indicators in Biobased Chemical sectors

Sub-indicator	Sources	Useful models
Labour units	Industry survey	?
Labour skills	Industry survey	?

Required sub-indicators in Biobased Energy sectors

Sub-indicator	Sources	Useful models
Labour units	Industry survey	?
Labour skills	Industry survey	?

Required sub-indicators in Total (fossil +biob) Chemical

Sub-indicator	Sources	Useful models
Labour units	Eurostat, LS	Magnet, IO, SAM
Labour skills	Eurostat, LS	Magnet, IO, SAM

Required sub-indicators in Total (fossil +biobased) Energy

Sub-indicator	Sources	Useful models
Labour units	Eurostat, LS	Magnet, IO, SAM
Labour skills	Eurostat, LS	Magnet, IO, SAM

3. What is the impact of the biobased economy on food security?

This chapter provides an overview of datasets, indicators and models that can be used to evaluate and monitor the following question:

- *What is the impact of the biobased economy on food security?*

First, the background and importance of this bioeconomy question is described in section 3.1. Then, section 3.2 discusses the data and model tools required in order to provide empirical based answers to the raised question, whereas section 3.3 addresses the data and model gaps that need to be solved in order to ensure a proper analysis.

3.1 Background and importance of issue

In 2000, the Millennium Declaration (MD) recognized the importance of food security by setting a Millennium Development Goal (MDG) to 'halve, between 1990 and 2015, the proportion of people who suffer from hunger' (target 1.C). The latest FAO estimates (FAO 2014) indicate that global hunger reduction continues: in 2012–14 about 805 million people are estimated to be chronically undernourished, down more than 100 million over the last decade, and 209 million lower than in 1990–92. In developing countries, the prevalence of undernourishment has fallen from 23.4 to 13.5%. Food insecurity remains particularly high in Sub-Saharan Africa, Southern Asia and South Eastern Asia.

The demand for biomass for the production of food is expected to double between now and 2050, while at the same time, the use of biomass for energy purposes is expected to increase rapidly as well. The use of biomass for energy has been subject of intense debate, because of possible negative impacts on, among others, food security. Higher food prices are in general considered to contribute to food insecurity in poor urban regions. Therefore bioenergy and especially biofuels from food crops have become unpopular, particularly where government policy directly stimulates markets (Osseweijer *et al*, forthcoming). The food versus fuel debate emerged as a result of the quick succession of peaks of international prices of major agricultural commodities in 2007-2008 and 2010-2011 in combination with the rapid increase in biofuel use since the beginning of this century (Sagar and Kartha, 2007). Most of the biofuels that are currently used are made from conventional starch-, oil- and sugar-containing crops, such as wheat, maize, rapeseed, palm fruit, soybeans and sugarcane. This has resulted in a large number of studies about the contribution of the biofuels to these price peaks and their impact on food security. Empirical studies suggest that biofuels contributed to 10-15% of food prices increases (UNEP, 2011). However, according to recent econometric evidence by Baffes and Dennis (2013) oil prices were the main driver of the higher food prices.

In line with recent empirical evidence, Van Meijl *et al* (forthcoming) and Osseweijer *et al* (forthcoming) conclude that the impact of current biofuel use on food prices and food security is limited, and that biofuel production may potentially also contribute to reduce food insecurity, e.g. by generating employment and additional income and by stimulating technical change. However, these reflect only some aspects of the bioeconomy, and there are many other ways through which the bioeconomy can potentially contribute to improving food security, e.g. through the development of more efficient agricultural production systems.

3.1.1 Food security concept

Food security is realised 'when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life' (World Food Summit, 1996). Food security, like the bioeconomy, is a complex phenomenon, whereby usually four dimensions are distinguished (FAO, 2006):

1) *availability* of sufficient quantities of food of appropriate quality, supplied through domestic production or imports (including food aid). Available land and food production play an important role;

2) *access* by individuals to adequate resources for acquiring appropriate foods for a nutritious diet. Dietary patterns, disposable income, consumer prices, infrastructure and land play an important role;
3) *utilisation* of food through adequate diet, clean water, sanitation and health care to reach a state of nutritional well-being where all physiological needs are met. Nutrition, diets, water and sanitation play an important role;
4) *stability*, because to be food secure, a population, household or individual must have access to adequate food at all times. Macro-economic (business cycles, trade balance), weather (droughts, climate change, irrigation) and political (violence, corruption) conditions play an important role in stability.

For food security objectives to be realized, all four dimensions must be fulfilled.

3.1.2 Linkage between bioeconomy and food security

Some stylized linkages between the bioeconomy and the four dimensions of food security are described below. This analysis summarizes the work of Achterbosch *et al* (2013), Van Meijl *et al* (forthcoming) and especially the Osseweijer *et al* (forthcoming).

