# Sustainable Agriculture, Forestry and Fisheries in the Bioeconomy

# A Challenge for Europe

*4th SCAR Foresight Exercise*


*Research and Innovation*

**EUROPEAN COMMISSION**

Directorate-General for Research and Innovation
Directorate F – Bioeconomy
Unit F.3 – Agri-Food Chain

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# Sustainable Agriculture, Forestry and Fisheries in the Bioeconomy - A Challenge for Europe

4th SCAR Foresight Exercise


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# FOREWORD

People have both developed and benefitted from land- and sea-based biological production systems since the beginning of civilisation. Today, such systems are faced with the challenges of scarce natural resources, increased demand, climate-related stresses and diminishing land availability. This unpredictability has provoked the need for pragmatic and sustainable solutions, which invoke cross-sectorial integration of the complete food and non-food production chains, while fully engaging societal needs.

Research and innovation solutions are addressed within the political objectives of the new Juncker Commission which, amongst others, focuses upon jobs growth and investment, climate change and Europe as a stronger global actor. Accordingly, the Commissioner for Research and Innovation, Carlos Moedas, is addressing these political objectives through Open Innovation, Open Science and European Research Open to the World. This involves a focus upon capitalising the results of research & innovation, boosting excellence in cutting-edge fundamental research and reinforcing our international engagement through science diplomacy. A major driver of research funding is the Horizon 2020 programme launched in 2014, which will capture the complexity of the problem through practical, cooperative solutions within a fit-for-purpose bioeconomy research and innovation agenda. Underpinning this approach is the 2012 Communication of the European Commission (COM(2012)60) on 'Innovating for Sustainable Growth: A Bioeconomy for Europe' which began the transition towards realising the full societal and competitive potential of biological production systems.

It is also within this context that the Standing Committee on Agricultural Research (SCAR) in 2014 decided to extend the previous 2011 SCAR foresight beyond agriculture and encompass the broad bioeconomy sectors of forestry, fisheries and aquaculture and bio-based products. They embarked upon the 4$^{th}$ SCAR Foresight Exercise to identify the principles that would enable primary production to address the complexity of the challenges and how the bioeconomy can develop within the paradigm of a competitive bioeconomy fundamentally framed by the need for sustainability.

It gives me great pleasure to present to you the results of this exercise. It represents a formidable body of work and a critical research and innovation response to these challenges, carried out by a dedicated group of experts, who engaged all relevant stakeholders from the outset in a fully participatory process. The report equally reflects the opinion of SCAR, which plays a key role in representing Member States' opinion. Through these principles, a common understanding on how to develop a sustainable bioeconomy has been defined. New insights are presented identifying what a fully operational bioeconomy will mean for the primary sectors, with respect to biomass demand and availability. Recommendations are made on the underpinning principles, the overall scope, emerging themes and the necessary organisational structure. It brings added value in helping to orient both national bioeconomy policies and the European research and innovation agenda while positive sectorial results can serve as examples of working bioeconomy models for all stakeholders.

The report can be seen as part of a new narrative to help shape the EU's future research and innovation approach to global Food and Nutrition Security (FNS). The 2015 MILAN EXPO 'Feeding the Planet, Energy for Life' has been welcomed by global leaders and international actors who realise that good governance, economic growth and better functioning markets, and investment in research and technology, together with increased domestic and private sector investment and development assistance can all contribute to increasing food security and improving nutrition. Along with the EXPO conclusions it will also help the different development actions and agencies to align the Post-2015 Development Agenda, which aims to lift 500 million people in developing countries out of hunger and malnutrition by 2030.

Substantial research and innovation investment will be required to strengthen and support dynamic rural transformations, promote responsible investment, sustainable and climate-smart agriculture and food value chains, and foster multi-sectorial approaches to nutrition, even in areas of conflict and crisis.

In this report, we have not only a road map for a sustainable bioeconomy that will help to boost jobs, growth and investment, but also an important research and innovation contribution towards achieving these ambitious and urgent global goals.

John Bell

Director, Bioeconomy, DG RTD, EC

# 1. The 4th foresight exercise

## 1.1. Introduction

This publication includes five core parts: the foreword signed by the Chair of the Standing Committee on Agricultural Research (SCAR), the explanation on the foresight exercise and its background, the 4th Foresight experts report, an infographic prepared on the basis of the report, and the Reflection of the Standing Committee on Agricultural Research.

The first chapter is based on the terms of reference endorsed by the SCAR at its plenary meeting in December 2013. The terms of reference were used to guide the exercise and as reference material for the experts to develop their report.

The second chapter comprises the experts report. The report has its own structure and the content is the sole responsibility of the 10 experts who wrote it, which does not reflect the SCAR's or the European Commission's opinion.

The foresight exercise was meant to frame a wider discussion at Member States level. To facilitate the debate, an infographic about the possible scenarios inspired by the report was produced in all EU languages. The aim was to steer the discussions not only in the EU institutions but also in the (beneficiary) countries. The foresight exercise and its recommendations should trigger a national discussion on the future of the primary production sectors such as agriculture, forestry, fisheries and aquaculture in the bioeconomy and on the possible solutions for challenges ahead. For reprinting and dissemination purposes, the infographic is available for download on the SCAR webpage.

The SCAR developed and endorsed its own reflection about the experts' report presented in the forth chapter. The Member States' opinion could serve as background material for policymakers. On the basis of this publication, each sector and each stakeholder should identify a message on the objectives for a common future. This shall have an influence on the work of the European Commission, the work of the SCAR and implicitly for the work of national governments.

## 1.2. Background of the SCAR Foresight process

When the SCAR began to rebuild its position as a European advisory body on research policies for the Member States and the European Commission (EC), the foresight process was identified as a principal instrument to develop research agendas. In June 2006, the SCAR-Plenary agreed to execute regular foresight exercises. Consequently, SCAR implemented a mechanism for monitoring foresights in the agricultural field and the EC took the initiative to organise these exercises. Since 2006, linked with the 7th Framework Programme (FP), three Foresight Exercises have been carried out. The results built the basis for the advisory functions of the SCAR to Member States, the EC and for innovative research activities at EU level. The SCAR Foresight process continuously adapts to new challenges, takes up cross-cutting issues, feeds the strategic planning of research policymaking and gives advice to political decision-makers.

The 1st Foresight (2007) Study examined prospects for agriculture on a 20-year perspective based on a challenge approach allowing the identification of innovation needs based on disruption scenarios.

The 2nd Foresight (2009) Study highlighted the necessity of better balancing the current predominant economic thinking with attention to ecological resilience and social crises. The increasing scarcity of resources (oil, water, phosphorus (P), potassium (K), biodiversity, land) and the adverse impacts on the environment (e.g. pollution of air, water, land, greenhouse gas emissions, etc.) are a major challenge for agriculture and increasingly for global food security.

The 3rd Foresight (2011) Study clearly recognised the challenge of scarcity based on the productivity and sufficiency paradigms. The scarcity issues were strongly interlinked and any action in one field needs to take the action in others areas into account because of the many feedback loops among them. There is an urgent need to get a better understanding of the key linkages and feedback loops of these scarcity issues for agriculture and food security, for energy security and for environmental sustainability.

The questions of the 3rd Foresight Study remain relevant for the coming decades and the new SCAR Foresight exercise should address them. The greatest challenge of our century is to provide enough food, feed, fuel and fibre in a resource-constrained world. Sustainable development requires long-term maintenance of: (1) life support factors such as biodiversity, sufficient (clean) water, soil fertility, suitable climate; (2) renewable resources; and (3) technology to avoid depletion of non-renewables (rare metals, minerals, petroleum). To meet the target of sustainable biomass production and conversion, new ecologically-based and resource-efficient technologies are needed.

Under the Horizon 2020 a new cycle of the SCAR Foresight process was needed in order to orient the Bioeconomy Strategy for Europe with a longer term perspective. Due to the speed of change and the further development of the process, the 4th SCAR Foresight Exercise should follow the evolution of the three previous exercises in the context of implementing the Bioeconomy Strategy for Europe. The aim is to identify emerging research questions and to anticipate future innovation challenges.

## 1.3. The mandate of the 4th SCAR Foresight Group

The SCAR Foresight Group (FG) led by Germany, France and Italy (1) received a mandate from the SCAR plenary (17 December 2012) to carry out an analysis for the continuation of the SCAR Foresight process. SCAR members, strategic and collaborative working groups (SWGs/CWGs) and other relevant groups and initiatives (e.g. Joint Programming Initiatives (JPIs), ERA-Nets, European Innovation Partnerships) were included in the exploration process. With the support of the German Federal Ministry of Food and Agriculture, a consultation was held in Berlin on 23 October 2013 to agree on the objectives and the method of work for a cooperative new Foresight Exercise.

In February 2013 a Bioeconomy Observatory was set up with the Joint Research Centre (JRC) to implement the bio-economy strategy in Europe. The main tasks of the Observatory are to monitor, to map and to collect data relevant to the pillars 'Research', 'Policy' and 'Markets'. SCAR and the Bioeconomy Observatory agreed to work in close contact and to use synergies. SCAR also cooperates in the same way with the JRC Foresight group on Global Food Security.

The 18th SCAR plenary took a formal decision on the approach, direction and timeline presented by the Foresight Group for a new SCAR Foresight Exercise under the heading: 'Sustainable Agriculture, Forestry and Fisheries in the Bioeconomy — A Challenge for Europe'. The SCAR Foresight Group was mandated to prepare the 4th Foresight Exercise based on specific Terms of Reference (ToR) for the 4th Foresight Experts Group (4th FEG) to be appointed in 2014. The ToR was discussed by representatives from relevant SCAR groups with their own foresight activities, as well as with relevant bioeconomy stakeholders and the EC.

## 1.4. New challenges for agriculture, forestry, fisheries and aquaculture sectors in the Bioeconomy

Within the last few years, the rate of change has accelerated and trade-offs between food and biomass supply on one hand and loss of biodiversity and ecosystem services on the other hand have become increasingly critical. Moreover, political decisions that have been taken (e.g. implementation of the EC's Bioeconomy Strategy (2) and parallel strategies at national level by some Member States and the Common Agricultural Policy (CAP) Reform) could have a greater influence in a medium-term perspective than climate change alone.

The Bioeconomy Strategy for Europe should have a long-term perspective that considers the expected climate and other scarcity challenges by which in turn the bioeconomy will be strongly influenced. It is essential that a longer-term perspective is taken with regards to political decisions. The strategy developments should include integrated and coherent policies to address the trade-offs that will be required to deliver the agreed bioeconomy vision. This includes those that will emerge between the key priorities of food- and energy-security and preserving sustainable ecosystem functionality. The broader concept of bioeconomy (3) adopted by the EC encompasses such sectors that, until recently, were outside the scope of SCAR, namely the forestry sector and the complex marine, maritime and aquaculture sector that are now essential components of a successful bioeconomy strategy. In

(1) Represented by Elke Saggau from Germany, Egizio Valceschini from France, Stefano Bisoffi from Italy

(2) Communication COM(2012) 60

(3) 'The Bioeconomy encompasses the sustainable production of renewable biological resources and their conversion and that of waste streams into food, feed, bio-based products such as bio plastics, biofuels and bioenergy. It includes agriculture, forestry, fisheries, food and pulp and paper production, as well as parts of chemical, biotechnological and energy industries'

order to cover all the biomass related sectors the SCAR set up Strategic Working Groups (SWGs) on Forestry, Fisheries and Bioresources.

An important consideration was that many groups under SCAR have carried out, or intend to carry out foresight activities in their sector. Therefore, building upon the knowledge and findings of its groups it is a great opportunity for the 4th SCAR Foresight Exercise to bring in a holistic approach. The 4th SCAR Foresight Exercise is meant to take an 'oversight function' and to create linkages between different SCAR Foresight activities as well as EU initiatives within Bioeconomy.

## 1.5. Key questions for the 4th SCAR Foresight Expert Group

To meet the necessary requirements for a sustainable bioeconomy in 2020 SCAR needs to look at a longer time period (2050 and even beyond) regarding the complex challenges: expected climate change, biodiversity loss and emerging scarcities (land, water, minerals, ecosystem functioning, time, etc.)

The key priority is food and biomass security while preserving sustainable ecosystem functionality. Trade-offs between food/biomass supply on one hand and loss of biodiversity and ecosystem services on the other are rarely emphasised and analysed in the scope of the bioeconomy.

The 4th Foresight should explore:

- To what extent is the primary sector (agriculture, forestry, fisheries and aquaculture) affected by the implementation of the Bioeconomy Strategy (evolution of land use, ecosystem services, farming structures etc.) and by the CAP reform?
- How can the primary sector actively contribute to the implementation of the Bioeconomy Strategy?
- How can the bioeconomy contribute to sustainable agriculture?
- How can the bioeconomy contribute to a better use of scarce resources?
- How can the bioeconomy improve food security, environmental quality and food safety?
- How to implement innovation in the bioeconomy?
- What are the opportunities and risks for the different sectors, social groups and regions?

The Foresight exercise explores the linkages among sectors that a holistic concept of bioeconomy implies. With an emphasis on the future, it should consider not only what will happen, but also what might happen by developing the paradigm of the bioeconomy, with the fundamental constraint of sustainability. Internal contradictions within sectors, and possible conflicts among sectors should be a major point of interest. Divergent views are interesting and interactions are likely more important than the main effects in complex systems.

The ultimate goal of the Foresight Exercise is to provide 'food for thought' understanding of the present to explore the future, and particularly to provide elements to guide decisions of Member States, the EC and policymakers. The Foresight will help to set the agendas, establish priorities (especially on research and on the structure of the ERA), and provide ground for policies (including CAP). A strong interaction will have to be established with the JRC Bioeconomy Observatory, possibly contributing to its 'Research' and 'Policy' pillars.

Key issues should be the spatial scale of approaches and strategies to the bioeconomy across Europe, changes induced (social, economic, environmental) and opportunities provided (or missed) by the bioeconomy, as well as constraints to its implementation. Attention should be paid to the identification of stumbling blocks and risks.

Although the focus is on Europe, the 4th Foresight Exercise maintains a global view.

## 1.6. Composition and qualifications of the 4th Foresight Expert Group (4th FEG)

### The core expert group, the 'long-term experts':

| Country | Expert name | Gender | Institution — function | Field of expertise |
|---|---|---|---|---|
| BE | Erik MATHIJS | Male | Katholieke Universiteit Leuven | Agricultural economist / 3rd SCAR Foresight / Chair of the 4th FEG |
| CH | Luisa LAST | Female | ETH Zurich, Institute of Agricultural Sciences | Agro-food foresight / Molecular ecology |
| DE | Michael CARUS | Male | nova-Institut GmbH | Specialist in on non-food bioeconomy |
| FR | Michel GRIFFON | Male | Adviser for sustainable development | Agro-economist / Ecological intensification |
| IT | Gianluca BRUNORI | Male | University of Pisa | Socio-economist / 2 and 3 SCAR foresight |

### The 'short-term experts' selected for specific sector:

| Country | Expert name | Gender | Institution — function | Field of expertise |
|---|---|---|---|---|
| UK | Margaret GILL | Female | CGIAR Senior Research Fellow | International agricultural research |
| AT | Antje POTTHAST | Female | BOKU | Forestry |
| FI | Tiina KOLJONEN | Female | VTT Technical Research Centre of Finland | Energy |
| HU | Eva LEHOCZKY | Female | Hungarian Academy of Sciences | Soil ecology/ environment |
| NO | Ingrid OLESEN | Female | NOFIMA | Fisheries and aquaculture |

# 2. 4th Foresight Experts Report

# Sustainable Agriculture, Forestry and Fisheries in the Bioeconomy – A Challenge for Europe

This report has been written by

**Long-term experts**

Erik Mathijs (chair)
Gianluca Brunori
Michael Carus
Michel Griffon
Luisa Last

**Short-term experts**

Margaret Gill
Tiina Koljonen
Eva Lehoczky
Ingrid Olesen
Antje Potthast

**June 2015**

# Executive summary

## *1. Introduction*

The 4th SCAR Foresight exercise aims to identify emerging research questions and to anticipate future innovation challenges that can support the implementation of the Bioeconomy Strategy for Europe. The concept of the bioeconomy brings together the agriculture, forestry, fisheries and aquaculture sectors (the primary sectors) on the one hand and the sectors producing processed food, chemicals, materials and energy on the other. The 4th Foresight exercise explores the interactions between the primary sectors and the broader bioeconomy. With an emphasis on the future, the exercise explores what might happen by developing the paradigm of the bioeconomy, within the fundamental constraint of sustainability.

## *2. The transition to a sustainable European bioeconomy: premises and conditions*

In 2012, the European Commission launched the strategy for 'Innovating for sustainable growth: a bioeconomy for Europe'. The bioeconomy concept is built on two premises. First, current biomass is being underexploited, as many waste streams are not used in an optimal way. More materials and energy can be extracted from current biomass streams. Second, the biomass potential can be upgraded by increasing current yields by closing yield gaps, increasing productive land, introducing new or improved species that may or may not be generated by various biotechnological advances, and introducing new and improved extraction and processing technologies. Technology development in the field of use and transformation of living matter has opened the way to a variety of scenarios. The occurrence of one or the other scenario will depend on how the potential presented by the technologies will be integrated into rules, organisational patterns, policies, infrastructures and patterns of behaviour. Looking at future scenarios through a bioeconomy lens implies broadening the scope of the possible interdependencies related to biological resources and assessing risks, costs and benefits that may occur.