Availability

The production of biomass for bioenergy affects the goal of availability dimension of food security in several ways. We first discuss the direct or static effects. First, if agricultural land is used for the production of biomass for bioenergy, it is no longer available for food production, and thus in principle, it negatively affects food production. Double cropping, reduction in fallow periods, and complimentary crop-shifting within cropping systems help counteract or eliminate these effects. The dynamic effects are initiated by the higher farm prices and increased income allows investments in irrigation, better varieties, fertiliser, education and increased efficiency. All these investments increase food production and food availability. The increased availability of high quality energy sources also has a positive effect on agricultural production, especially in areas where there is energy poverty.

Access

Access refers to the relationship between food prices and disposable income. Also, it relates to access to land and other natural resources for subsistence or smaller-scale producers, where resources are used to generate income, and/or to provide energy services or food. Prices play a role in the sense that food may be available, but are too expensive to purchase in sufficient quantities by poor households. Any additional income that is generated by bioenergy production is raising the purchasing power of the households, and is further resulting in a lower share of food costs in household expenditures. Where biobased (non-food) production is organised at small-scale and/or household-level, the access benefits could accrue directly. However, the costs and benefits will differ, such as in the case of sugarcane production in Brazil, depending on the degree of mechanisation and the extent to which displacement of small farmers occurs. To some extent these shifts are a basic feature of industrialising societies and are not closely related to bioenergy per se.

The impact on food access for farmers and land owners will be negatively affected by the higher food prices, but positively influenced by the higher income gained. Bioenergy will have a negative effect on food access for consumers that do not increase their income from biobased (non-food) production in case they do not share in increased prosperity. These effects are clearly different between the urban poor and the rural poor, like the farmers.

Utilisation

Utilisation refers to the type of food that people consume; quality and diversity is an important nutritional concern. This also relates to prices and income, but other factors, such as health care, access to clean water, education, knowledge about nutrition etc., are important as well. There is a weak link between biobased (non-food) products and utilisation. An important health issue might be the 'switching' from the use of traditional low quality fuels to inefficient and unhealthy cooking and heating devices, which leads to indoor pollution at rates that result in the annual mortality of nearly 4 million women and young children prematurely (Bruce *et al*, 2006; Conway, 2012). Modern, small scale bioenergy technologies such as advanced/efficient cook stoves, biogas for cooking and village electrification, biomass gasifiers and bagasse based co-generation systems for decentralized power generation, and energy for (clean) water pumping, can provide energy for rural communities with energy services that also promote rural development (IEA, 2011). Such improved systems could increase food safety by avoiding microtoxins and aflotoxins through better prepared and stored food (PAC, 2013). Another valuable perspective for utilisation is that of landscape ecology, in which integrated management methods can improve diversity and resilience (Dale *et al*, 2013).

Stability and resilience

Stability refers to the fact that a population, household or individual must have access to adequate food at all times. They should not risk losing access to food as a consequence of sudden shocks from weather or social factors or chronic economic and social conditions. An improvement in the functioning of markets leads to more stability (Achterbosch *et al*, 2013). Markets are closely related to prices and income as well. They determine food and biofuel prices, and consequently household incomes. It is important to understand how markets can contribute to a stable household income, allowing a stable access to food and good quality nutrition. Three ways in which households can achieve this have been identified: inclusion into value chains, opportunities of small to medium enterprises (SMEs) and local value adding. In general, producing biomass and fuels for the energy market, in addition to the food market, diversifies revenue sources for the agricultural sector and from a portfolio and risk point of view. This might reduce risk and increase income. Whenever the food market is weak (low prices) for farmers they can sell more to the non-food (e.g. energy) market. Producing energy locally might also increase energy self-sufficiency, which might increase resilience when energy markets get tight. This occurred in the developed market of the United States, where commodity use for bioenergy helped to significantly increase rural incomes. Assato and Moraes (2011) also noted that jobs generated by the expansion of the sugarcane industry in Brazil and related sectors have played a key role in reducing rural migration. Similarly, Satolo and Bacchi (2013) assessed the effects of the sugarcane sector expansion over municipal per capita GDP, noting that the GDP for one municipality and that of its satellite neighbours.

3.2 Data and model requirements

3.2.1 Data and indicators of food security

There are more than 450 indicators of food security (Hoddinott, 1999). In this report we focus on the set of indicators that is defined by the Committee on World Food Security (CFS) Round Table on hunger measurement (see Table 5). This set of indicators is also used by the FAO for measuring the progress towards the MDGs along the four dimensions of food security. The indicators are classified as indicators of determinants and outcomes of food insecurity. **Determinants**, which can be either static or dynamic, refer to structural conditions that worsen food insecurity in absence of adequate policy interventions, including emergency assistance. **Outcome indicators** capture results in terms of inadequate food consumption or anthropometric failures. Note that these indicators are especially relevant for global and national level food security assessments. Assessing food security at, for example, the level of households, is mostly done using questionnaires and surveys that include more detailed data and indicators.