Within the coming decades, the world is projected to face enormous and unprecedented challenges that are influenced by environmental, social, political and economic changes taking place across geographical scales. Overall, a population of more than 9 billion (bn) people is projected by 2050, which, together with projected increases in income, will result in increasing demand for consumables such as food, feed, fuel and materials to be provided by depleted and finite resources in an environment facing increasing pressure alongside the effects of climate change. Business-as-usual scenarios show that in the near future competition over the use of land, water and biological resources will increase as a result of the effects of climate, population growth, technology, economic and policy trends. Worst-case scenarios, based on the acceleration of some of the existing drivers, entail increased insecurity, inequality, conflicts and even collapse. In the best-case scenarios, solar, wind and other renewables will play a major role; waste will be fully recycled; policy decisions will be more coherent and submitted to sustainability and resilience checks; investments will be made responsibly and consumers will share responsibility for the outcomes of their actions and change their consumption patterns accordingly.

For the bioeconomy to deliver on its goals of food security, sustainable resource management, reducing dependency on non-renewable resources, tackling climate change and creating jobs and maintaining competitiveness, a set of principles should be strived for:

- **Food first** — How can availability, access and utilisation of nutritious and healthy food be improved for all in a global view. Relevant policies, such as those related to agriculture, food, environment, health, energy, trade and foreign investments should be checked through a food security test and direct and indirect impact assessment should become common currency.

- **Sustainable yields** — Users should consider the renewable nature of biomass production and apply economic rules that govern their exploitation, such as the sustainable yield approach that prescribes that the amount harvested should not be larger than regrowth. This should be regarded from a holistic view, which takes all biomass into account, including that in the soil. An important indicator here is the amount of organic matter in the soil.

- **Cascading approach** — To avoid unsustainable use of biomass, the concept of cascading use prescribes that biomass is used sequentially as often as possible as material and finally for energy. Cascading use of biomass increases resource efficiency, the sustainable use and the generation of value added from biomass and is part of the circular economy. Creating higher resource efficiency also increases the general availability of raw material supply because biomass can be used several times. While appealing in theory, the practical application of cascading rules meets with two problems: (1) how can a sequential use of biomass be implemented? And (2) how can rules be implemented if they run against today's existing market environment?

- **Circularity** — The cascading approach does not address the issue of waste reduction *per se*. Waste is generated where the costs of reuse and recycling are higher than the value created. The concept of a circular economy is based on three principles: (1) waste does not exist, as products are designed for a cycle of disassembly and reuse; (2) consumables should be returned to the biosphere without harm after a cascading sequence of uses, contributing to its restoration, while durables are designed to maximise their reuse or upgrade; and (3) renewable energy should be used to fuel the process.

- **Diversity —** Production systems should be diverse, using context-specific practices at different scales and producing a diversity of outputs. As diversity is key to resilience, innovations in the bioeconomy should be developed to foster diversity rather than limit it.

A transition to a sustainable bioeconomy is a process that cannot be governed only by markets and technology. It requires a constant monitoring of these principles and a strong strategic orientation based on a clear identification of societal challenges, a holistic view, reflexive governance and a sound base of empirical evidence. Given the interplay of different issues, interests and actors involved, attention should be paid to processes of integration of policies, which would imply giving attention to interaction patterns, tools and mechanisms. Member States should carefully evaluate, in a comprehensive way, the expected impact of support policies that change the intensity of material and trade flows and land use. Research should generate the knowledge base necessary to support coherent policies and to anticipate problems.

## *3. State of play in the bioeconomy*

**Food and feed** together account for the majority of biomass demand. These products are generated by agriculture (including livestock), horticulture, fisheries and aquaculture. The main drivers of food and feed demand are human population growth and changes in diet. High growth in population in the next few decades will mainly occur in Asia and Africa, with any change in Europe potentially being a slight decrease. Changes in Europe's diet are also predicted to be small, with the major driver of global dietary change deriving from Asia, due to the growth in economies such as China and India and the size and predicted growth of their populations. The main demand impacts on Europe, therefore, will mainly be the consequence of global trade, unless consumers respond to the efforts of governments to tackle diet and health issues. A number of recent Foresight studies highlighted both current and future risks and opportunities arising from recent scientific advances. At the same time, food commodity markets are increasingly integrated with energy markets, more volatile and subjected to geopolitical influences. The digital revolution may be an important game changer in supply chains and retail both of which are increasingly concentrated and globalised.

Currently, biomass for **bio-based chemicals and materials** is used for animal bedding, construction and furniture, pulp and paper, textiles and the chemical and plastics industry. The most interesting fields of innovation in the bio-based economy are the chemical-technical industry with the pulp and paper industry and the man-made fibre industry owning the largest facilities for biomass fractionation due to their history and long-standing expertise in biomass conversion. The oil-based chemical industry has matured into a central, sophisticated and advanced economic branch with significant economies of scale and low transport cost of the starting material. If chemicals and products are to be made out of sustainable resources, the whole chemical industry sector faces a transition with regard to starting materials, intermediates and processes. This requires a transition period with oil-refineries and bio-refineries running in parallel. For a bio-refinery, the economies of scale differ from that of an oil refinery and the transport costs for the starting biomass is much higher. Hence, economic efficiency needs to be reached by different means than in traditional fossil-based refineries. In order to cope with the mixed mode of operation of oil and biomass as starting materials novel concepts are required which still need a lot support from basic research efforts at all levels.

With regard to **forestry**, the future trend is to prepare the forestry sector for a multifunctional, better use: energy, fuels and chemicals, plastics, construction, furniture, landscape, recreational activities and other ecosystem services. Platform and specialty chemicals from biomass gain more importance relative to the established uses in the pulp and paper and materials sector. Forestry is directly affected by major changes in the chemical industries, where whole production lines are adjusted to cope with an increased share of the (partly) new starting materials from forestry. The pressure to operate high-value utilisation modes will increase. In addition, new tree species will be tested for their ability to cope with climate change and to secure resilience of the forest. More efficient nutrition management is needed in forest management, together with more diversified ways of generating the raw material and ecologically efficient approaches to wood harvesting are required.

The current energy system is still dependent on fossil fuels and nuclear energy. Reducing our dependence on fossil fuels requires a significant shift from using technologies based on transformation of fossil fuels towards using technologies based on renewable electricity, heat, and fuels in all end uses: industry, transport (electrical vehicles, synthetic fuels, biofuels), buildings (heat pumps, solar and other renewables), etc. As a result, **bioenergy and biofuels** will play a double role: first as a transition fuel as long as electrification is not yet fully implemented and second for those applications for which electrification will be difficult to implement. The range of feedstock that can be used for bioenergy and biofuel production is large. Currently, the largest share of biomass is wood and agro-biomass (i.e., energy crops and residues), but sewage sludge, animal wastes, organic liquid effluents and the organic fraction of municipal solid waste is used as feedstock. However, these feedstock need to be pre-treated and systems for processing biomass have to be designed to avoid fouling and corrosion. Pre-treatment technologies aimed at upgrading the energy density of feedstock include drying, pelletisation and briquetting, torrefaction, pyrolysis and hydrothermal upgrading. Biomass combustion for heat production is based on stoves, incineration or gas combustion and is available at both a small scale for individual house heating and at a large scale. Biomass is converted into power, heat, and biofuels using steam turbines, thermal gasification, engines or bio-refineries.

The current **policy framework** of the European bioeconomy consists of a multitude of regulations and strategies from several policy areas, including the Common Agricultural Policy, the EU Forest Strategy, the Common Fisheries Policy, the Blue Growth Agenda, the new EU framework for aquaculture, quality schemes for agricultural products and foodstuffs, food and feed safety regulations, the Renewable Energy Directive (RED), the 2030 policy framework for climate and energy, standards, certification and labelling for bio-based products and the Circular Economy Package. The cascading use principle could be a valuable tool to ensure the most efficient use of renewable resources and should play a significant part in the package, but its implementation meets with controversy. Further, it has become clear by now that the RED has had some adverse effects on bio-based chemicals and materials, which could offer more value-addition and be an innovative part of the bioeconomy. Finally, sustainability criteria is an area where policy decisions and scientific advancement are strongly connected to each other, as the object of research is highly uncertain and there are different — and conflicting — interests at stake. Addressing sustainability criteria in a proper way will need a specific focus of research on how to develop appropriate inter- and trans-disciplinary approaches and methods.

## *4. Scenarios*

In order to develop a research agenda to tackle future challenges and opportunities, the difficulty is that the future is unknown. What can be done is to identify the most important uncertainties influencing agriculture, forestry, fisheries and aquaculture (the primary sectors) and then to explore what will, can and should happen in the alternative futures defined by these uncertainties. Two major uncertainties were identified to form the scenario framework. The first one is the **demand growth for biomass for materials and energy**. This variable depends on population and economic growth, the relative markets of classical resources (e.g., fossil fuels), the evolution of bio-based and other competing technologies (influencing conversion efficiency and costs) and the evolution of non-biomass based technologies, like other renewables. The second is the **supply growth of biomass**. This variable depends on the development and implementation of new technologies and the rate of intensification in the primary sectors. We selected three scenarios:

- **Scenario A** assumes that the growth in demand for biomass for materials and energy is relatively low, for instance because solar, wind and other clean energy technologies take off more quickly than expected, making bio-based solutions less competitive. In this scenario, it does not matter so much whether the supply growth is low or high, so here we only assume a medium level of supply growth. We call this scenario BIO-MODESTY.

- **Scenario B** assumes that growth in demand for biomass for materials and energy is relatively high, while supply growth is also high. We therefore call this the BIO-BOOM scenario—a scenario in which a high demand for biomass coming from the non-food bio-based economy is met by supply.

- **Scenario C** assumes that the same driving forces leading to high demand for biomass to be used by non-food applications apply. Low supply growth is assumed, for instance because of societal resistance towards new technologies. As a result, the amount of biomass available for bio-based materials and chemicals and bio-energy is lower than it is now (and even 0 for biofuels). However, when the food-first rule cannot be enforced, high demand will increase prices for biomass considerably, as biomass is a scarce commodity. We thus call this scenario BIO-SCARCITY.

It can be concluded that similar research topics appear in all scenarios, but their relative importance differs across the scenarios. For example, governance needs to make sure that a proper implementation of the bioeconomy strategy is inclusive with respect to small-scale and diverse systems, while in the BIO-SCARCITY scenario the focus of governance research is much more on mitigating the negative side effects of competition for biomass. Climate change research is much more pressing in the BIO-SCARCITY scenario. Employment issues appear in all scenarios.

## *5. Recommendations*

In order for the bioeconomy to achieve its multiple goals of food security, environmental care, energy independence, climate change mitigation and adaptation and employment creation, it needs to be implemented according to the set of principles outlined earlier—food first, sustainable yields, cascading approach, circularity and diversity. Based on our analysis and three stakeholder workshops, the following research themes are proposed:

- **New paradigms for primary production based on ecological intensification**: Ecological intensification entails increasing primary production by making use of the regulating functions of nature. Its practices range from the substitution of industrial inputs by ecosystem services to the landscape-level design of agroecosystems. Research is needed to underpin ecological intensification to shift from the study of individual species in relation to their environment to the study of groups of organisms or polycultures in relation to each other and their environment. More insight is needed into the synergetic effects of combinations of ecosystem service processes as current research mainly addresses how single service processes work in isolation.

- **Emerging enabling technologies: the digital revolution**: Sensor technology, remote sensing, etc. contributing to precision techniques in the primary sectors have great potential to improve resource efficiency. However, combined with other advances in technologies, the digital revolution fundamentally transforms the way science operates, as well as manufacturing, retail and even consumption. Research should further investigate how the digital revolution will affect primary production and their food and non-food supply chains, but also how these developments can help sectors address the diversity of production systems and their outputs with different qualities thus contributing to the realisation of a circular economy.

- **Resilience for a sustainable bioeconomy:** A resilient bioeconomy encompasses systems that are able to deal with different types of hazards. The bioeconomy and particularly the circular economy entail an increased coordination and integration of different sub-sectors. Combined with the increasing pressures from various driving forces, this may have significant effects on animal, plant and human health hazards as well as adaptation and risk reduction strategies tackling these hazards. Research should investigate the impact of the bioeconomy on resilience on the one hand, but should also develop new solutions and systems that are more resilient, from a biological and technological point of view as well as a social perspective.

- **The new energy landscape:** The transition to a new energy landscape involves abandoning fossil-fuel based technologies in favour of renewable energy technologies. This will have an enormous impact on primary production which currently is still heavily dependent on fossil fuels, particularly the production of inputs, such as fertilisers and pesticides. Research should investigate how this transition affects agriculture, forestry, aquaculture and marine resources, identify the needs of these sectors related to these changes and develop appropriate solutions.

- **Business and policy models for the bioeconomy**: A bioeconomy that is based on the concepts of circularity and cascading presents a particular challenge to making the economics work. Circularity implies new ways of designing and manufacturing products, new relationships between economic actors, new ways of recycling components and waste, etc. In other words, actors and activities will be reassembled in time and in space. In addition, different production models in terms of scope and size should not only be able to co-exist, but also capture the synergies between them. Public sector involvement is needed for these new business models to work, as public goods are generated in the circular economy but often not remunerated by the market. Research should support the development of these business models.

- **Socio-cultural dimensions of the bioeconomy**: A sustainable bioeconomy implies that knowledge about social impacts of technology and mechanisms of social change should progress as fast as technology itself. All stakeholders should be fully involved in the governance of the bioeconomy. Science may also radically change food production and consumption patterns, with potential to reduce pressure on ecosystems, through changes in diet, the multifunctional use of land and aquatic resources, urban-rural nutrient cycles and the production of alternative proteins for animal feed and human consumption. However, this may break established routines and create resistance and anxieties, which need to be understood better.

- **Governance and the political economy of the bioeconomy:** The outcomes of the development of the bioeconomy through the implementation of a circular economy will depend on the rules put in place to regulate the system. The development of bio-based materials and bio-energy may create pressure on natural resources and on social inequalities in a scarcity-dominated world. Research should help develop a framework aimed at fostering the bioeconomy, including policies and sustainability and safety standards that are coherent, create a level playing field, avoid the overexploitation of natural resources and foster a diversity of practices. Research should also help in tackling the regional differences in national economic structures and the best use of national biomass resources.

- **Foresight for the biosphere:** Current foresight is mostly conducted using forecast-based modelling platforms with comparative-static approaches and within a limited set of structural features. Research should also expand foresight capacity by integrating data and dynamic and flexible tools, in order to avoid lock-ins and monitor the sustainability and resilience of the bioeconomy and the biosphere as a whole.

Research and innovation are built upon a **Knowledge and Innovation System (KIS)** that develops and diffuses knowledge, inspires and identifies opportunities, mobilises resources, helps manage risks and forms markets, and legitimises activities and develops positive externalities. EC initiatives support the transition towards a system in which knowledge is co-produced by all actors that engage with each other in processes of learning and co-evolution that has the following characteristics:

- **Challenge-oriented** — Rather than only being driven by scientific curiosity, the KIS should also be challenged-oriented. The KIS should find a right balance between basic and applied research. Orientation is currently provided by the Europe 2020 strategy and specifically the Grand Challenges for the bioeconomy.

- **Trans-disciplinary** — The KIS should be trans-disciplinary, that is, multiple theoretical perspectives and practical methodologies should be used to tackle challenges. Trans-disciplinarity goes beyond inter-disciplinarity as it transcends pre-existing disciplines.

- **Socially distributed** — Knowledge should be diverse and socially distributed in the KIS. Communication barriers have been largely lifted, such that knowledge is created in diverse forms, in diverse places and by diverse actors. However, several barriers still exist, such as intellectual property rights and unknown cost structures, hindering the inclusive and public-good character of knowledge. Open access and open innovation should guide knowledge production as much as possible. Particular attention should be devoted to social innovation and the inclusion of socially disadvantaged actors and regions.

- **Reflexive** — Rather than an 'objective' investigation of the natural and social world, research has become a process of dialogue among all actors. The KIS should devote sufficient attention to these reflexive processes, both within the boundaries of a research project and at the meta-level of organising and programming research. Current efforts of multi-actor participation and stakeholder engagement in projects and in programming are steps in the right direction.

- **New rewarding and assessment systems —** Quality control transcends the classical peer review as trans-disciplinarity makes old taxonomies irrelevant. In addition, the integration of different actors also broadens the concept of quality into multiple definitions of qualities. As a result, assessment/rewarding systems relating to researchers, research projects and programmes, research institutes/bodies, other actors, education and even the organisation of regional/national/international KIS need to change. This makes the research and innovation process more uncertain from a traditional perspective on research.

- **Competencies and capacities** — Researchers, other actors and stakeholders in the KIS need to acquire a new set of skills and competencies. Institutions of higher education can play a key role by integrating these skills and competencies into their curricula. The capacity to engage in KIS not only depends on the aforementioned competencies, but also on resources that need to be invested by actors and stakeholders.