Data on the food indicators in the table above are obtained from mostly publically available statistics, such as the statistical database of the FAO, OECD, WHO, ILO, etc. It should be noted that the list of indicators only partially covers indicators for measuring the severity of food insecurity. A better method is to use the Integrated Food Security Phase Classification (IPC), which is a set of standardized tools classifying the severity and magnitude of food insecurity. Aspects that are considered in the IPC are crude mortality rate, malnutrition prevalence, food access/availability, dietary diversity, water access and availability, coping strategies, livelihood assets. Second, neither the issue of vulnerability to food insecurity is covered by the indicators in the table above.

Table 5. Food security indicators of the Committee on World Food Security (CFS)

FAO Food Security Indicators	Data source
STATIC and DYNAMIC DETERMINANTS	
AVAILABILITY	
Average Dietary Energy Supply Adequacy	FAOSTAT

Average Value of Food Production	FAOSTAT
Share of Dietary Energy Supply Derived from Cereals, Roots, Tubers	FAOSTAT
Average Protein Supply	FAOSTAT
Average Supply of Protein of Animal Origin	FAOSTAT
ACCES – PHYSICAL	
Percent of Paved Roads over Total Roads	WDI
Road Density	WDI
Rail-lines Density	WDI
ACCES – ECONOMIC	
Domestic Food Price Level Index	ILO, ICP
UTILIZATION	
Access to Improved Water Sources	WDI
Access to Improved Sanitation Facilities	WDI
STABILITY - VULNERABILITY	
Cereal Import Dependency Ratio	FAOSTAT
Percent of Arable Land Equipped for Irrigation	FAOSTAT
Value of Food Imports in Total Merchandise Exports	FAOSTAT
STABILITY - SHOCKS	
Political Stability and Absence of Violence/Terrorism	WorldWide Governance Indicators
Domestic Food Price Volatility Index	N/A (FAO computation)
Per Capita Food Production Variability	FAOSTAT
Per Capita Food Supply Variability	FAOSTAT
OUTCOMES	
ACCESS	
Food availability	FAOSTAT
Prevalence of Undernourishment	FAOSTAT
Share of Food Expenditure of the Poor	FAO elaborations and ILO publications
Depth of the Food Deficit	FAOSTAT
Prevalence of Food Inadequacy	FAOSTAT
UTILIZATION	
Percentage of Children under 5 years of age Affected by Wasting	WB WDI
Percentage of Children under 5 years of age who are Stunted	WB WDI
Percentage of Children under 5 years of age who are Underweight	WB WDI
Percent of Adults who are Underweight	WB WDI
Prevalence of anaemia among children under 5 years of age	WHO
Prevalence of Vitamin A deficiency among children < 5 years of age	WHO
Prevalence of Iodine deficiency	WHO
Prevalence of anaemia among pregnant women	WHO
ADDITIONAL INDICATORS	
Number of People Undernourished	FAOSTAT
Minimum Dietary Energy Requirement (MDER)	FAOSTAT
Average Dietary Energy Requirement (ADER)	FAOSTAT
Minimum Dietary Energy Requirement (MDER) - PAL=1.75	FAOSTAT
Coefficient of Variation of Habitual Caloric Consumption Distribution	FAOSTAT
Skewness of Habitual Caloric Consumption Distribution	FAOSTAT
Incidence of Caloric Losses at Retail Distribution Level	FAOSTAT
Dietary Energy Supply	FAOSTAT
AVERAGE FAT SUPPLY	FAOSTAT

Vulnerability is defined in terms of three dimensions: 1) vulnerability to an outcome, 2) from a variety of risk factors, and 3) because of an inability to manage those risks. Two main intervention options are discussed: 1) reduce the degree of exposure to the hazard, and 2) increase the ability to cope. It goes beyond the scope of this report to discuss indicators and data sources that are relevant when measuring the severity of food insecurity and vulnerability to food insecurity. Further information may be found on: http://www.ipcinfo.org, http://www.foodsec.org/web, http://www.foodsecure.eu.

Many potentially useful statistics are available that provide information on issues that directly or indirectly relate to food security, such as food prices, food price volatility, (un)employment rates, agricultural and trade policies, literacy rate, educational attainment, farm survey data, land ownership, etc. An overview of such data sources is provided in Deliverable Report 2.1 and Deliverable Report 2.2.

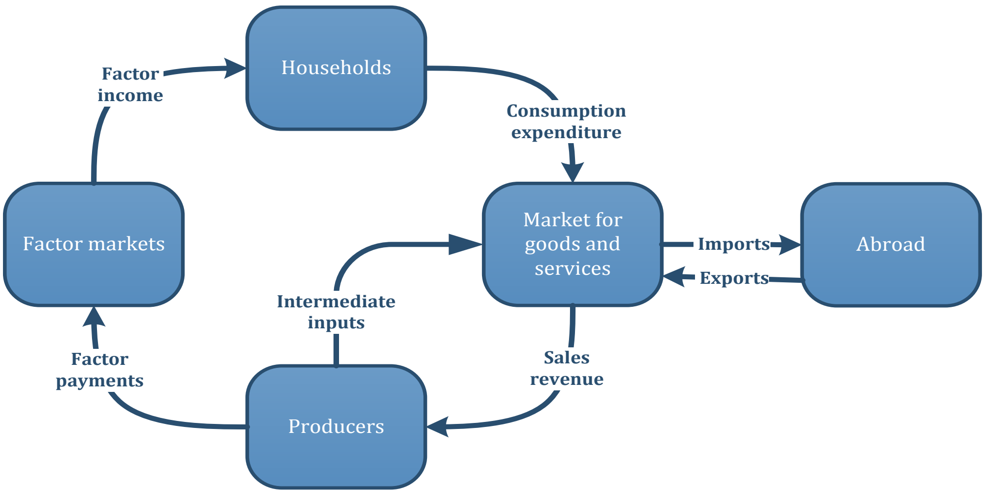
3.2.2 Modelling the food security impact of the bioeconomy

Chapter 2 and Deliverable Report 2.3 identify and characterize a large number of tools and models that are relevant to evaluate the impact and progress of the bioeconomy. In this section we briefly discuss the most important types that are relevant for monitoring the food security impact of the bioeconomy: econometric assessments, PE models, CGE models and site specific decision support tools. Each of these three approaches has its specific advantages and disadvantages. Note that many more tools and models are indirectly relevant, see further Deliverable Report 2.3.

Econometric assessments use historical time series to determine economic correlations. For example, increasing the use of biofuels result in higher correlations and price transmission effects between energy and agricultural markets, which reflects one of the most fundamental changes in agricultural economics of the last decades. Serra and Zilberman (2013) carried out a review of 45 models that investigate the impact of biofuel policies on the price level and price volatility of agricultural commodities. However, such assessments only provide partial insight into the exact pathways and factors through which biofuels influence food security, since these studies do not consider the explicit impact on food consumption and the extent to which incomes may be positively affected by biofuel production. Moreover, econometric assessments usually do not deal with the food security indicators in Table 5, but often only investigate price and consumption effects.

PE and CGE models are better equipped to show the different pathways through which the bioeconomy influences the use of production factors such as land, labour, water, influences incomes and prices as well as production, consumption (Figure 5). Food access requires analyses at household level to identify the impact for various households (see www.foodsecure.eu). Utilisation requires that not only monetary but also nutrition flows should be taken into account. Key drivers of the impact of the bioeconomy on food security are demographic developments, consumer preferences, economic development, innovation and technical change and climate change and resource efficiency (for an overview of relevant data sources see Deliverable Report 2.1 and Deliverable Report 2.2).

Figure 5. Circular flow of expenditure and income



Three **CGE models** are included in the inventory of models and tools: 1) MIRAGE: Modelling International Relationships in Applied General Equilibrium, 2) MAGNET: Modular Applied GeNeral Equilibrium Tool, and 3) GTAP: Global Trade Analysis Project. In all three models the GTAP database is crucial, which is the most widely used collection of global data, describing bilateral trade patterns, production, consumption and intermediate use of commodities and services. This database provides only economic data at the national level. For foodsecurity analyses it should be extended with household and nutrition data (see www.foodsecure.eu). In addition, the detail of its sector disaggregation level is limited (see further Deliverable Report 2.1).

The principal 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. The models make assumptions about demographic and economic developments which are exogenous, whereas innovation and technical change and consumer preferences are usually endogenously determined. CGE models are particularly useful for studying the food security impacts of significant bioenergy deployment in the short and medium term, especially when they are used and designed with a high level of disaggregation, and when sectoral and regional inter-linkages are relevant.

As explained in Chapter 2, there are also many important uncertainties and limitations to CGE modelling analyses. 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. 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. The representation of technology and technological change is usually limited, although there are some recent developments to improve this (see, section 2). The study of Smeets *et al* (2014) is relevant because it evaluates the impacts of the use of wheat straw in the bioeconomy in the EU on land use, food prices, food production, consumption and trade in the EU and globally (Box 2). In general, the current CGE models cover the food availability dimension and to some extent the food accces dimension by generating income and price developments. Within the Foodsecure project (www.foodsecure.eu) the MAGNET and MIRAGE CGE models are extended with household level data to model better capture the food access dimension and a first attempt is made to extend these models with nutrition data to cover the food utilisation dimension.