# 2.1. Introduction

The SCAR Foresight reports highlight potential weaknesses as well as future opportunities (i.e., mid- to long-term priority setting) to provide input for a more integrated research system for agriculture in Europe. The 1st SCAR Foresight Exercise (FEG1) identified four scenarios pointing to declines in fossil fuel, land, water, biodiversity, energy availability and ecological services, and increasing world population, demand for food and feed and growing climate change impacts. The 2nd SCAR Foresight Exercise (FEG2) put more emphasis on the socio-economic driving forces and on the different paradigms underpinning our knowledge and innovation system. The purpose of the 3rd Foresight Exercise (FEG3) was to update the state on some critical driving forces and to focus on the transition towards an agricultural and food system in a resource-constrained world, given the likely critical importance of those driving forces. Its aim is to provide building blocks for longer term perspectives to prepare a smooth transition towards a world with resource constraints and environmental limits and to guide agricultural research in the EU and its Member States. The aim of the 4th SCAR Foresight exercise is to identify emerging research questions and to anticipate future innovation challenges that can support the implementation of the Bioeconomy Strategy for Europe.

The broader concept of the bioeconomy adopted by the EU, encompasses sectors that, until recently, were outside the scope of SCAR, namely the forestry sector and the complex marine, maritime and aquaculture sector, but also the materials, chemicals and energy sectors, that are now essential components of a successful and sustainable bioeconomy strategy. In order to cover the new sectors as well as the new challenges to produce more biomass, SCAR set up Strategic Working Groups (SWGs) on Forestry, Fisheries and Biomass.

The 4th Foresight exercise, launched in Spring 2014, explores the interactions between the primary sectors (agriculture, forestry, fisheries, aquaculture) and the other parts of the bioeconomy. With an emphasis on the future, the exercise explores what might happen by developing the paradigm of the bioeconomy, with the fundamental constraint of sustainability. Internal contradictions within sectors and possible conflicts between sectors are a major point of interest. The Foresight report will help to set the agendas and establish priorities (especially on research and on the structure of the ERA).

The 4th Foresight exercise also interacts with other recent and ongoing foresight exercises, such as the JRC (Joint Research Centre) foresight on Global Food Security 2030 (2014), the foresight analysis in the ERA-NET COFASP (Cooperation in Fisheries, Aquaculture and Seafood Processing, 2014), the SUMFOREST Foresight on 'Emerging Issues in European Forest-Based Sector and Research Priorities' (2014), the AKIS (Agricultural Knowledge and Innovation Systems) foresight by the AKIS working group of the SCAR and several others.

An expert group was set up in Spring 2014 to carry out the foresight exercise in collaboration with the SCAR and its working groups in three phases:

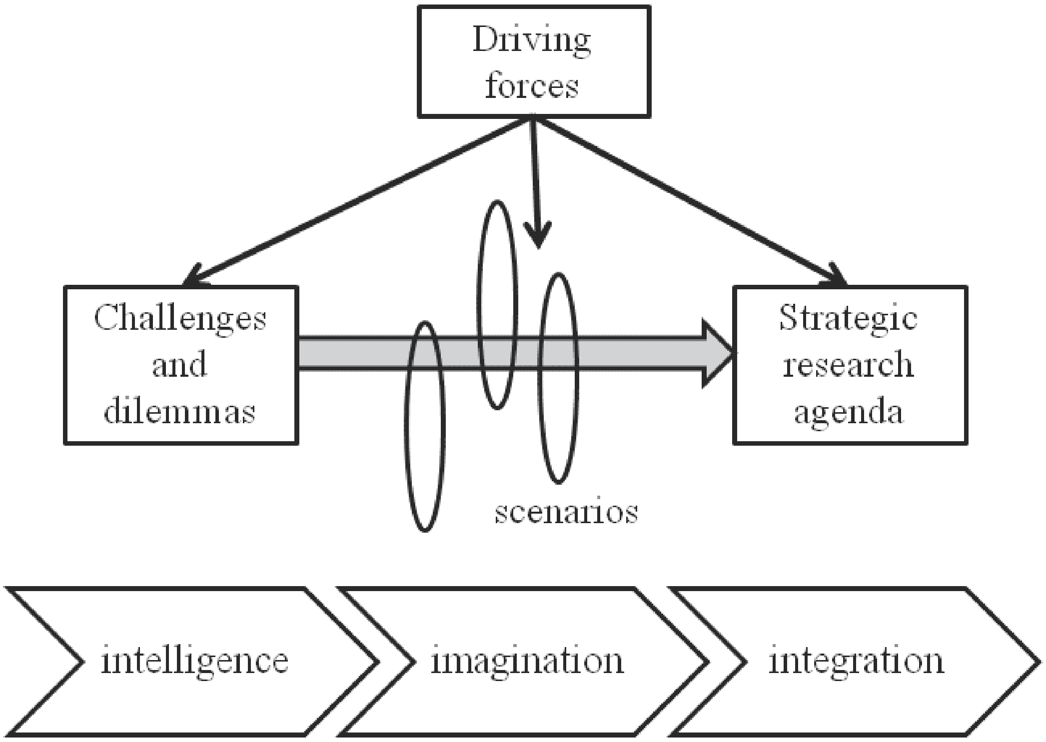
- In the **intelligence** phase (June — December 2014), the scope of the exercise was determined and information was gathered. Work was organised around a set of key dilemmas governing the interactions between the primary sectors and the bioeconomy.
- In the **imagination** phase (January — February 2015), scenarios were developed highlighting possible visions as well as pathways towards a sustainable future.
- In the **integration** phase (February — May 2015), the implications of the different scenarios were explored.

The Foresight exercise proceeded in a participative way. For this, three interactive Brussels-based workshops were organised with members of the SCAR and its working groups, the European Commission (EC) and various stakeholders of the bioeconomy:

- Workshop 1 (18 November 2014) explored and determined the key **dilemmas** governing the interactions between the primary sector and the bioeconomy and structuring the foresight work.
- Workshop 2 (9 December 2014) brought together and validated the **information** base underpinning the dilemmas identified before.
- Workshop 3 (17 February 2015) analysed the **implications** of the various scenarios developed by the expert group for the primary sectors, the bioeconomy and research policy.

In addition, an online survey was carried out among stakeholders to ask they see as the main challenges to realising the bioeconomy (see Annex 1).

The process of the 4th Foresight exercise can be summarised as follows:




Broadening the scope of the exercise to include all primary production sectors and all uses of the products and services of these sectors (i.e., food, feed, ecosystem services, bio-based materials and chemicals and bio-energy) poses particular problems of terminology. We have therefore chosen to use the general word **biomass** when we refer both to the output of the primary sectors (agricultural products, wood, fish) and the by-products of the primary sectors but also of downstream sectors (processing, retail). We recognise that the word biomass covers a very heterogeneous set of categories representing different **values** and **qualities**, ranging from waste streams in the paper and pulp industry to high quality food products that may be labelled with a geographical indication, and so on. What all of these products have in common is that they originate from plants, animals and other organisms raised or caught using natural resources such as land and water.

The report is structured as follows: Chapter 2.2 considers the scope of the bioeconomy and its challenges, premises and conditions; Chapter 2.3 summarises the current situation in three sub-sectors of the bioeconomy—food and feed, bio-based materials and chemicals and bio-energy; Chapter 2.4 sketches out the scenarios and Chapter 2.5 formulates recommendations that result from the analyses in the previous Chapters.

# 2.2. The transition to a sustainable European bioeconomy: premises and conditions

## 2.2.1. Introduction: bioeconomy and societal challenges

In 2012, the European Commission launched the strategy for 'Innovating for sustainable growth: A bioeconomy for Europe'. The strategy, together with its Action Plan, aims '*to pave the way to a more innovative, resource efficient and competitive society that reconciles food security with the sustainable use of renewable resources for industrial purposes, while ensuring environmental protection*' (EC, 2012a).

The bioeconomy concept is built on two premises. First, current biomass is being underexploited, as many waste streams are not used in an optimal way. More materials and more energy could be extracted from current biomass streams. Second, the biomass potential can be upgraded by increasing current yields by closing yields gaps, increasing productive land, introducing new or improved species that may or may not be generated by various biotechnological advances, and introducing new and improved extraction and processing technologies.

Technology development in the field of use and transformation of living matter has opened the way to a variety of scenarios. The occurrence of one or another scenario will depend on how the potential disclosed by the technologies will be integrated into rules, organizational patterns, policies, infrastructures, patterns of behaviour. Looking at future scenarios through a bioeconomy lens implies broadening the scope of the possible interdependencies related to biological resources, and assessing risks, costs and benefits that may occur.

Within the coming decades the world is projected to face enormous and unprecedented challenges that are influenced by environmental, social, political, and economic changes taking place across geographical scales. Overall, a population of more than 9 billion people projected by 2050, together with projected increase in income, will result in increasing demand for consumables such as food, feed, fuel and materials to be provided by depleted and finite resources in an environment facing increasing pressures and the effects of climate change. Business-as-usual scenarios show that in the near future competition over the use of land, water and biological resources will increase as a result of the effects of climate, technology, economic and policy trends. Worst-case scenarios, based on the acceleration of some of the existing drivers, entail increased insecurity, inequality, conflicts, and even collapse. In the best-case scenarios, solar, wind and hydrogen may play a major role; waste will be fully recycled; policy decisions will be more coherent and submitted to sustainability and resilience checks; investments will be made responsibly and consumers will share responsibility for the outcomes of their action and change consumption patterns accordingly. Production will be resource-efficient and respond to societal needs, business cases will consider long-term perspectives and shift profits from nature and resource depleting to biosphere conscious scenarios.

The challenge for a bioeconomy strategy is to take into account both risks entailed by worst-case scenarios and opportunities linked to best-case scenarios. The purpose of this Chapter is to discuss the premises underscoring the bioeconomy as well as the conditions that a bioeconomy should fulfil in order to be both successful and sustainable. Section 2.2.2 defines the concept of a bioeconomy. Section 2.2.3 discusses the societal challenges that a bioeconomy seeks to address. Section 2.2.4 lays out the principles for a transition to a sustainable bioeconomy. Section 2.2.5 concludes.

## 2.2.2. The bioeconomy concept

### *Definition*

According to the European bioeconomy strategy, the bioeconomy or bio-based economy '(...) encompasses the production of renewable resources and their conversion into food, feed, bio-based products and bio-energy. It includes agriculture, forestry, fisheries, food and pulp and paper production, as well as parts of chemical, biotechnological and energy industries' (EC, 2012a). However, the bioeconomy is more than a simple addition of sub-sectors. It can be seen as the set of existing relations between society and the biosphere in several aspects: provision of goods and services, the emission of pollutants and negative externalities but also the production of positive externalities to ensure that the biosphere continues to be functional for future generations.

The use of living matter (biomass) for economic purposes has been part of society's development for millennia. The bioeconomy has contributed to society ever since (McCormick and Kautto, 2013). Why, then do we refer to a transition to a bioeconomy? The reason is mainly related to the tremendous advancement in scientific knowledge and in technologies that have opened unprecedented possibilities of creating more value from living matter, including the development of new chemicals, materials, etc. Although the original use of the concept primarily referred to the use of biotechnologies for economic growth (Brunori, 2013), now growth in the bioeconomy is seen as being supported by a wide range of multiple scientific areas (e.g., life sciences, agronomy, etc.), a wide range of technologies (e.g., biotechnology, nanotechnology, communication, etc.) and anticipates continuous knowledge transfer.

Technology development, industrial investments and institutions affect the balance between human societies and the biosphere. During the last century the human impact on the biosphere has exceeded its boundaries (Rockström et al., 2009a; Steffen et al., 2015). Therefore, among the possible scenarios for a bioeconomy that the combination of technologies, industrial patterns and institutions offer, Europe will have to choose the one that pursues a long-term economic, social and environmentally sustainable use of the biosphere as well as an urgent repair of past damage. This is what we call a 'sustainable bio-based economy'.

## *Potential benefits and concerns: values for a bioeconomy*

Around the transition to a bioeconomy there are a lot of expectations, but also some concerns (see Pfau et al., 2014, for a recent overview). A successful strategy requires approval and uptake by society. A public online consultation held in 2011 considering potential benefits and risks of a bioeconomy strategy showed a predominantly positive perception by respondents from different professional fields (EC, 2011a). Overall, greatest potential short-term benefits were seen within areas such as the reduction of waste and pollution (EC, 2011a). At the same time, major concerns were raised regarding global food security issues and the overexploitation of resources in developing countries. Here the respondents saw an increasing pressure on human livelihoods and resources due to the increasing use of biomass for feed and non-food use such as for fuel or materials.

Emphasis on the bioeconomy may radically change the policy agenda. Agricultural and forestry policies have been pursuing a model aimed at optimizing the production of public goods and services. The concept of multifunctional agriculture and forestry has been embedded into business models and rural development pathways that have increased the quality of life in rural areas, allowed farmers and foresters in many cases to retain an equitable share of added value and contributed to the diversification of rural economies. Product quality has supported small- and medium-sized enterprises in search of competitiveness by giving them instruments (e.g., Protected Designation of Origin (PDO) and Protected Geographical Indication (PGI) labels) to protect cultural food traditions and local biodiversity, and doing this has enhanced consumers' freedom of choice. Demand for organic and local food is growing, and harmonisation of standards regulations has taken place across Europe. Biodiversity is widely considered to be vital to the resilience of agricultural and forestry systems to global change. Furthermore, reformed policies of fisheries and aquaculture promote sustainable harvesting and farming and growth of the blue economy.

All these values would be at risk if the 'transition to a bioeconomy' was intended only to provide cheap biomass for a growing bio-based industry. In fact, without giving adequate priority to the use of biomass as food, the transition may generate pressures on food prices. Excessive emphasis on alternative uses of biomass would shift the focus away from models of agriculture and food production based on high quality products and services, conservation and management of cultural landscapes, preservation of multifunctional ecosystems, support to local economies based on synergy with tourism (Schmidt et al., 2012), which are key to the competitive advantage of many rural areas and give a strong identity to European agriculture. The full potential of the bioeconomy to contribute to sustainability and green growth needs clear principles to which its development should aspire, as well as clear policy and governance priorities (EC, 2011a,b; Menrad et al., 2011).

### *Avoiding new externalities*

Is the bioeconomy a miracle solution that generates less externalities than the fossil-based economy? Experience from the past warns us away from accepting uncritically the rhetoric of technological miracles. The application of a technology always has consequences that the inventors of that technology did not intend and that are often not foreseen. For instance, the 'rebound effect', also known as the 'Jevons paradox', by which gains of ecological efficiency turn into a higher total resource consumption, is now recognised by the International Energy Agency (IEA) and the United Nations Intergovernmental Panel on Climate Change (IPCC; Alcott, 2005). Another example is that technologies that have proven their effectiveness in boosting technology may have negative consequences on employment as firms use them to replace labour with capital. A recent survey by The Economist (2014) shows pessimism about the impact of new information and communication technologies on employment, at least in the next two to three decades.

To anticipate unintended consequences of breakthrough technologies it is necessary to be aware that their impact depends very much on how people will organize around the opportunities and threats opened up by them and how legal and social rules will regulate their use. In other words, technologies contribute to shaping socio-technical systems and at the same time they are 'domesticated' within them. Resilient socio-technical systems develop coping devices that are able to reduce harmful consequences of change or change themselves in order to adapt and survive (Geels, 2004). When considering the impact of new technologies or of new business or policy approaches, one has to ask: will the market, helped by deregulation and subsidies, be the main driving force of adaptation? What role should the state have? How will citizens and civil society be able to have a voice in the process and pro-actively co-create solutions?

The knowledge base that supports a bio-based economy has made giant steps. Convergence between technologies and the ability to analyse large amounts of data open possibilities unthought-of a few years ago. However, the impact of these resources on society will depend on who will use them and how. The debate on genetically modified crops, besides their potential impact on the wider environment, is more and more focused on their socio-economic impact in given institutional settings and regulatory environments. Biofuel policies in Europe are an example of regulatory adjustment after negative impacts of early measures have become visible, but there is a long way to go before policies are fully aligned around coherent objectives. Application of nanotechnologies to food production still raises concerns about unintended, and unknown, consequences.

Given the expectations it has generated, the transition to a bio-based economy should be carefully defined, thought through and monitored. Decisions related to this process are often based on uncertain information and uneven distribution of impacts. For instance, what would be the consequence of a massive shift towards using marine-based biomass on the equilibrium of oceans and hence on climate change? What would be the consequences, in terms of vulnerability to food insecurity, of country specialisation on biomass production for external trade?

But there can also be other consequences that are more of a social and even a cultural nature. Production of cheap biomass is likely to require, given existing dominant technologies, economies of scale, heavy mechanisation, and monoculture. Fast growth in early generation bioprocessing infrastructures creating demand for cheap biomass, has favoured the establishment of these patterns at the expense of more resilient agricultural systems. What would be the implications for farming if this process were to be accelerated? What would be the impact on landscapes and, for rural economies? Will a bio-based economy accelerate the drive for farms and fishing vessels to become ever larger, but fewer in number? Will it accelerate the commercialisation of the primary sectors at the expense of family–run businesses (Borras et al., 2013), and will larger vessels continue to out-compete smaller vessels, which generally form the backbone of fishing communities? With regard to poorer countries, there is much evidence that investments in early generation bio-based business have greatly endangered the livelihoods of local people and caused harm to the environment (Borras et al. 2010; Elbehri et al., 2013). However, different strategies of biofuel development may result in very different outcomes. There are on-site technological options aiming at closing energy and nutrient cycles at farm level and possibly beyond through the future Internet of Energy, and efficient decentralised collection and fractionation technologies for biomass might allow conciliating availability at reasonable prices with sustainability.