A wide variety of **PE models** has been identified and classified in Deliverable Report 2.3 of WP2. The advantage of PE models is their high level of flexibility in incorporating a large amount of detail in process representation and input data. Their strength is in the domain of food availability; food access is a challenging topic as these models do not cover factor markets. While CGE models also require a large quantity of information related to input-output tables, the information needed in PE models is limited to sectors under consideration. This limits the need for lengthy and distortive full rebalancing of the dataset. This means that PE models can deal with a high(er) level of detail. Models such as the Common Agricultural Policy Regionalised Impact (CAPRI) model (Shrestha *et al,* 2013), encompass a large number of sectors and regions, and provide a high level of detail in the supply and demand representation. Other examples of PE models that consider the agricultural sector are AGMEMOD, AGLINK, RAUMIS, IMPACT, GLOBIOM and ESIM. A similar variety of PE models is available for energy models (e.g. POLES, TIMER). Moreover, the HORTUS model covers the horticultural sector in the EU, EFI-GTM considers the global forest sector, FISHRENT deals with the fisheries sectors only, and GAZMO is about the biogas sector. See Deliverable Report 2.3 for an overview of PE models.

An example of food insecurity projections using a PE model is the agricultural IMPACT model (Rosegrant *et al*, 2013). IMPACT provides several projections of food availability and malnutrition by estimating the relationship between dietary energy intake (and other correlates) and changes in malnutrition status in young children. Note that food security tends to be more closely monitored in developing countries, compared to most EU countries. Therefore, indicators that are derived from the internal calculations of economic models of the agricultural economy tend to be better calibrated for the less-developed regions in which hunger is a major policy concern. However, obesity is also a form of malnutrition that is becoming more prevalent in OECD countries and emerging economies where diets are rapidly changing. At present, there is no model-based assessment that captures the potential changes in the incidence or prevalence of obesity in a systematic way. The focus on dietary energy (calories) in PE/CGE assessments also leaves out the important dimensions of 'hidden hunger' that are embodied in deficiencies of key micro-nutrients in the diet, such as vitamin A, Zinc and Iron (Kennedy at al. 2003). Even if the micro- or macro-nutrient content of foods that are consumed could be captured through straightforward calculations, based on observed data – their correlation with actual health outcomes is relatively weak, and remains an area for further research collaboration between specialists in the field of health and agriculture. The illustrative work of Msangi *et al* (2010) is an example of model-based methods of assessments that have been applied to less-developed regions.

Box 2: Evaluating the land use change and food security effects of the use of residues and waste for bioenergy production

The use of residues and waste is frequently suggested as a way to avoid undesirable land use change and food security effects arising from the use of crops for energy and material production. However, the use of, for example, wheat straw increases the profitability of wheat production, which increases the incentive to produce wheat. This concept is implemented in MAGNET, a computable general equilibrium (CGE) model, using the sustainable potential of wheat straw of 0.54 EJ available for energy production in the EU in 2030 as a case study. Two scenarios are evaluated that differ with respect to the price of wheat straw and thereby the profitability of the collection of wheat straw. Scenario 1 assumes a wheat straw price of 5.9 US$/GJ; scenario 2 a wheat straw price of 9.4 US$/GJ.

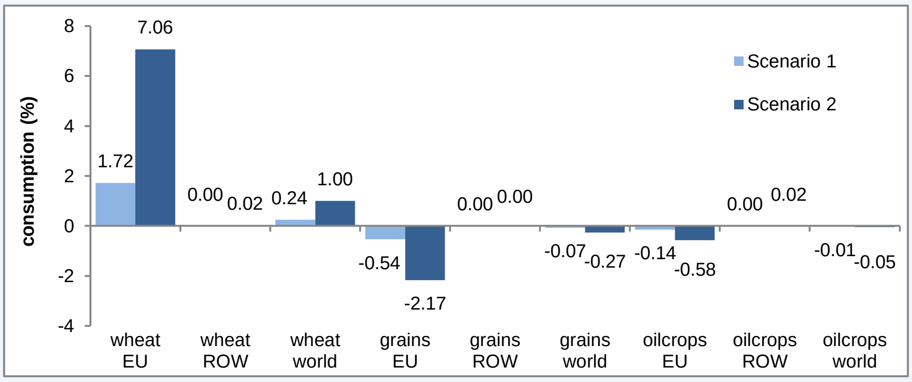


Figure: Consumption of wheat, grains and oilseeds in scenario 1 and 2 compared with the BAU scenario (in % change).

Results show that the price of wheat in the EU decreases, while at the same time the production and consumption of wheat in the EU increase. The consumption of wheat in the EU increases substantially (1.7% to 7.1%; see the Figure above). Substitution of the use of grains and oil crops for animal feed with wheat reduces the consumption of these crops in the EU. The consumption of wheat in the rest of the world (ROW) increases slightly (0.02% or less) and the same goes for the consumption of other primary agricultural commodities. The net effect is that the total consumption of food (i.e. the direct consumption of primary agricultural commodities and of processed food) increases, both in the EU (up to 0.01% in scenario 2) and in the ROW (0.002% or less). These results show that the use of wheat straw in the EU contributes to an improvement of the food security situation in the ROW and in the EU. However, the food security effects differ per country and per population group. Consumers benefit from the lower prices of agricultural commodities, but producers and workers in agricultural sectors may experience a reduction of food purchasing power in case food prices decrease more than the decrease in income.

Source: Smeets *et al* (2014a)

PE models have several limitations. The first is that PE models do not include links with other sectors. However, bioenergy being at the nexus between agricultural/forestry and energy/chemical sectors. There are several ways to circumvent this issue. Two PE models can be linked and solved simultaneously (Msangi *et al,* 2014). The PE model can be extended to a simplified representation of fossil fuel markets (Chen *et al,* 2012). A mix of the two is also possible, by establishing links between the various model approaches (see the section on integrated assessment models). Incorporating food access in PE models is a challenge as factor markets, where incomes are determined, are not included. Another issue is the absence of macro-economic closure, which can introduce a 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. In addition, for oil exporting countries, the effect on the exchange rates of production and trade of technologies that replace oil based production systems and the feedback loops from government revenues on welfare and consumption are often neglected, which does not allow to make a full welfare and food security analysis of biofuel policy impacts with PE models.

A fourth category of tools and models are **decision support tools**. Such tools are frequently used in day to day management in agriculture and forestry production systems (see for example http://www.csiro.au/Organisation-Structure/Flagships/Sustainable-Agriculture-Flagship/Decision-support-tools-agri.aspx). An example is the Roundtable on Sustainable Biofuels (RSB) certification system states. Principle 6 of the RSB states "Biofuel operations shall ensure the human right to adequate food and improve food security in food insecure regions". This principle applies to operators believed to work in food insecure countries and regions of countries where a significant proportion of the population are deemed to be at risk of food insecurity. Principle 6 of the RSB standard has two criteria - 6a and 6b - that should be addressed by any food security impact assessment (FSIA). Criterion 6a states, "biofuel operations shall assess risks to food security in the region and locality and shall mitigate any negative impacts that result from biofuel operations". The RSB also includes detailed protocols for measuring food security and provides five guidance mitigation measures for biofuel operators to enhance food security, such as setting aside land for growing food and increasing the yield of food crops.

3.3 Gaps and further needs

Monitoring and evaluating the food security effects of the bioeconomy requires a large amount of data on food security indicators and information on economic mechanisms that determine food security effects. Data for the food security indicators in Table 5 are in general available from existing statistics and also data for other indicators can be collected from existing databases (Table 6). The quality of these data varies, but is generally sufficient at an aggregated level. However, for specific indicators and aspects there are large gaps in data and/or data quality, such as for the production and use of residues and waste, illegal logging, household level data on food security, intake of macro- and especially micro-nutrients, cascading of biomass, etcetera. A more detailed description of gaps in data can be found in Deliverable Report 2.1 and Deliverable Report 2.2.

Table 6. Overview of data availability and quality

Indicators	Data requirements	Data availability	Data Quality	Relevant sources
WFS Food security indicators	Various, see Table 4.	4	4	FAOSTAT, WHO, ILO, WDI, IPC.
Change in food prices	European and Global food prices and food price indices, on annual basis	4	5	FAOSTAT, EUROSTAT
% change in food price volatility	Estimation of percent change in food prices and crops for bioeconomy	4	5	FAOSTAT, EUROSTAT
Change in malnutrition	Data on changes in numbers of undernourished people in global and national levels	5	3	WHO, FAOSTAT
Change in employment rate	Data on employment rate on an annual basis	5	5	EUROSTAT, OECD, ILOSTAT
Number of Full Time Equivalent jobs	Full time equivalent jobs per sector per year	5	5	OECD, ILOSTAT, EUROSTAT
Job creation in skilled / unskilled labour	Data on employment and employment creation in skilled, low skilled, manual, elementary occupation labour	4	4	EUROSTAT, ILOSTAT
Average income of employees in the bioeconomy sectors	Data on average annual income of workers per sector	2	4	ILOSTAT, EUROSTAT
Average number of work days lost per worker per year	Data on average number of work days lost per worker per year, per sector	2	4	ILOSTAT, EUROSTAT
Quality of life	Data on level of life satisfaction, ability to meet needs, values, rights, social interaction, health, etc. at a national level	2	2	Eurostat

Legenda:	1 (weak)	2	3	4	5 (strong)

Further, Dale *et al* (2013) mentions that to come up with an unambiguous indicator for food security is made difficult because of the uncertainty of impact pathways. Typical indicators used are food prices and malnutrition while at the same time food (in)security impacts cannot solely be attributed to one proxy as they are also related with poor governance, low-priced food commodities and food aid, food price volatility etc. This is also acknowledged by the United Nations that state that "better data and additional indicators are needed to provide a more holistic assessment of undernourishment and food security" (UN 2013).