### 2.2.3. Addressing societal challenges

According to the EU Bioeconomy Strategy '*the bioeconomy's cross-cutting nature offers a unique opportunity to comprehensively address inter-connected societal challenges such as food security, natural resource scarcity, fossil resource dependence and climate change, while achieving sustainable economic growth*' (EC, 2012a). Given the conditions for the transition to a sustainable bioeconomy considered above, how can the bioeconomy strategy contribute to addressing societal challenges? Overall, to overcome these challenges the improvement of the knowledge base for the bioeconomy and the investment in research, skills and innovation need to be supplemented by policies that are strategic, comprehensive and coherent (EC, 2012b). This is crucial to address those complex and interdependent challenges related to the bioeconomy in Europe. In what follows we discuss the five objectives of the European Bioeconomy Strategy (EC, 2012a).

#### *Ensuring food security*

While Europe is likely to remain in a position in which it can produce and purchase the food required to meet the demand of its consumers (despite an increase in poverty and stress on food access), it has shown (through for example signing up to the Millennium Development Goals) that it also accepts some responsibility for global food security and access to affordable food by citizens of developing countries. Thus, while ensuring all European inhabitants have access to affordable, sufficient, safe and nutritious food, Europe should develop a coherent policy framework that respects the right to food outside Europe. This implies a deep understanding of systemic implications of European regulation, corporate strategies, technology development, and trade.

A growing global population will inevitably create pressure to increase global food production. However, food security is not correlated with aggregate supply only. Humankind is producing sufficient food for all, but still almost a billion people are malnourished. Political and market forces and consumption patterns play a key role here. In other words, although there may be enough biomass to meet demand for food, feed, energy and materials in aggregate, locally this may not be the case because of resource availability, other political priorities, lack of infrastructure, market imperfections or incapacity to purchase food.

Competition over the use of resources, land and water above all (Pfau et al., 2014) that can be framed as a 'Malthusian' dilemma, raises concerns related to equity, as uneven distribution of power will worsen the access to resources by vulnerable groups and regions, and to the uneven impact of trade and foreign investments. Given that the production of food, energy and materials will be based on the same pool of resources, higher demand for non-food items may raise the level of food prices, increasing the number of vulnerable groups and deepening inequality among groups and among regions. Prices are generated by demand and supply curves that are relatively steep, resulting in high volatility that can be caused by relatively small supply or demand shocks. In addition, it should not be forgotten that supply curves reflect marginal cost curves, not average cost curves, which leads to often surprising dynamics (e.g., farmers that can pay extremely high prices for land on the margin). Large-scale investments aimed at creating processing capacity in the non-food sector may generate a structural demand shift for dedicated crops, activating international trade flows and creating local imbalances. Technology developments in some sectors, not compensated by adequate social and legal regulation, may create radical systemic change. Subsidies may distort competition between sectors limiting the development of promising industries. The 2007/2008 food price spike was an important wake-up call, as the demand for biomass for biofuels was part of this spike (although certainly not the only reason).

Another way to increase the availability of food in the future may come from a change in the allocation of resources between food and feed. Conversion of feed to dairy products or meat implies a loss of resources such as energy, land, water, and nutrients. About 60 % of world biomass is at present utilised as feed. This means focusing attention not only on the supply side, but also on the demand side, and this would imply addressing education, information, corporate social responsibility, certification schemes, and strategic public procurement. 'Sustainable diets' approaches (Johnston et al., 2014; Sabatè and Soret, 2014) may address at the same time the challenges of adequate nutrition, avoidance of overconsumption and waste, reducing environmental footprints and bring health benefits (Stehfest, 2014; Tilman and Clark, 2014).

#### *Managing natural resources sustainably*

Managing natural resources in a sustainable way implies establishing feedback mechanisms— at all societal levels—that signal impending risks and encourage action to prevent them (Young et al, 2006). Feedback mechanisms should control both supply and demand of resources. According to scientists, humanity has already trespassed some of the 'boundaries' of a safe operating space with respect to the Earth system, increasing the possibility for some subsystems to shift into a new, and less favourable, state (Rockström et al, 2009a; Steffen et al., 2015). How to turn these signals into action? How to develop these early warning devices?

> Biodiversity is one of the planetary boundaries identified by Rockström et al. (2009a). Homogenisation in primary production results from the specialisation by breeders and growers in a limited number of superior plants and animals, such as maize, wheat and rice in crop production and pine, eucalyptus and poplar in forestry production. Similar trends are observed in the production of feedstock for the bio-based economy with the focus on soybean and maize. The bioeconomy may accelerate these homogenisation processes if purely economic considerations are applied, also with respect to the selection of improved crops and trees and the development of new technologies. A way to overcome the efficiency-diversity dilemma is that both technologies and reward mechanisms are developed that stimulate diversity and resilience. An example is LIHiD grassland systems (low-input high-diversity systems) that have higher energy potential than traditional monocultures (Tilman et al., 2006)) or mixed systems such as agroforestry. Rather than focusing narrowly on continued improvement of a limited number of cash crops modern plant breeding could exploit the full genetic pool and identify desirable traits in plants and varieties that have not yet been optimised.

The relationship between ecology and the economy underscores the limits of economic growth and the need to create feedback loops between the economic subsystem and the ecological subsystem. From a business perspective, market competition may introduce a delay in investing in clean technologies that may raise production costs. From a social perspective, solving ecological problems is delayed, because insufficient resources are being devoted to those problems. Porter and Kramer (2011) developed the concept of 'shared value', i.e., business can create value in such a way that it both yields more profit and has social impact. In other words, the challenge is to identify win-win pathways, and to set a market environment in which firms are encouraged to undertake them. The Rio+20 Earth summit has reaffirmed the need for a transition to a 'green economy'. This transition entails a coordinated effort to address financial, institutional, regulatory and cultural domains (Bailey and Caprotti, 2014).

There is a growing convergence on the principle that growth of food production should be achieved by halting agricultural expansion, closing 'yield gaps' on underperforming lands, and increasing cropping efficiency (Foley et al., 2011). 'Sustainable intensification' (Godfray et al., 2010) embodies concerns with resource availability and issues of sustainability. However, sustainable intensification cannot apply where yields are well above their sustainability threshold, as in the case of many European agricultural systems. In these cases, 'sustainable extensification' is proposed (van Grinsven et al., 2015), which may imply a reduction of yields in order to restore equilibrium with agro-ecosystem carrying capacity (Buckwell et al., 2014). Similarly within fisheries and aquaculture, requests for sustainable harvesting of marine stocks for food and feed are emphasised. Such emphasis on sustainability implies that attention should be given to the stability and resilience of food systems, to the potential and the ecological limits of primary supply growth, to the ways to give decent incomes to primary producers and to the quality and diversity of supply.

Another issue of natural resources management is related to waste, that according to many estimations is about 30 % of total biomass produced (Gustavsson et al., 2011). Reducing the amount of biological waste could increase considerably the amount of biomass available for human use. Better management could result in a consistent reduction of losses.

### *Reducing dependence on non-renewable resources*

Fossilised biomass is a non-renewable resource: what is produced over millions of years is used up in decades. The economic rationale of exploiting fossil fuels is driven by demand and the discount factors used to take into account future preferences on the one hand and the cost of exploitation on the other. Various reasons lead to a too rapid exploitation of fossil fuels. First, high discount factors reflect the short-sighted vision of firms and nations with respect to using the exhaustible resource to maximise short-term profits without much regard for future generations. Second, external costs generated by using fossil fuels are not at all, or insufficiently, factored in, leading to costs that are underestimated. Similar patterns can be observed in the case of biomass: rainforests are being destroyed for the cultivation of soybean or palm oil; land may be overexploited to plant hyped crops grown for biofuels (e.g., Jatropha), etc. Fossil fuels are used as energy sources, but also as sources of many other chemicals and materials.

In a world with high dependencies on all kinds of non-renewable resources from all over the world, the bioeconomy strategy aims to make Europe less vulnerable and more competitive. Various reasons support the EU's strategy to reduce its dependence on fossil fuels: their non-renewable nature, their impact on the environment through climate change and air pollution, geopolitical considerations, etc. Part of this strategy is to replace fossil fuels—which are nothing else but biomass that was formed millions of years ago—with cultivated or recycled biomass. In order to achieve independence from non-renewable resources, lowering the carbon demand, increasing resource-use efficiency, increasing use of bio-based products and energy as well as fostering research towards the production of new renewable resources without increasing competition for resources is part of the bioeconomy strategy.

The experience gained so far shows that a reduction of dependency on fossil resources will not come by a mere replacement of fossil resources with biomass. This outcome will be based on a radical redesign of production processes and products, as well as on patterns of consumption. It should not be forgotten that other, non-bio-based renewable energy sources are also part of the solution (solar, wind, water and other renewables energies in combination with $CO_2$ utilisation as storage and carbon feedstock for chemical industry). Bio-energies represent only 13 % of total energy consumption, and even most optimistic scenarios show that bio-energies will not go beyond 20 % (see Chapter 2.3). Consumption is growing in all areas of biomass use, making a limited amount of biomass a strongly sought-after resource, and competition over its use will increase.

In the near future, considerations about sustainability criteria and the need for policy coherence may limit the growth of biomass use for energy. The same logic holds for other uses of biomass: there is always a danger that biomass is used for the least sustainable but most profitable option—a situation which is not only driven by markets (and speculation) but also by governments and policies. This does not mean that the bioeconomy cannot contribute to reducing dependence on non-renewable resources, but it will have to be done in a smart way, avoiding shortcuts that do not take into account the complexity of socio-ecological systems.

Reduction of dependence on oil will be highly relevant in specific sectors and in specific geographical areas, where the marginal return of biomass use and processing will be higher. For example, agriculture is currently highly energy intensive due to the use of nitrogen fertilisers, chemical pesticides, irrigation, and machinery, as well as feed for livestock production. The replacement of fossil based inputs by regulating and supporting ecosystem services promises to reduce agriculture-induced impacts while reducing yield gaps (Bommarco et al., 2013). Development of local bio-economies may improve the resilience of vulnerable areas, especially remote rural areas. Farm-sized biogas plants may reduce farmers' dependence on energy while solving the manure management problem. Rural bio-refineries may help remote rural areas to obtain energy and material self-sufficiency (Papendiek et al., 2012).

### *Mitigating and adapting to climate change*

A sustainable bioeconomy can make a decisive contribution to mitigation. In the industrial sector, mitigation can derive from goods produced with renewable resources and fit for reuse or recycle.

> Coffee producer Lavazza and chemistry research group Novamont have developed the first fully compostable expresso capsule. The capsule is made of Mater-Bi® 3G, a material of Novamont's third generation bioplastics. It contains a significant proportion of renewable resources and has a reduced dependence on materials of fossil origin, while producing less greenhouse gas emissions than traditional products in the coffee capsule category (Source: www.foodbev.com, 5 March 2015).

However, the use of renewable resources does not always reduce greenhouse gas (GHG) emissions. According to IPCC, the agricultural sector is the largest contributor to global anthropogenic non-$CO_2$ GHGs, accounting for 56 % of emissions in 2005 (U.S. EPA, 2011). Annual total non-$CO_2$ GHG emissions from agriculture in 2010 were estimated to be 10–12 % of global anthropogenic emissions. The most significant categories of GHG emissions from agriculture are manure, enteric fermentation and synthetic fertilisers. Deforestation contributes to GHG with 12 % of total emissions. There is a strong consensus over the range of mitigation options in the primary sectors, both supply-side (i.e., by reducing GHG emissions per unit of land/animal, or per unit of product), and demand-side (e.g., by changing demand for food and feed products and reducing waste).

When considering a sustainable European Bioeconomy, the challenge of climate change mitigation also calls external trade into question, since trade generates relevant indirect effects on areas outside Europe. Progress in the field of impact assessment has generated a series of tools to measure the indirect impact of trade and to give decision-makers cognitive tools to make responsible choices. Voluntary sustainability standards based on multi-stakeholder consultations are being developed in many fields of agriculture, forestry and fisheries. Biofuel policies have progressively embodied concerns related to Indirect Land Use Change (ILUC), and ILUC assessment has adopted a substantial revision of the GHG emission potential saving of biofuels. The second bioeconomy panel meeting claims that '*The EU should lead the development of internationally harmonised sustainability criteria for biomass, including social and environmental dimensions, without which we cannot define how much biomass can be grown sustainably. Experience gained with the implementation of the biofuels criteria should be useful in this regard*'. Private groups have already made attempts to introduce voluntary labelling indicating the carbon footprint of the labelled product. Although the outcomes of these attempts are not always satisfactory, this interest has generated a wide effort to refine footprint measurement (Lifset, 2014), and 'big data' are creating the conditions for further developments (Cooper et al., 2014).

According to IPCC (Smith et al., 2014), adaptation entails '… changes in the decision environment, such as social and institutional structures, and altered technical options that can affect the potential or capacity for these actions to be realized …' (p. 518). The bioeconomy can make a strong contribution to adaptation. In the primary sector, it will provide innovative crop management systems and improved varieties. In the secondary sector, it can create the premises for no-waste production systems, based on 'reuse and recycle' principles. Adaptation will require the engagement of producers, consumers, policymakers, and other stakeholders '*…in evaluating transformative, pro-active, planned adaptations such as structural changes…*' (IPCC, Smith et al., 2014).

### *Creating jobs and maintaining competitiveness*

Overall, fulfilling the demand for more, and sustainably produced, biomass, and contributing to the mitigation and adaptation to climate change is closely linked to sustainable economic growth. The potential that arises from investing and progressing in such a broad field as the bioeconomy provides major opportunities in multiple sectors and on various levels to create high skilled jobs and maintain European competiveness, while opening new markets and developing bio-based products.

According to estimates of nova-Institute (see Annex 2), the present bioeconomy provides around 19 million (m) jobs. Future development of the bioeconomy may bring about a radical redesign of products and processes, and will require social and institutional adjustment. It will create demand for new skills, will open new markets, and will generate new patterns of daily life, as in the case of waste management.

At the same time, it may make some of the old products, processes and skills obsolete. The net effect will depend on the way bio-economic strategies will be implemented. A bioeconomy based on large-scale industrial plants, which meet the interests of financial investors and multinational corporates, may result in concentration, intensification of international trade and direct investments, with an uneven geographical and social distribution of costs and benefits and with a net loss of jobs. A decentralised capacity for transformation of biomass tailored to local natural and human resources, with the full involvement of primary producers in segments of the processes, could make employment and incomes grow while maintaining biological and cultural diversity. Focus on bulk biomass production may generate low-skilled and low-paid jobs, while focus on high added value would generate demand for skilled jobs. Priority given to low added-value products may result in tensions in the food sector, while focus on high added-value products addressing niche markets may give more space to small- and medium-sized enterprises.

### 2.2.4. Key principles for a sustainable bioeconomy

The transition to a sustainable bioeconomy raises a set of policy issues: How to increase productivity, mitigate climate change and preserve ecosystems and biodiversity? How to support the growth of bio-based industry and ensure global and European food security? How to support cheap and abundant provision of biomass and protect family farming, high quality production and development of rural areas? Coherence is possible when clear hierarchies of priorities are established around a set of principles. In this section we propose four principles on which the transition should be based: food first, sustainable yields, cascading and circularity.

*Food first*

In a food first approach to the bioeconomy, attention will be focused on how to improve availability, access and utilization of nutritious and healthy food for all in a global view. Applying this principle entails appropriate governance tools. Relevant policies, such as those related to agriculture, food, environment, health, energy, trade and foreign investments should be checked through a food security test, and direct and indirect impact assessment should become common currency.

*Sustainable yields*

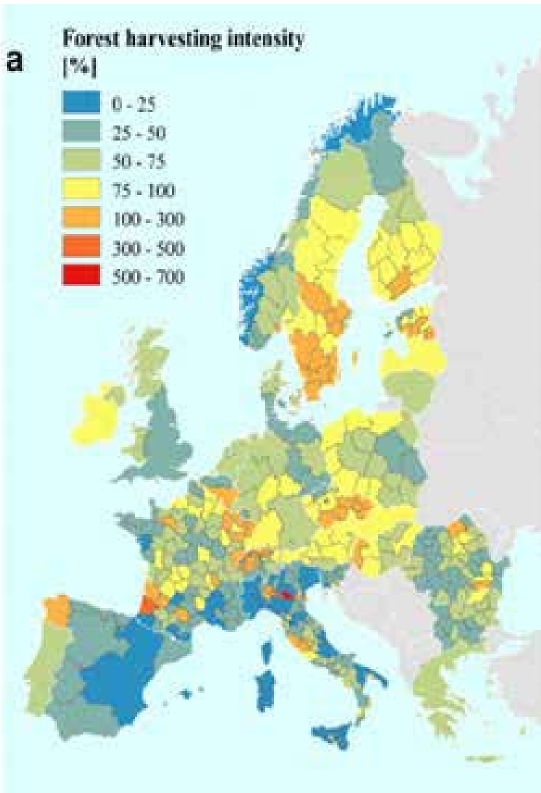
Users should consider the renewable nature of biomass production and apply economic rules that govern their exploitation, such as the sustainable yield approach that prescribes that the amount harvested should not be larger than regrowth. In population ecology and economics, maximum sustainable yield (MSY) is, theoretically, the largest yield (or catch) that can be taken from a species stock over an indefinite period. This should be regarded from a holistic view, which takes all biomass into account, including that in the soil. An important indicator here is the amount of organic matter in the soil.

To what extent is the sustainable yield rule implemented? In the case of woody biomass, the concept 'net harvesting rate' captures the idea of a sustainable yield. Figure 2.1 depicts the net harvesting rate defined as the ratio between annual felling and annual increment. It shows a high degree of utilisation in for instance Sweden, but in many EU countries net harvesting rates are still lower than 50 % suggesting considerable growth perspectives.