From the modelling perspective, first of all, the same shortcomings or challenges remains as identified in Chapter 2. The representation of new biobased technologies or sectors and the modelling of land use (agriculture, forestry) are problematic. Key challenges for CGE models are the sectoral details and representation of technologies, while for PE models they are the linkages with other sectors and factor markets. The latter is even more important for food security impacts as disposable income is important for food access. Two important additional challenges to cover all four dimensions of food security are (1) the explicit modelling of various households and (2) the inclusion of the nutritional dimension. The coverage of household data for various regions in the world is mixed and information on macro- and especially micro nutrients is scarce.

Within the Foodsecure project, the MAGNET and MIRAGE CGE economic models are extended to include multiple types of households for key developing countries. The resulting model can be used to identify the winners and losers of an expansion in the biobased economy, and to identify the conditions under which such a shift can be beneficial for those in developing countries. Also more detailed food security indicators are currently implemented in MAGNET, such as data on the intake of calories, proteins, fats and carbohydrates by country, by household type and by sector. The next step is the inclusion of policies aimed at improving the food security situation. Examples of such policies are the use of degraded, low productive area, abandoned cropland or rest land, the use of wastes and residues from agriculture and forestry, reducing food losses, increasing the efficiency of agricultural and forestry production systems, the use of local workers and inputs; providing of fair wages (e.g. Ecofys 2010; Ernst & Young 2011; Wicke *et al,* 2011; RSB 2012; Achterbosch *et al,* 2013).

4. Key findings

The SAT-BBE project responds to the challenge of optimizing the emerging bioeconomy by providing an analytical framework (a Systems Analysis Framework for the Bioeconomy) to assess and address the short and long term challenges for an effective and sustainable EU strategy. The project provides an interdisciplinary scientific basis to inform the bioeconomy policy development and decision-making by all stakeholders working within the EU to help improve the conditions for satisfying the bioeconomy potential today and in the coming decades.

The SAT-BBE project describes, monitors and models the bioeconomy part of the economic system, by the development of an appropriate conceptual toolkit. In WP1, the concepts of bioeconomy and non-bioeconomy sectors are defined, the major interactions and feedback effects between the bioeconomy and other parts of the system are identified and analysed. Also, the likely impacts and trade-offs of the bioeconomy drivers (e.g. economic growth, climate change) are studied. WP2 in the SAT-BBE project provides an inventory of tools for evaluation and monitoring the EU bioeconomy, according to the data bases required, the indicators available, and the quantitative and qualitative models currently used or under development.

To make report 2.4 useful for policy makers, the data and model gap analysis in this report is aligned with taking the following bioeconomy related issues as research objects to be monitored and evaluated:

- What is the socio-economic competitiveness of the EU bioeconomy?
- What is the impact of the bioeconomy on food security?

These issues make clear that the development towards a bioeconomy is a complex systems change, as it deals with broad aspects like food security, resource efficiency, biodiversity, and job and GDP creation.
Measuring the current and future development of the bioeconomy highly depends on modelling analysis, surveys and expert knowledge, which means that the delivered outcomes still show a high degree of uncertainty. In general, more detailed data about **new biobased products and markets** are needed, due to the impact of innovation and technical change, is a key task to limit the uncertainty in monitoring the bioeconomy process.

There is a need to **improve data availability and quality for environmental, economic and social indicators**. 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 more aggregated NACE levels[2] are not useful. Other data and model gaps that have been found when studying the aforementioned two bioeconomy related issues. The following necessary data is not available to out knowledge:

- rate of employment and quality of employment in biobased sectors;
- returns and production costs related to biobased sectors;
- Use of biomass material for product and design of biomaterials;
- potential and current use from forest/agricultural sectors;
- state of natural resources in EU and beyond;
- impact of innovation and technological change;
- food security indicators.

New biobased technologies or sectors and the modelling of land use (agriculture, forestry) should be included in models to calculate the socio-economic aspects and or competitiveness of the bioeconomy. CGE models in general lack sectoral details and representation of technologies, while PE models lack linkages with other sectors and factor markets. Extending the analyses to the food security impacts of the bioeconomy requires that all four dimensions of food security (i.e. availability, access, utilisation, stability) are taken into account. This requires the explicit modelling of various households and the

[2] 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).

inclusion of the nutritional dimension. However, the availability of household data in various regions in the world is mixed and information on macro- and especially micro nutrients is scarce.

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Annex 1. Summary table based on information from Deliverables 2.1, 2.2 and 2.3

Table A1 Indicators, data and model qualification for monitoring the evolution of the EU bioeconomy

Indicators - Economic	Data requirements	Data from statistics	Data availability	Data quality	Data from Models	Model data quality
Turnover of the bioeconomy (and contribution to total GDP)	Economic accounts of bio-based sectors (input-output tables)	National accounts (e.g. SN, 2013), OECD Input Output tables database (OECD, 2013), Eurostat (2013a). Insufficient desaggregation of bioeconomy sectors	3	2	GTAP database (GTAP, 2013); Social Accounting Matrix (Müller, 2009); MAGNET/ORANGE database. Insufficient desaggregation of (new) bioeconomy sectors	2
	Statistics on production and trade of various bio-based products	National or international statistics, such as Eurostat (2013b), Prodcom, national statistical databases, OECD databases, UNCOMTRADE database (2013), or specific databases such as the Pellets@las database on wood pellets (Pellets@las, 2013)	5	4	GTAP database (GTAP, 2013); MAGNET/ ORANGE database. Insufficient desaggregation of (new) bioeconomy sectors	2
Primary production within the EU (agriculture, forestry, waste and residues)	Statistics on production of biomass by type of biomass	Various Eurostat databases (Eurostat, 2013b): Supply Balance Sheets; Crop production and Land use; Livestock and Meat; Milk and Dairy; FAOSTAT (FAO, 2013), USD PSD database (USDA, 2013)	4	4	AGLINK database; AGMEMOD database. Cover various biomass processing flows; need to be enhanced. Data on waste and residues are weak.	3
Import of biomass from various countries and sources (agriculture, forestry, waste and residues)	Data on import volume and value by country and by biomass type	UNCOMTRADE database (2013), Forest Products Trade Flow Database (EFI, 2013), Eurostat COMEXT databases (Eurostat, 2013b); specific databases,e.g. Pellets@las database on wood pellets (Pellets@las, 2013)	4	4	GTAP database (GTAP, 2013); BACI database, MAGNET database. Insufficient desaggregation of bioeconomy sectors	2
Production and use of biobased products	Statistics on production and use of bio-based products in volume and value per country and bio-based product	National or international statistics, such as Eurostat (2013b), Prodcom, national statistical databases, OECD databases, or specific databases such as the Pellets@las database on wood pellets (Pellets@las, 2013) and industry association statistics (e.g. EU bioplastics)	5	4	GTAP database (GTAP, 2013); Social Accounting Matrix (Müller, 2009); MAGNET/ORANGE database; AGLINK database; AGMEMOD database. Insufficient desaggregation of (new) bioeconomy sectors	2
Price of biomass and biobased products (and changes therein)	Data on price of biomass and biobased products from various sources and countries	Eurostat (2013b), Spot and futures (Wall Street Journal, London, Paris), FAOSTAT (Consumer Price, Food Price Index, International Prices, National Prices, PriceStat), specific database such as the UNECE database (UNECE, 2013) on forest product prices.	4	4	GTAP database (GTAP, 2013); Social Accounting Matrix (Müller, 2009); MAGNET/ORANGE database; AGLINK database; AGMEMOD database. Insufficient desaggregation of bioeconomy sectors	1

Indicators – Social	Data requirements	Data from statistics	Data availability	Data quality	Data from Models	Model data quality
Employment in the bioeconomy (and contribution to total employment)	Data on net employment in the bioeconomy sectors by e.g. type of labour and skills	LABOURSTA (ILO, 2013), national statistics, industry statistics, Eurostat (2013). Insufficient desaggregation of (new) bioeconomy sectors	3	2	GTAP database (GTAP, 2013); Social Accounting Matrix (Müller, 2009); MAGNET/ORANGE database. Insufficient desaggregation of (new) bioeconomy sectors	2

Legenda:	1 (weak)	2	3	4	5 (strong)

Indicators - Environmental	Data requirements	Data from statistics	Data availability	Data quality	Data from Models	Model data quality
Global land use for biomass based consumption in EU	Data on import volume by country and by biomass type as well as conversion values (e.g. yield rates) for converting to land and national harvested land area	UNCOMTRADE database, Eurostat COMEXT database, FAOSTAT yield factors, German Ministry for Agriculture, LCA studies and generic sources such as USDA-ERS. Insufficient desaggregation of (new) bioeconomy sectors	2	2	CLU-Mondo; Global Forest model G4M; Insufficient desaggregation of bioeconomy sectors GLOBIO (PBL, 2010): Insufficient desaggregation of biodiversity aspects	2
Energy use in bioeconomy (and contribution to total energy use)	Data on net energy use in bioeconomy sectors by e.g. type of use	Environmental statistics, industry statistics, Eurostat (2013). Insufficient desaggregation of (new) bioeconomy sectors	3	2	GTAP database (GTAP, 2013); MAGNET/ORANGE database: insufficient desaggregation of (new) bioeconomy sectors	2
Emission in bioeconomy (and contribution to total emission)	Data on net emission in bioeconomy sectors by e.g. type of emission	Environmental statistics, industry statistics, Eurostat (2013). Insufficient desaggregation of bioeconomy sectors	3	2	Erosion Prediction Impact Calculator EPIC (IIASA); country/region level. GTAP database (GTAP, 2013); MAGNET/ORANGE database: insufficient desaggregation of bioeconomy sectors	2

Legenda:	1 (weak)	2	3	4	5 (strong)