In the case of marine resources, the situation looks less promising. At the global level, 61.3 % of the fish stocks monitored by the Food and Agriculture Organization of the United Nations (FAO) are considered to be fully exploited (i.e., close to maximum sustainable yield), while 28.8 % are overexploited, depleted or recovering from depletion. Only 9.9 % of stocks are under fished (FAO, 2014a).

For agriculture, the picture is less clear. One approach is to consider the share of human appropriation of the Earth's net primary production (NPP), but this concept is broader than just agriculture. Haberl et al. (2007) estimated that 23.8 % of NPP is appropriated by humans, or 28.8 % of the aboveground NPP. This corresponds to over 8 Pg carbon per year which represents a caloric value of about 300 exajoules. To meet an additional amount of 200-300 exajoules of bio-based energy would imply a doubling of present biomass harvest. However, according to Berndes (2013) such a development should be possible given favourable economic and technological developments.

**Figure 2.1: Net harvesting rate in EEA countries, 2000-2010**
(Levers et al., 2014)



*Cascading approach*

To avoid potential unsustainable use of biomass, the concept of cascading use of biomass has been developed: biomass is first used for the option with the highest 'value', then for the second highest, and so on. Today, a large amount of biomass in the EU is directly used for bioenergy and biofuels. It would be a vast improvement to have and to implement a strategy to exploit biomass and products from it as often and as efficiently as possible in chronologically sequential steps of material use, with energy recovery at the very end of the products' life-cycle (Kosmol et al., 2012).

There are many theories and concepts about cascading use based on different conceptions of what cascading means (Fraanje, 1997; Dornburg, 2004; Keegan et al., 2013). Along with repairable products and second-hand products, these concepts also include complex combinations of main and by-products in so-called primary and secondary cascades (Sirkin and ten Houten, 1994). The term cascading use often overlaps with other topics such as coupled production, circular economy and recycling and it can equally have different meanings in different contexts.

Cascading use of biomass increases resource efficiency, sustainable use and the generation of value-added from biomass and is part of the circular economy. Creating higher resource efficiency also means increasing the general availability of raw material supply, because the biomass can be used several times. Cascading use is an indispensable part of any resource efficiency and sustainability strategy. One is not conceivable without the other. However, one should consider that often biomass flows are exported and that the location of their use is different from the location of their production, which makes the implementation of cascading use more difficult.

The following references show that the European Commission is aware of the importance of cascading use to develop the sector of bio-based products:

> *'Biorefineries should adopt a cascading approach to the use of their inputs, favouring highest value added and resource efficient products, such as bio-based products and industrial materials, over bioenergy. The principle of cascading use is based on single or multiple material uses followed by energy use through burning at the end of life of the material, including taking into account the greenhouse gas emissions (GHG) mitigation potential. By-products and wastes from one production process are used to feed into other production processes or for energy. Biorefineries can thus contribute to the principles of a 'zero-waste society'' (European Commission; EC, 2012a).*

> *'Bio-based products: granting access to sustainable raw materials at world market prices for the production of bio-based products. This will require the application of the cascade principle in the use of biomass and eliminating any possible distortions in the allocation of biomass for alternative uses that might result from aid and other mechanisms that favour the use of biomass for other purposes (e.g. energy)' (European Commission, EC, 2014a, p. 10).*

> *'The Commission will ensure policy neutrality in access to biomass for different purposes to enable efficient application of the cascade principle in the use of the biomass to ensure an efficient and sustainable use of natural resources' (European Commission; EC, 2014b, p. 15).*

Furthermore, the European Parliament emphasised that cascading use should be a substantial part of the Commission's Bioeconomy Strategy:

> *'Emphasise [d] that bioeconomy policies must be better designed to ensure a cascading use of biomass; call[ed], in this respect, for the development of a legal instrument that will pave the way for a more efficient and sustainable use of this precious resource; stress[ed] that such an instrument should establish a cascading use principle in the 'pyramid of biomass', taking into account its different segments and strengthening it at its highest levels; point[ed] out that such an approach would lead to a hierarchical, smart and efficient use of biomass, to value-adding applications and to supporting measures such as coordination of research along the whole value chain' (European Parliament, 2013).*

Cascading use of biomass contributes to the rational utilisation of biomass as a natural resource, since material use in bio-based products comes before a raw material is 'lost' through burning. Therefore, the cascading use of biomass increases the resource efficiency and the total availability of biomass (Essel and Carus, 2014). For instance, a recent Life-Cycle Assessment (LCA) study on different wood cascades shows, in most cases, lower environmental impacts for cascading compared to use for energy (Höglmeier et al., 2015).

Many experts think that the waste hierarchy guarantees cascading use anyway, so there is no need for additional regulations, but that misses the point that cascading starts before a bio-based product enters the waste hierarchy after use. Cascade begins with the biomass itself. If a bio-based product is created from biomass, the waste hierarchy governs cascading use — but not before. The first step of a cascade is the pathway from biomass to the first bio-based products. This can only happen, if the biomass is not used for energy. It is a paradoxical situation: before the biomass becomes a bio-based product, incentives lead the biomass directly to energetic use, while after the biomass has been turned into a bio-based product, incineration is only the least preferred option in the waste hierarchy. That means that only the cascading principle closes the gap between biomass utilisation and the waste hierarchy (Carus et al., 2015).

An often-quoted example for the cascading use of biomass is the wood cascade (stem wood). The wood cascade might start with the production of furniture from solid wood, the subsequent use of this furniture as raw material for the production of particle boards, the recycling of particle boards and their final incineration as wood pellets for electricity. These subsequent processes improve the resource efficiency by reducing the input of wood as raw material for the same output of products. Another example is the paper cascade, as paper is collected and recycled several times to produce new paper.

The same can apply to agricultural biomass, as for example in the case of starch or sugar crops used for the production of bio-based polyethylene terephthalate (PET), which is then used in the production of beverage bottles. After use, these bottles can be transformed into polyester-based textiles, which can also be recycled. The fibres can then be used for compound materials, for example as car parts, and be incinerated for energy at the end of the life cycle. Therefore, the availability of raw materials can be increased with every cycle of cascading use — not only in the case of wood but also in the use of all kinds of biomass to produce materials.

While appealing in theory, the practical application of cascading rules meets with two problems: (1) what value is considered and who decides about this and (2) how can these rules be implemented if they run against market logic, for it sure that market logic leads to the application of cascading.

*Circularity*

The cascading approach, based on the principle that any matter can be reused or recycled, addresses the dilemma of the best use of biomass, but it does not address the issue of waste reduction *per se*. The concept of waste is inherent in the costs of 'reuse or recycle'. Waste is generated where the (economic and ecological) costs of 'reuse and recycle' are higher than the value created. To address this problem, the concept of the circular economy has been developed.

A circular economy is '… *an industrial system that is restorative or regenerative by intention and design. It replaces the end-of-life concept with restoration, shifts towards the use of renewable energy, eliminates the use of toxic chemicals, which impair reuse and return to the biosphere, and aims for the elimination of waste through the superior design of materials, products, systems and business models*' (MacArthur Foundation, 2014).

According to the MacArthur Foundation, a circular economy is based on three principles. The first principle is that, in an ideal circular economy, waste does not exist, as products are designed for a cycle of disassembly and reuse. The second principle implies a strict distinction between consumable and durable components of a product. Consumables should be returned to the biosphere without harm after a cascading sequence of uses, contributing to its restoration. Durables are designed to maximise their reuse or upgrade. To encourage the circularity of durables, these products are leased, rented or shared rather than sold, so that the owner will be responsible for retiring them after use and starting a new cycle. The third principle is the use of renewable energy to fuel the process.

The concept of circularity links to the principle of durability of material goods. The higher the number of cycles of repair, reuse or remanufacturing, the lower the ecological footprint of a product. At the same time, the longer the time of each cycle the lower the demand for resources to create new products.

In a circular economy, processing plants placed in adjoining layers of the cascading ladder are located close to each other, and firms are encouraged to collaborate to explore synergies in the respective material flows. 'New generation' bio-refineries process multiple feedstock to produce multiple products. Industrial clustering, designed to adapt the logistics to the opportunities offered by the circular approach, may reduce considerably the costs of biomass management and would radically reduce waste.

The circular economy is an official concept in the EU. In its Communication on a circular economy (2014), the European Commission pledges to further analyse the major market and governance failures which hampers the avoidance and reuse of material waste; establishes a reinforced partnership to support research and innovative policies for the circular economy; facilitates the development of more circular models for products and services, encourages the cascading principle in the sustainable use of biomass; further integrates circular economy priorities into EU funding; and sets targets for reuse and recycling of waste.

### 2.2.5. Concluding remarks

A transition to a sustainable bioeconomy is a process that cannot be governed only by markets and technology. It requires a constant monitoring of three key conditions, that is, the renewable nature of biomass, the optimal equilibrium between the various uses of biomass—primarily food—and the monitoring and avoidance of any unintended consequences that any new technology brings about. The transition to a sustainable bioeconomy will require a strong strategic orientation based on a clear identification of societal challenges, a holistic view, reflexive governance and a sound base of empirical evidence.

Given the interplay of different issues, interests and actors involved, attention should be paid to processes of integration of policies, which would imply paying attention to interaction patterns, tools and mechanisms. States should carefully evaluate in a comprehensive way the expected impact of support policies that change the intensity of material and trade flows and land use. Research should generate the knowledge base necessary to support coherent policies and to anticipate problems.

# 2.3. State of play in the bioeconomy

## 2.3.1. Introduction

The bioeconomy, a successful transition from a fossil-based towards a bio-based society, requires the consideration of a highly complex framework. Chapter 2.2 highlighted certain aspects of this framework, while this Chapter starts by providing insights on the extent of current (2011) biomass demand and supply at global scale and in EU-28 (2.3.2) and highlighting important aspects of the current state of the environment and natural resources (2.3.3), which are prerequisites for a successful bioeconomy. The major part of this Chapter then addresses the three areas which provide the main demand for biomass. These areas are food and feed (Chapter 2.3.4), biobased materials and chemicals (2.3.5), and bio-energy (2.3.6). Within these areas, trends in technologies, relevant policies, business and market aspects as well as current challenges, dogmas and dilemmas are presented. The Chapter concludes with a discussion about the overarching policy framework, which will link the policy framework of the European bioeconomy — now and in the future (2.3.7).

## 2.3.2. Current supply of and demand for biomass: an overview

### *World*

**Biomass supply**

For the estimation of global biomass supply, we consider four types of biomass: harvested agricultural biomass, primary residues of harvested agricultural biomass, grazed biomass, and forest biomass. Other types of biomass are not accounted for since they are compared to the types above, either very difficult to quantify (such as hunted animals) or currently insignificant compared to these four categories (such as aquatic biomass). We do not account for domestic livestock directly but indirectly through the feed demand.

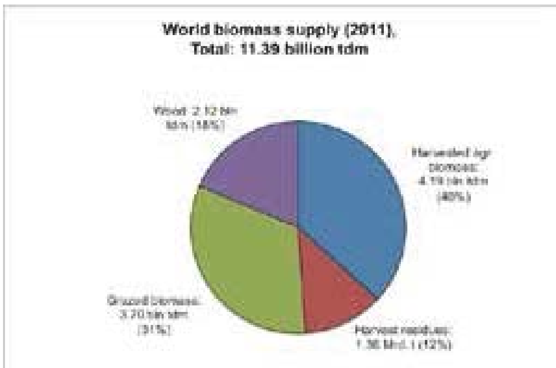
**Biomass demand**

As sectors of biomass demand, we take into account food, feed, and biomaterial use, bioenergy for heat and power and biofuels. Food demand is calculated based on the FAO Food Balance Sheets. Feed demand is based on the world livestock population and species- and region-specific estimates of feed intake (FAO Food Balance Sheets). As sectors of main material uses we take into account the chemical industry, construction and furniture, paper and pulp industry, textiles and animal bedding. Main sources were CEFIC 2014, OPEC 2013 and Piotroski et al., 2015 (for the chemical industry) and FAOSTAT (for the other sectors, 2014a). Bioenergy demand was calculated based on the information by IEA 2013 that about 52 EJ of primary energy were used for heat and power in 2011. Demand for biofuels was calculated from global production figures of biodiesel and bioethanol (REN21 2012).

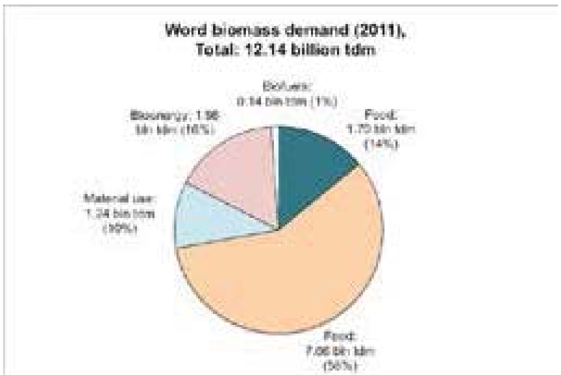
In 2011, the total demand for biomass amounted to about 12.14 billion tonnes of dry matter (tdm) (1.70 billion tdm for food, 7.06 billion tdm for feed, 1.26 billion tdm for materials, 1.98 billion tdm for bioenergy and 0.14 billion tdm for biofuels) compared to a supply of 11.39 billion tdm (see Figure 3.1a/b, Table 3.1).

Figure 3.1: The total amount of global biomass (in tdm) (a) supply and (b) demand in 2011 (Piotrowski et al., 2015).

a)




b)



## *EU-27*

### Biomass supply

For the estimation of biomass supply in the EU-27 in 2011 we took into account domestic biomass production as well as imported biomass in the form of harvested agricultural biomass, woody biomass as well as imports of animal products converted into their equivalent feed demand.

### Biomass demand

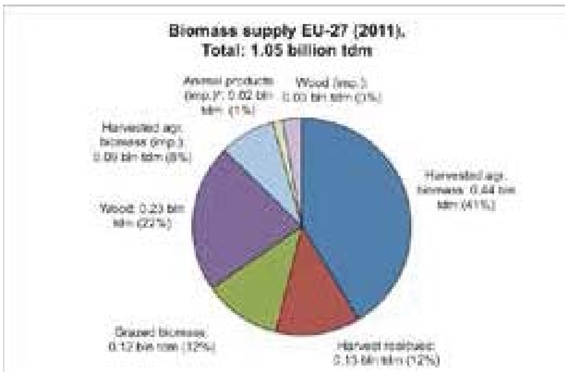
For the estimation of EU-27 biomass demand, the same variables as for the world were considered. In addition, the export demand for agricultural products (plant products and animal products converted into feed demand) and wood was considered. The domestic food demand was calculated based on the FAO Food Balance Sheets, whereas the export demand was calculated based on Eurostat Extra-EU-27 trade database (SITC-classification). The feed demand for domestic consumption was calculated as the difference between the feed demand of the domestic livestock plus the feed demand for imported animal products minus the feed demand for the export of animal products. The feed demand for the export of animal products was based on Eurostat Extra-EU-27 trade database (SITC-classification).

The main sectors of material use which we took into account were the chemical industry, construction and furniture, paper and pulp industry, textiles and animal bedding. The demand for bioenergy was calculated based on the information by Eurostat that about 4.3 EJ of primary energy were used for heat and power in 2011 in the EU-27. The demand for biofuels was calculated from production figures of biodiesel and bioethanol for the EU-27 (Eurostat, AEBIOM 2013).

The total demand for biomass in 2011 amounted to about 1.062 billion tdm (111 M tdm for domestic food, 44 M tdm for export of agricultural biomass, 487 M tdm for domestic feed, 28 M tdm feed demand for exported animal products, 24 M tdm for exported wood, 164 M tdm for materials, 177 M tdm for bioenergy and 27 M tdm for biofuels) compared to a supply of 1.054 billion tdm (see Figure 3.2a/b, Table 3.1).

**Figure 3.2: The total amount of biomass (a) supply and (b) demand in the EU-27 in 2011. The asterix (*) indicates that this value is based on feed equivalents (Piotrowski et al., 2015).**

a)




b)

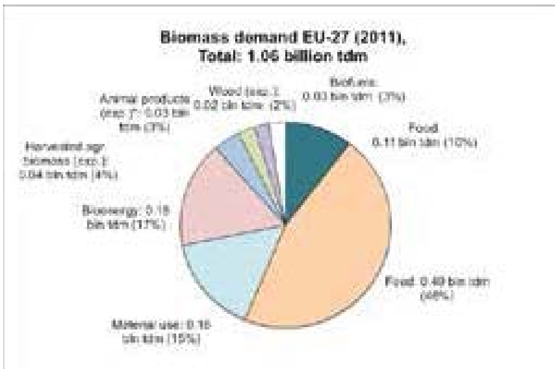


**Table 3.1: The supply of biomass from different sources and the demand for biomass by different sectors at global scale and in the EU-27 in 2011.**

| | World (billion tdm) | EU-27 (billion tdm) |
|---|---|---|
| Biomass supply (2011) | 11.390 | 1.054 |
| Harvested agr. biomass (domestic) | 4.190 | 0.436 |
| Harvested agr. biomass (imported) | - | 0.087 |
| Harvest residues | 1.380 | 0.132 |
| Grazed biomass | 3.700 | 0.122 |
| Wood (domestic) | 2.120 | 0.232 |
| Wood (imported) | - | 0.030 |
| Animal products (imported)* | - | 0.016 |
| Biomass demand (2011) | 12.140 | 1.062 |
| Food (domestic) | 1.700 | 0.111 |
| Feed (domestic) | 7.060 | 0.487 |
| Harvested agr. biomass (exported) | - | 0.044 |
| Animal products (exported)* | - | 0.028 |
| Wood (exported) | - | 0.024 |
| Material use | 1.260 | 0.164 |
| Bioenergy | 1.980 | 0.177 |
| Biofuels | 0.140 | 0.027 |

* in feed equivalents

### 2.3.3. Current state of the environment

The land area in the European Union in 2011 was 4,181,721 km$^2$, excluding land under inland water bodies and national claims to the continental shelf. Several million km of flowing waters and more than a million lakes cover the European continent. The current status of these resources is discussed in the following sections.

*Water*

The earth's water resources are mainly salt water, with only 3.5 % being fresh water (Table 3.2). However, approximately 51 % of the fresh water available is frozen in the icecaps and the remaining 49 % is available for consumption (Shuttleworth, 2012). Each body of water has its own characteristics, such as ecological and good chemical status, and faces its own specific environmental problems, such as eutrophication due to natural and/or human pollution (EEA, 2011a).

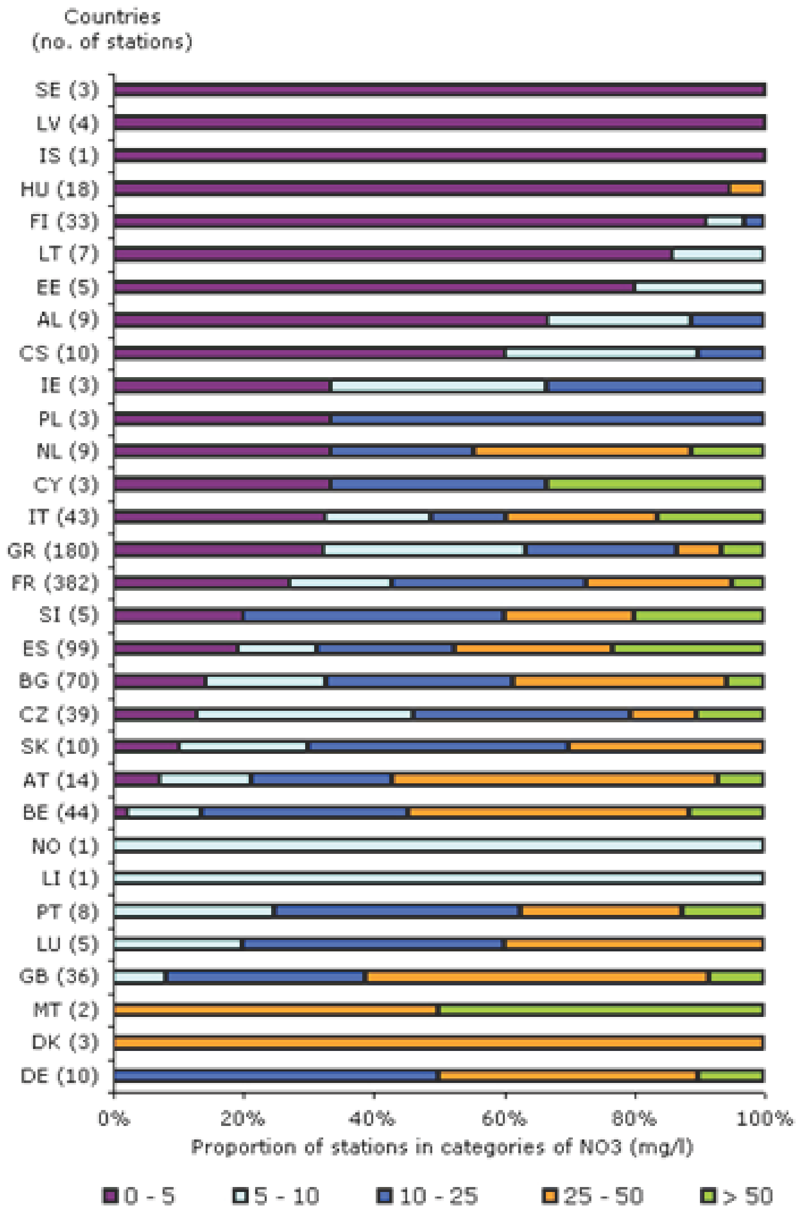
**Table 3.2: Estimated sizes of the main water reservoirs in the earth system, the approximate percentage of water stored in them and turnover time of each reservoir (Shuttleworth, 2012)**

| | Volume (106 km$^3$) | Percentage of total | Approximate residence time |
|---|---|---|---|
| Oceans (including saline inland seas) | ~1340 | ~96.5 | 1000-10 000 years |
| Atmosphere | ~0.013 | ~0.001 | ~10 days |
| Land: polar ice, glaciers, permafrost | ~24 | ~1.8 | 10-1000 years |
| Groundwater | ~23 | ~1.7 | 15 days-10 000 years |
| Lakes, swamps, marshes | ~0.19 | 0.014 | ~10 years |
| Soil moisture | ~0.017 | 0.001 | ~ 50 days |
| Rivers | ~0.002 | ~0.0002 | ~15 days |
| Biological water | ~0.0011 | ~0.0001 | ~10 days |

Clean fresh water is essential for a good quality of life, but our water resources are under increasing pressure. It is essential to improve the way we use and manage our water resources to ensure our ecosystems provide us with sufficient fresh water. Salt water is a potential source of clean water, if the conversion of salt water into fresh water can be achieved economically. The utilisation of cheap solar and wind energy may arise in the future, in order to achieve better efficiency, but there are many economic and environmental contexts and impacts beyond the fresh water demand and energy considerations (Mokheimer et al., 2013; Sharon and Reddy, 2015).

For the protection of drinking water resources — and for ensuring their ecological quality — the Water Framework Directive (WDF) (2000/60/EC) was a milestone of the EU environmental policy. This was the first declaration to take an integrated 'ecosystem-based approach' to this issue: protecting water ecosystems equally in terms of water quality, water quantity and their role as habitats (Figure 3.3). Surface water (water in rivers and lakes) quality and quantity are strongly influenced by overuse by humans, natural and industrial pollution and floods as well as by the influence of land use and climate change (EEA, 2013a).

**Figure 3.3: Present concentration of nitrate in groundwater bodies in European countries (EEA, 2012a).**



The **management and protection of water resources**, of fresh and saltwater ecosystems and of the water we drink and bathe in is one of the cornerstones of environmental protection (Table 3.3). Thus the EU has had a policy in place for over 30 years that has focused on the protection of water resources. The most recent policy document is the *Blueprint to safeguard Europe's water resources* (COM/2012/0673), which aims at ensuring that good quality water of sufficient quantity is available for all legitimate uses.

**Table 3.3: Water resources — long-term annual average (1,000 million $m^3$, Eurostat 2014a).**

| | Precipitation | Evapo-transpiration | Internal flow | External inflow | Outflow | Fresh water resources |
|---|---|---|---|---|---|---|
| Belgium | 28.9 | 16.6 | 12.3 | 7.6 | 15.6 | 19.9 |
| Bulgaria | 69.8 | 52.3 | 18.1 | 89.1 | 108.5 | 107.2 |
| Czech Republic | 54.7 | 39.4 | 15.2 | 0.7 | 16.0 | 16.0 |
| Denmark | 38.5 | 22.1 | 16.3 | 0.0 | 1.9 | 16.3 |
| Germany | 307.0 | 190.0 | 117.0 | 75.0 | 182.0 | 188.0 |
| Estonia | 29.0 | : | : | : | : | : |
| Ireland | 80.0 | 32.5 | 47.5 | 3.5 | : | 51.0 |
| Greece | 115.0 | 55.0 | 60.0 | 12.0 | : | 72.0 |
| Spain | 346.5 | 235.4 | 111.1 | 0.0 | 111.1 | 111.1 |
| France | 500.8 | 320.8 | 175.3 | 11.0 | 168.0 | 186.3 |
| Croatia | 65.7 | 40.1 | 23.0 | : | : | : |
| Italy | 241.1 | 155.8 | 167.0 | 8.0 | 155.0 | 175.0 |
| Cyprus | 3.0 | 2.7 | 0.3 | - | 0.1 | 0.3 |
| Latvia | 42.7 | 25.8 | 16.9 | 16.8 | 32.9 | 33.7 |
| Lithuania | 44.0 | 28.5 | 15.5 | 9.0 | 25.9 | 24.5 |
| Luxembourg | 2.0 | 1.1 | 0.9 | 0.7 | 1.6 | 1.6 |
| Hungary | 55.7 | 48.2 | 7.5 | 108.9 | 115.7 | 116.4 |
| Malta | 150.4 | 72.5 | 0.1 | - | : | 0.1 |
| Netherlands | 31.6 | 21.3 | 8.5 | 81.2 | 86.3 | 89.7 |
| Austria | 98.0 | 43.0 | 55.0 | 29.0 | 84.0 | 84.0 |
| Poland | 193.1 | 138.3 | 54.8 | 8.3 | 63.1 | 63.1 |
| Portugal | 82.2 | 43.6 | 38.6 | 35.0 | 34.0 | 73.6 |
| Romania | 154.0 | 114.6 | 39.4 | 2.9 | 17.9 | 42.3 |
| Slovenia | 31.7 | 13.2 | 18.6 | 13.5 | 32.3 | 32.1 |
| Slovakia | 37.4 | 24.3 | 13.1 | 67.3 | 81.7 | 80.3 |
| Finland | 222.0 | 115.0 | 107.0 | 3.2 | 110.0 | 110.0 |
| Sweden | 342.2 | 169.4 | 172.5 | 13.7 | 186.2 | 186.2 |
| United Kingdom | 275.0 | 117.2 | 157.9 | 6.4 | 164.3 | 164.3 |
| Iceland | 200.0 | 30.0 | 170.0 | - | 170.0 | 170.0 |
| Norway | 470.7 | 112.0 | 371.8 | 12.2 | 384.0 | 384.0 |
| Switzerland | 61.6 | 21.6 | 40.7 | 12.8 | 53.5 | 53.5 |
| FYR of Macedonia | 19.5 | : | : | 1.0 | 6.3 | : |
| Serbia | 56.1 | 43.3 | 12.8 | 162.6 | 175.4 | 175.4 |
| Turkey | 503.1 | 275.7 | 227.4 | 6.9 | 178.0 | 234.3 |

(¹) The minimum period taken into account for the calculation of long-term annual averages in 20 years.

The total renewable freshwater resource in Europe is around 3,500 $km^3 \cdot year^{-1}$. The Mediterranean islands of Malta and Cyprus and the densely populated European countries (Germany, Poland, Spain and England and Wales) have the least available water per capita. Inflows from trans-boundary watersheds can be a significant percentage of freshwater resources in countries, either as surface flow or as groundwater flow (Table 3.4).

**Table 3.4: Number of Member States, RBDs (River basin districts), water bodies, and length or area, per water category**

| Category | Member States | RBDs | Number of water bodies | Total length or area | Average length/area |
|---|---|---|---|---|---|
| Rivers | 26 | 157 | 104 311 | 1.17 million km | 11.3 km |
| Lakes | 24 | 144 | 19 053 | 88000 $km^2$ | 4.6 $km^2$ |
| Transitional | 16 | 87 | 1010 | 19600 $km^2$ | 19 $km^2$ |
| Coastal waters | 22 | 114 | 3033 | 358000 $km^2$ | 118 $km^2$ |
| Groundwater | 27 | 148 | 13 261 | 3.8 million $km^2$ | 309 $km^2$ |

The downstream countries of the Danube Basin have the highest dependency on external resources. Several million km of flowing waters and more than a million lakes cover the European continent. Each body of water has its own characteristics, such as clarity and biodiversity level, and faces its own specific environmental problems, such as eutrophication (EEA, 2014a). EU Member States have reported 13,300 groundwater bodies and more than 127,000 surface water bodies. 82 % of these are rivers, 15 % are lakes and 3 % are coastal and transitional waters (EEA, 2012b).

### *Soil*

According to the European Environment Agency the soil continues to be degraded in Europe. Soil is a conditionally renewable resource for ecosystems, playing an essential role in services such as biomass production and water purification. Additionally the soil layers are also important global carbon sinks, with significant potential to remove climate-changing gases from the atmosphere. This applies in particular also to forest soils.

The European Commission's Joint Research Centre work on soils highlighted the necessity of protecting and maintaining them. The report warns that failure to tackle increased soil degradation could eventually compromise food production. Moreover, degraded soil is less able to prevent droughts and flooding and stop biodiversity loss (EEA, 2012c).

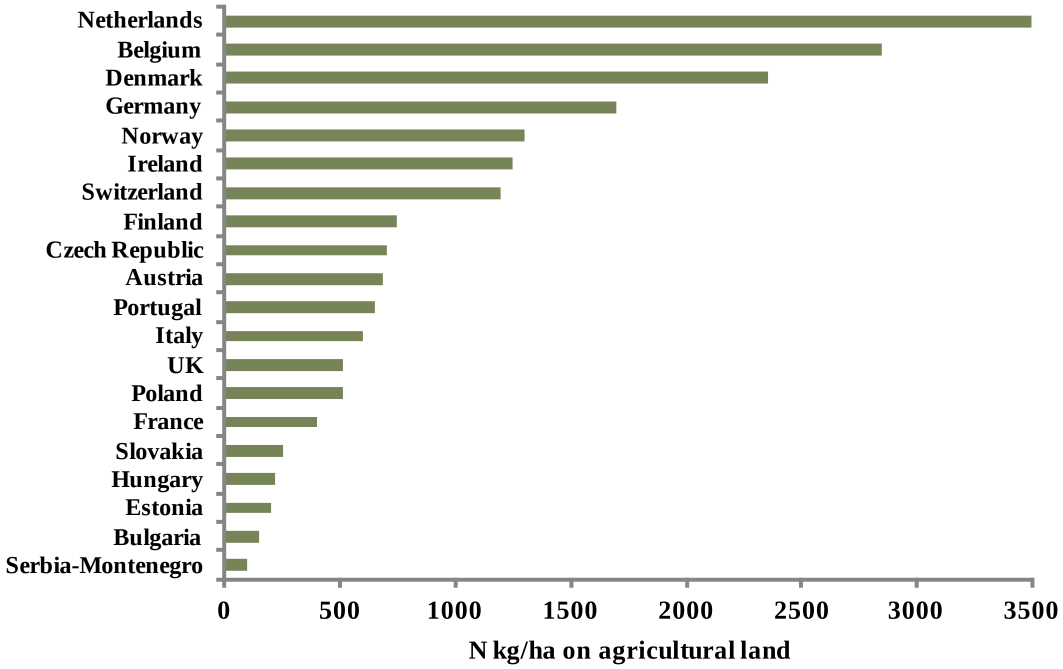
The EEA reported that the organic matter and biodiversity are both declining in some areas, while compaction, salinisation, and contamination are also significant issues. Different studies show that around 10 million hectares arable land is lost every year worldwide due to degradation (Piotrowski et al., 2015).

All of these problems have considerable economic and environmental consequences. For example, soil erosion by water affects around 16 % of Europe's land area, additionally the risk factor for extremely intensive rainstorms will double before 2100. The surface erosion is largely the result of poor land management, such as deforestation, overgrazing, construction activities and forest fires (EC, 2014c).

Unsustainable human land use and management is leading to increased soil degradation, and the loss of a soil organic matter resource that is fundamental for the growth of vegetation (Lee et al., 2010). Using site-specific precision technologies in plant nutrition can support both soil conservation and soil fertility maintenance (Németh et al., 2007).

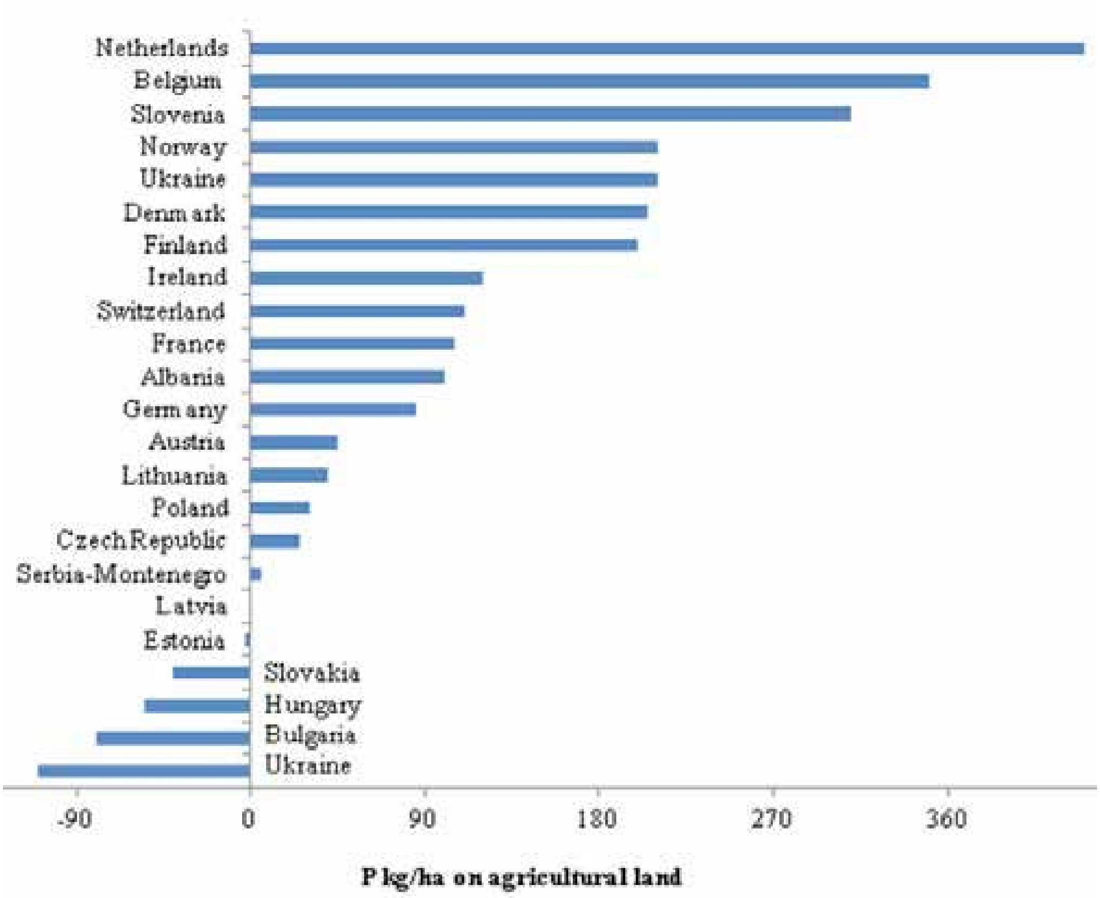
Around 45 % of the mineral soils in Europe have low or very low organic carbon content (0-2 %) and 45 % have a medium content (2-6 %). Excess nitrogen in the soil from high fertiliser application rates and/or low plant uptake can cause an increase in the mineralisation of organic carbon, which in turn leads to an increased loss of carbon from soils (EC, 2014d). Maximum nitrogen values are reached in areas with high livestock populations, intensive fruit and vegetable cropping, or cereal production with imbalanced fertiliser practices. While in extreme situations the surplus soil nitrogen can be as high as 300 kg N/ha, estimates show that 15 % of land in the EU-27 exhibits a surplus in excess of 40 kg N/ha (Jones et al., 2012). As mentioned above, maximum N (and P) cumulative NP balance values are reached in areas with high livestock densities. There was a positive correlation between the 1991-2005 cumulative NP balances and livestock densities (Csathó and Radimszky, 2012). The cumulated N balances in Europe are estimated for the period of 1991-2005 in Figure 3.4.

**Figure 3.4: Estimated cumulative N balance of European countries, 1991-2005 (Csathó and Radimszky, 2012).**




**Phosphorus (P)** is a macronutrient essential for plant growth and consequently, for the production of biomass. Compared to nitrogen (which can be fixed from the atmosphere), however, phosphorus, is a finite resource. Resources of rock phosphate are available on all continents (total $67*10^3$ Mt P in 2014). However, the majority (75%) of the global reserves is located in Morocco and the Western Sahara ($50*10^3$ Mt P, USGS 2014). Current concerns with regard to P reflect the depletion of P resources and reserves as well as the unequal access to P fertilisers. Similar to N, high P loads contribute to negative impacts on the environment such as the eutrophication of water bodies (Rockström et al., 2009b). Negative impacts also result from the high energy and water demands during P-mining and processing (Ulrich, 2013). In order to preserve the quality of water in Europe's lakes, reservoirs, streams and the upper reaches of estuaries, it is important, therefore, to ensure that the application of fertiliser and manure (as key sources of phosphorous and nitrogen) is done to maximise the chemical and physical availability of the P to crops, while minimising the risk that the P might be lost to the environment by runoff or erosion thereby damaging water quality (Beegle, 2015). The cumulated P balances in Europe are estimated for the period of 1991-2005 in Figure 3.5 (Csathó and Radimszky, 2012).

Figure 3.5: Estimated cumulative P balance in European countries, 1991-2005 (Csathó and Radimszky, 2012).

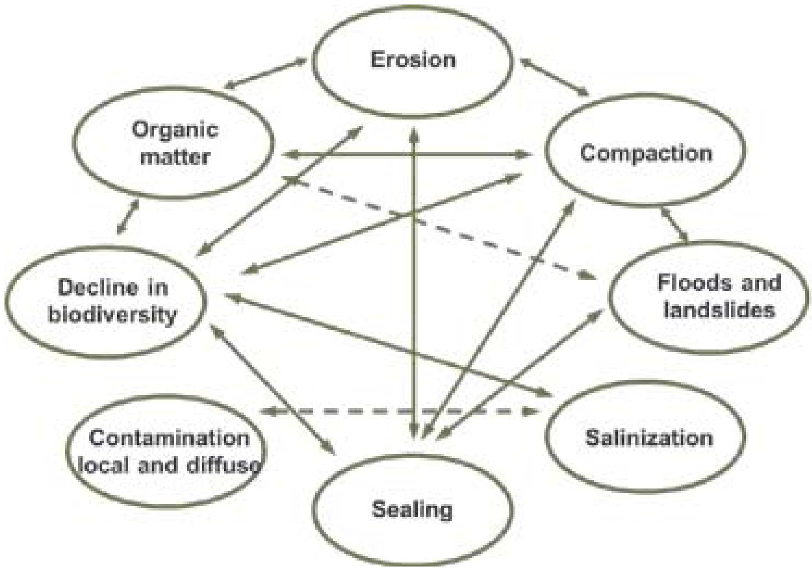



Additionally the soil water retention capacity and soil moisture content will be affected by rising temperatures and by a decline in soil organic matter due to both changes in climate and land management. Further projections of the European Environment Agency for 2071-2100 show a general reduction in summer soil moisture over most of Europe with significant reductions in the Mediterranean region and increases in the north-eastern part of Europe (EEA, 2008). Therefore we have to focus benchmarking actions at an international level on regional and global scales (EC, 2006a). But, locally maintaining water retention capacity and porosity are also important to reduce the impacts of intense rainfall and droughts, which are projected to become more frequent and severe (EEA, 2012b). According to Várallyay (2010) the soil layer is the biggest natural water reservoir, thus we could consider it as a potential fresh water pool. The benefits of adopting an environmentally-focused approach to tillage are in the assessment of risks in advance and in the elaboration and application of alternatives with a view to minimising damage. As a consequence of minimising environmental damage the soil status can be improved and favourable soil condition can be maintained (Birkás, 2008).

It is worth noting that it takes approximately 500 years to replace 25 mm of topsoil lost to erosion (Pimentel, 1998).

Four types of soil degradation are distinguished: (i) erosion (wind and water); (ii) physical (compaction, laterisation, hardsetting); (iii) biological (loss of soil biodiversity); (iv) chemical (depletion of organic matter and nutrients, contamination, mining activities, industrial activities, agricultural activities) (Figure 3.6). For instance in Europe, the principal causes of soil degradation are the following: deforestation (38 %), agricultural practices (29 %), overgrazing (23 %) and industrialisation (9 %) (EEA, 2011b).

**Figure 3.6: Major types and interactions of soil degradation (Várallyay, 2002).**




It is widely accepted that **organic matter (OM)** plays an important role in maintaining healthy soils, both in terms of physical structure and supporting the life of micro-organisms which live in soil. Activities such as the application of manures and composts, use of cover crops, refraining from burning of crop residues or living vegetation and reduced or zero tillage, have all been shown to lead to an increase in soil OM (SOM) content (Bot and Benites, 2005). SOM also has a beneficial effect on several ecosystem services, such as primary production, soil formation, biogeochemical cycles and the regulation of water quality and climate. At a global level, soils are a major reservoir of carbon (C) in terrestrial ecosystems; Soil contains more than 3-fold the amount of C that can be found in the atmosphere or in terrestrial vegetation.

A decrease in SOM, e.g., by oxidation following cultivation, the withdrawal of grass-leys from rotations or the absence of animal or 'green' manuring will thus have a negative effect, not only on soil health, but also on the release of carbon into the atmosphere. There is clear evidence of decline in SOM content in many soils as a consequence of the unprecedented expansion and intensification of agriculture during the 20th century. This decline in SOM content is a threat to the sustainability of agricultural production systems, because SOM is a major contributor to soil fertility and quality (EC, 2015a).

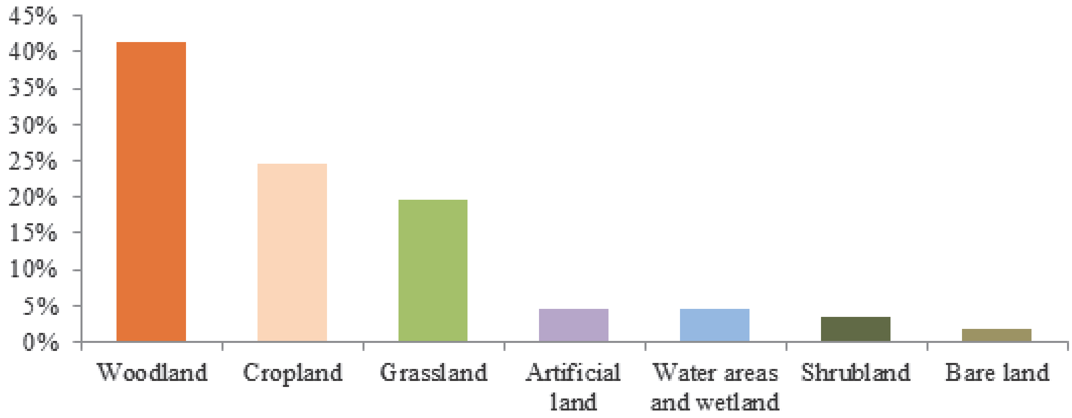
The breakdown of OM residues in soils tends to increase with ambient temperature. Large areas of soil in regions with warmer climates, where arable cultivation dominates, have soil organic carbon (SOC) content below or close to 2% in the cultivated horizon. Amounts of SOC are generally greater in the cooler, wetter regions, where long-term grassland dominates. Soil type also affects SOC content; the greater the clay content of the soil, then the greater the SOC, assuming similar land-use and management practices (Loveland and Webb, 2003).Where climate change results in significant warming, it may be more difficult, therefore, to maintain high levels of SOM, while keeping carbon in the soil can play a major role in mitigating climate change.

*Land*

Europe is one of the most intensively used continents on the globe in terms of land use, and covers a broad gradient of geographic and climatic conditions as well as a variety of soil types and management practices. Europe has the highest share of land (up to 80 %) used for settlements, production systems and infrastructure, which are the most important drivers for land use. Conflicting land use demands often arise within Member States as well as outside the EU, requiring decisions that will involve hard trade-offs. The EEA (2013b) claimed there are several important drivers for land use in Europe: the increasing demand for living space per person and the link between economic activity, increased mobility and growth of transport infrastructure usually result in land take. Europe is a mosaic of landscapes, reflecting the evolutionary pattern of land use changes in the past, which might induce large and often irreversible land-use footprints today. Generally the lands are overused (increasing degradation, erosion of landscape, ecosystem and other natural resources) due to the rising space requirement within the countries (EEA, 2013b).

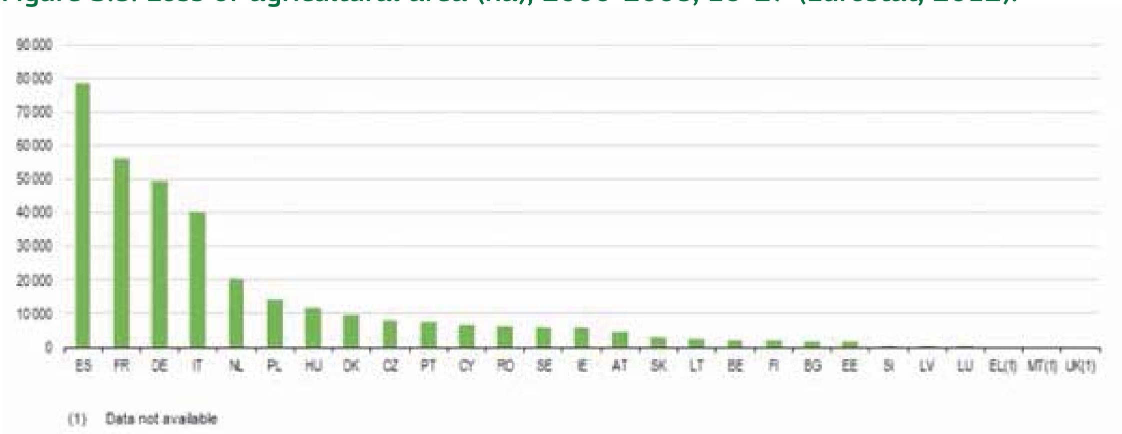
The composition of the agricultural zone is changing year by year but the most important types of land cover are arable land, permanent crops, forests, grasslands, open spaces, pastures and mosaic farmlands. Figure 3.7 shows the distribution of land use of EU-27 in 2012.

**Figure 3.7: Main land cover by land cover type ( % of total area), EU-27, 2012 (Eurostat, 2013e).**




Based on the EEA report the largest land cover category taken by urban and other artificial land development was agricultural land (Eurostat, 2013e). On average, almost 46 % of the land that changed to artificial surfaces was arable land or permanent crops (Figure 3.8). This dominant land take was particularly important in Denmark (90 %), Slovakia (85 %), Italy (74 %), Poland (67 %), Germany (65 %) and Hungary (65 %).

**Figure 3.8: Loss of agricultural area (ha), 2000-2006, EU-27 (Eurostat, 2012).**



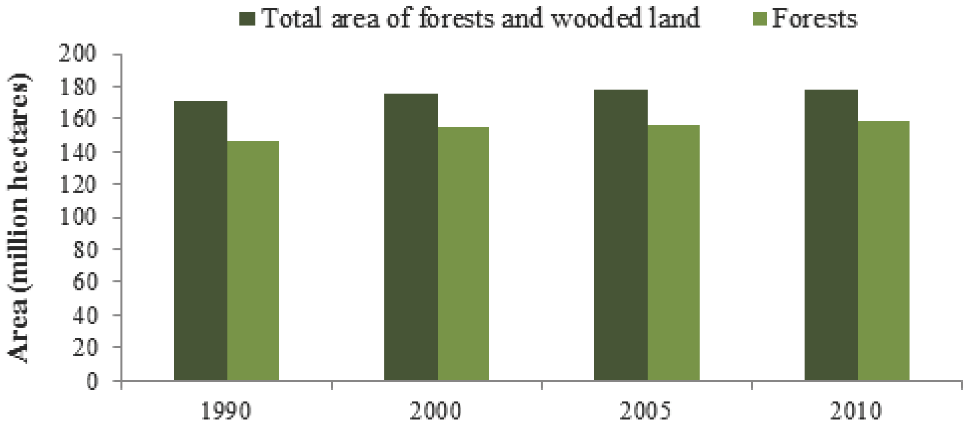

The environmental impacts of urban expansion reach far beyond urban areas themselves. In rapidly urbanising areas, agriculture intensifies on remaining undeveloped land and is likely to expand to new areas, putting pressure on land resources (Jiang et al., 2013).

## *Forests*

The EU currently contains 5 % of the world's forests with 155 million ha forests and 21 million ha of other wooded land. These together constitute more than 42 % of the EU land area. In Europe, the forest cover increased at an annual rate of 0.8 % (0.4 % in the European Union 27 Member States) over the last 20 years. It is growing at different rates in different regions, for example 1.3 % in South-West Europe and 0.15 % in Northern Europe (Estreguil et al., 2012).

Forests are important not only for primary production, but also for land cover (and carbon sequestration linked to climate change mitigation) and for biodiversity. Sustainable forest management should include concerns about landscape pattern and their changes, to address fragmentation and connectivity (EC, 2006b). Indeed, changes in pattern have an impact on ecological processes such as habitat provision, gene flow, pollination, wildlife dispersal, or pest propagation in different ways. In the EU, 40 % of the forest lands are within 100 m of other lands, thus potentially less suitable as interior habitat and more likely to be exposed to invasive species, pests and diseases (Figure 3.9). Forest edges are also mainly (60 %) alongside intensively used land (Estreguil et al., 2012).

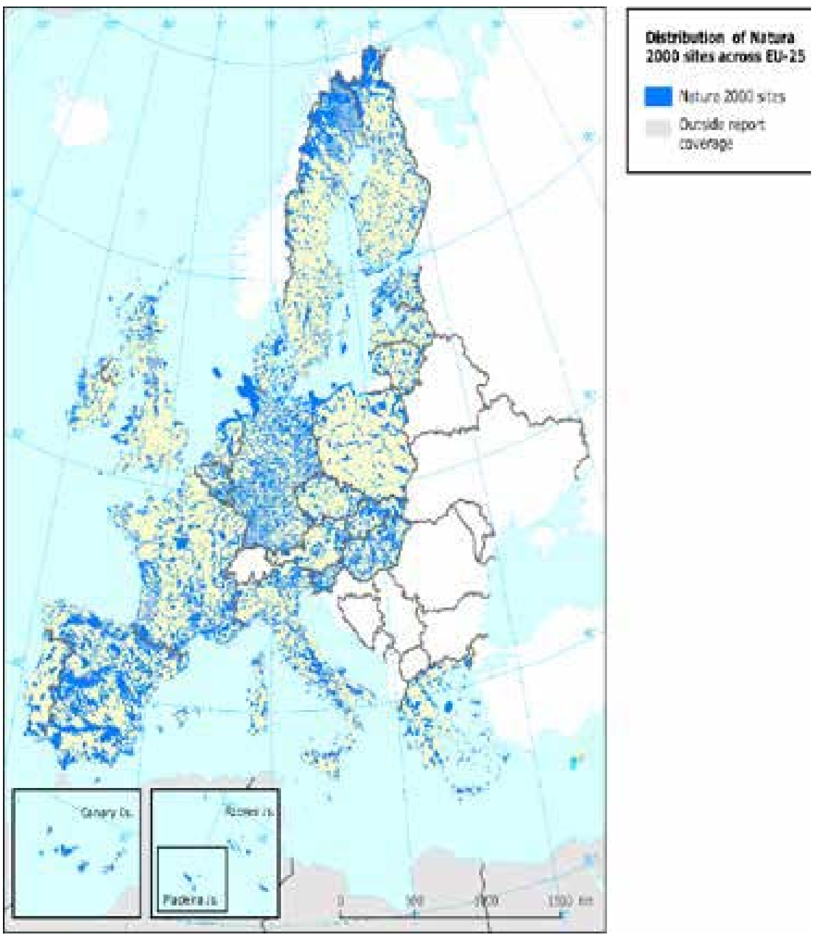
**Figure 3.9: The area of forests and total wooded land in the European Union (Eurostat, 2014b).**




## *Biodiversity*

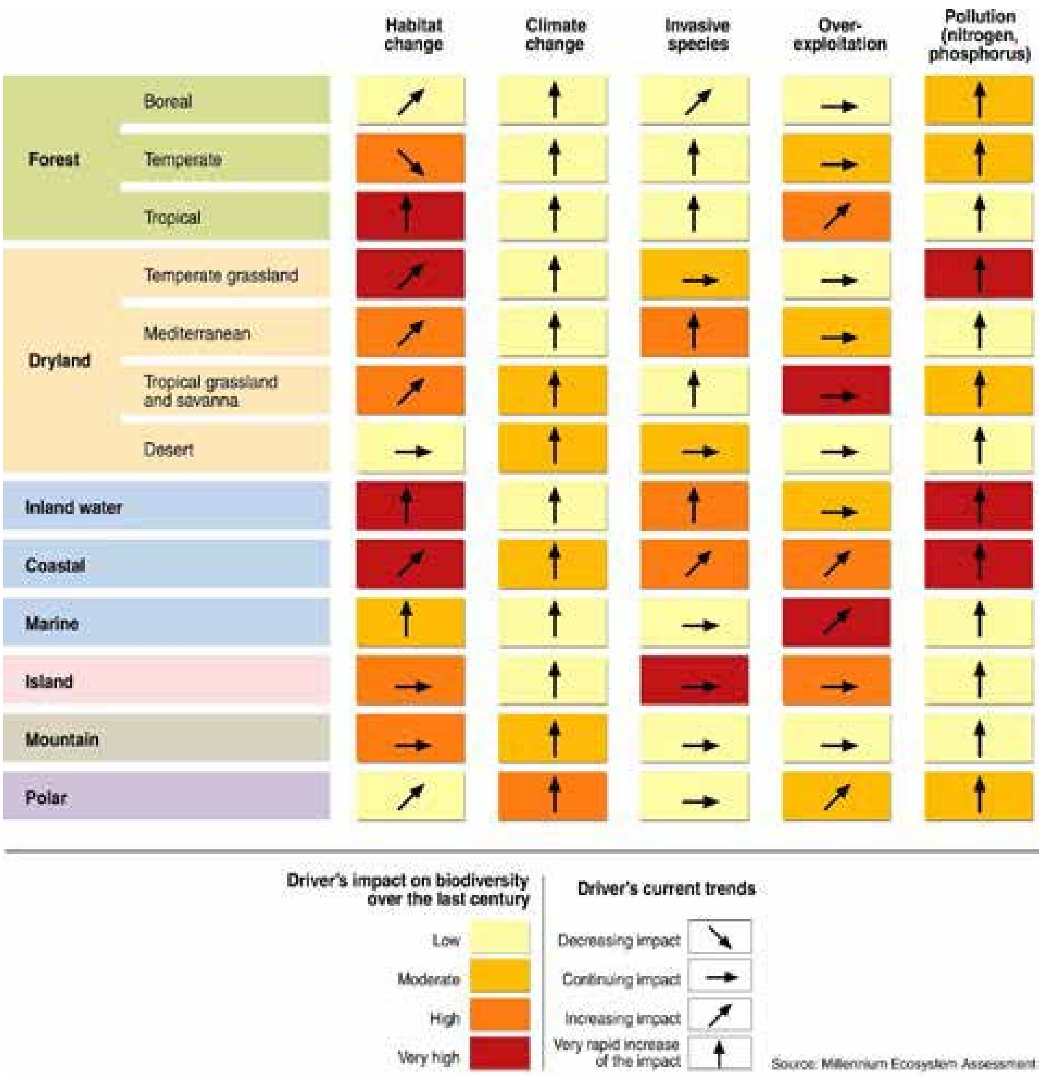
Biodiversity includes not only the diversity of species, but also the variety of different areas and habitats. Agricultural area and the lesser extended forests and semi-natural and natural areas are the native living space of a number of species. These decreased niches are generally fragments of the landscape therefore the Natura 2000 (Figure 3.10) and Emerald networks are meaningful to protect the living space and support the maintenance (Ma et al., 2014). The protected areas cover a quarter of Europe's land and almost 6 % of regional seas (EC, 1992). Wetlands and permanent grasslands (at least 100 years old) belong to protected areas. For instance the grasslands are one of the most widespread vegetation types worldwide, covering nearly one-fifth of the world's land surface (24 million km) (Suttie et al., 2005).

**Figure 3.10: Distribution of Natura 2000 sites across EU Member States (EEA, 2015).**



Biodiversity change is most clearly a consequence of direct drivers (Figure 3.11). However, these reflect changes in indirect drivers — the root causes of changes in ecosystems. These can be classified into the following broad categories: change in economic activity, demographic change, socio-political factors, cultural and religious factors, and scientific and technological change. Global economic activity increased nearly sevenfold between 1950 and 2000, and in the MEA (Millennium Ecosystem Assessment) scenarios it is projected to grow a further three- to six-fold by 2050 (Millennium Ecosystem Assessment, 2005).

### Figure 3.11: Main direct drivers (Millennium Ecosystem Assessment, 2005)




The importance of these drivers varies from one ecosystem to the other. Land use change (especially deforestation) and climate change generally have the greatest impact for terrestrial ecosystems, whereas biotic exchange is more important for freshwater ecosystems (Braimoh et al., 2010).

The Birds and the Habitats Directives are the main legislative instruments for ensuring conservation and the sustainable use of nature in the EU, particularly through the Natura 2000 network of areas of high biodiversity value. The directives are key elements of the EU Biodiversity Strategy, which aims to achieve the EU headline target of 'halting the loss of biodiversity and the degradation of ecosystem services in the EU by 2020 and restoring them in so far as feasible' (EC, 2015b).

About 15 % of all bird species are 'near threatened', declining or depleted and another 17 % of the species are threatened. The short-term population trends of the bird species indicate that only 4 % are non-secure but increasing, while 6 % are non-secure and stable, and a further 20 % are non-secure and decreasing. About 23 % of EU-level species assessments indicate a favourable status, while 60 % are unfavourable, of which 18 % are 'unfavourable-bad'. In relation to status trends the 60 % of assessments recorded as unfavourable are composed of 4 % that are improving, 20 % that are stable, 22 % that are deteriorating and 14 % without a known trend.

The conservation status of, and trends for, habitats are worse than for species. This is probably due to a more established tradition of conservation action for species, and the less complex nature and shorter response time for species to recover. Across the EU, 16 % of habitat assessments are favourable, while more than three quarters are unfavourable, of which 30 % are unfavourable-bad. In relation to status trends, the 77 % assessed as unfavourable are composed of 4 % that show improvement, 33 % that are stable, 30 % that indicate further deteriorations and 10 % with an unknown trend (EC, 2015b).

Birds are recognised as good indicators of environmental change and as useful proxies of wider changes in nature. The Wild Bird Index (WBI) measures average population trends of a suite of representative wild birds, as an indicator of the general health of the wider environment (Sheehan, 2010). The results show that the European farmland bird index declined by 52 % covering the period 1980–2010, representing a loss of 300 million birds (Birdlife.org).

Soil biodiversity is an important aspect of sustainable agricultural land use globally. According to the Convention on Biological Diversity soil biodiversity is the variation in soil life, from genes to communities, and the ecological complexes of which they are a part, that is from soil micro-habitats to landscapes (JRC, 2014). Nutrient supply can influence soil biodiversity as well as the composition and biomass production of weed flora in agro-ecosystems (Lehoczky et al., 2014; Kuroli et al., 2007). Some reports declare, a teaspoon soil sample may typically contain 1 billion bacterial cells, up to 1 million individual fungi, about 1 million cells of protists, and several hundred of nematodes. Beside microorganisms and microfauna, soil harbours different species of meso and macrofauna represented by arthropods, earthworms and mammals (JRC, 2014).

The soil biota plays many fundamental roles in delivering key ecosystem goods and services, and is both directly and indirectly responsible for carrying out many important functions, such as food and fibre production, driving nutrient cycling, regulation of water storage and flow and soil and sediment movement. Additionally they can have an effect on detoxification and regulation of atmospheric composition. The investigation of the soil biota is crucial, because the following most important functions are defined or at least significantly modified by soil biota: primary and secondary production, primary decomposition (fungi, bacteria), secondary decomposition (worms, insects, molluscs), soil structural dynamics, symbioses, soil organic matter formation, stabilisation, atmospheric gas dynamics (Jeffery et al., 2010).

Generally, knowledge is very limited for most species regarding their exact functions, their ability to respond to environmental pressures, their interactions with other organisms and the spatial distributions throughout the soil matrix. Current levels of soil biodiversity in most areas are still unknown and while quantification of current levels of soil biodiversity is difficult, it is vital to allow assessment of future impacts. Functional redundancy also makes the evaluation of a given threat's effects on a soil system difficult to quantify as function may remain, even when species diversity is reduced (Jones et al., 2012).

An effective policy for conservation of soil biodiversity should be integrated with both soil protection and broader environmental and sustainability strategies (EC, 2006c, 2011). For the European Union this objective could be achieved by broad application of the Soil Thematic Strategy, and by the effective application of the revised EU Sustainable Development Strategy (Jeffery et al., 2010).

The Living Planet Index (LPI) is an indicator of the state of the world's biodiversity: it measures trends in populations of vertebrate species living in terrestrial, freshwater, and marine ecosystems around the world. The LPI fell by about 40 per cent between 1970 and 2000 on global scale (Loh and Wackernagel, 2004).

### *Marine*

Seas have provided Europeans with food, livelihoods and well-being for millennia. But these benefits are increasingly coming under threat from multiple pressures. European seas cover around 11,220,000 km$^2$ — an area larger than Europe's land territory. Twenty-three out of 28 EU Member States have a coastline connecting Europeans to the sea and in 2011, 41 % of Europe's population — or 206 million people — lived in the 378 EU coastal regions. Climate change has led to higher sea temperatures, increased acidification, increased area influenced by oxygen depletion and a decrease in Arctic and Baltic Sea ice coverage. 39 % of assessed fish stocks in the North-East Atlantic and 88 % in the Mediterranean and Black Seas are overexploited and eutrophication remains a challenge (EEA, 2014a).

The regional seas surrounding Europe include the vastness of the open oceans as well as almost entirely land-locked seas (Table 3.5). Each sea is shared by a myriad of people, cultures, and activities. They are also the home to thousands of species of plants and animals, many of which are unique and fragile (EEA, 2014b).

At the European scale, it remains difficult to analyse the rate at which the loss of biodiversity and the related resilience of marine ecosystems occurs. This is mainly because of the lack of adequate available data. However, information reported by EU Member States under the Marine Strategy Framework Directive (MSFD) indicates that local biodiversity loss could be considerable (Figure 3.12) (EEA, 2014b).

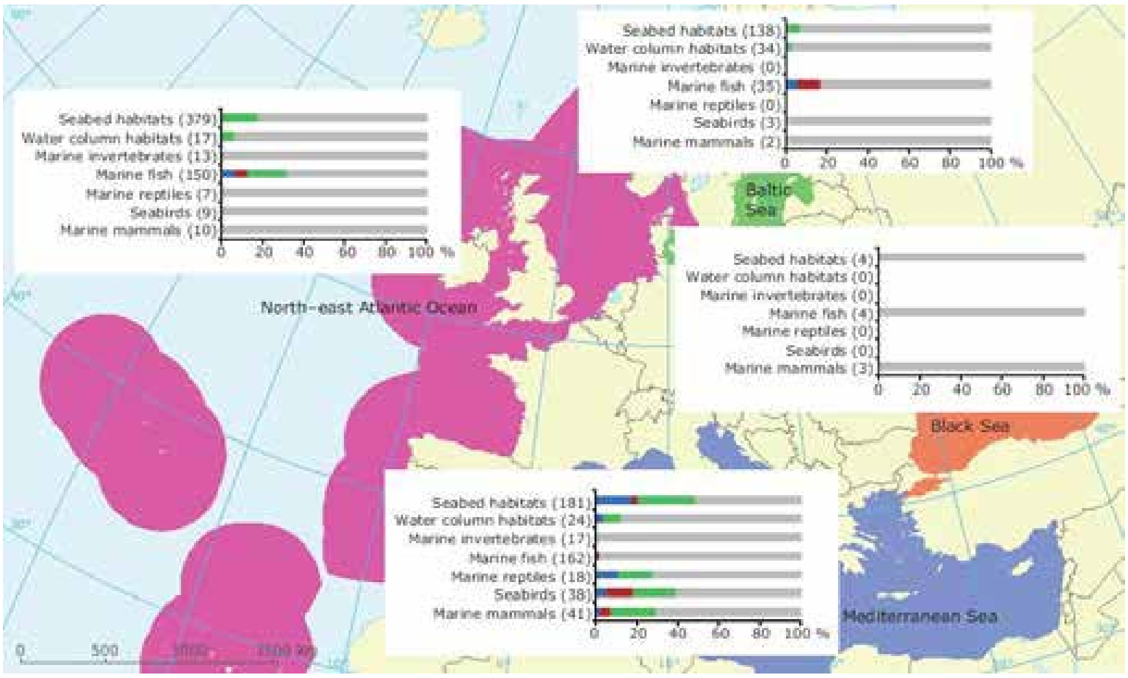
### Table 3.5: Regional seas surrounding Europe — selected geographic characteristics (EEA, 2014b)

| Regional seas surrounding Europe | Neighbouring EEA/ collaborating countries | Regional sea surface area ($km^2$) | EU Member State share of sea surface area ($km^2$) and ( %) | % of EU Member State sea surface area reported under the MSFD | Area of catchment ($km^2$) | Population in catchment |
|---|---|---|---|---|---|---|
| Baltic Sea | SE, FI, EE, LT, LV, PL, DE, DK | 394 000 | 370 000 (93.9) | 92 | 1 653 000 | 77 019 000 |
| North East Atlantic Ocean | UK, NO, DK, DE, NL, BE, SE, IE, FR, PT, ES | 7 835 000 | 4 076 000 (52.0) | 58 | 2 721 000 | 260 192 000 |
| Barents Sea | NO, RU | 1 944 000 | 0 (0) | – | 706 000 | 1 401 000 |
| Norwegian Sea | NO | 888 000 | 0 (0) | – | 89 300 | 824 000 |
| Iceland Sea | IS | 756 000 | 0 (0) | – | 103 000 | 283 000 |
| Celtic Sea | UK, IE | 920 000 | 916 000 (99.6) | – | 185 000 | 23 135 000 |
| Greater North Sea | DK, SE, NO, DE, BE, NL, FR, UK | 670 000 | 503 000 (75.1) | – | 966 000 | 183 889 000 |
| Bay of Biscay and the Iberian Coast | FR, PT, ES | 804 000 | 804 000 (100) | – | 661 000 | 48 500 000 |
| Macaronesia | ES, PT | 1 853 000 | 1 853 000 (100) | – | 10 300 | 2 160 000 |
| Mediterranean | ES, FR, IT, SI, MT, HR, BA, ME, AL, EL, CY, TR | 2 517 000 | 1 210 000 (48.1) | 86 | 1 121 000 | 133 334 000 |
| Western Mediterranean | FR, IT, ES | 846 000 | 660 000 (78.0) | – | 429 000 | 53 852 000 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Ionian Sea and Central Mediterranean Sea | IT, MT, EL | 773 000 | 240 000 (31.0) | – | 76 300 | 8 295 000 |
| Adriatic Sea | SI, IT, ME, AL, HR | 140 000 | 120 000 (87.7) | – | 242 000 | 37 327 000 |
| Aegean-Levantine Sea | EL, CY, TR | 758 000 | 190 000 (25.1) | – | 374 000 | 33 860 000 |
| Black Sea | BG, RO, TR | 474 000 | 64 000 (13.5) | 46 | 2 414 000 | 191 994 000 |
| Sea of Marmara | TR | 11 700 | 0 (0) | – | 39 290 | No data |
| Total | – | 11 220 000 | 5 720 000 (51.0) | 66 | 7 909 000 | 662 538 000 |

**NB:** AL: Albania; BA: Bosnia and Herzegovina; BE: Belgium; BG Bulgaria; CY: Cyprus; DK: Denmark; DE: Germany; EE: Estonia; EL: Greece; ES: Spain; FI: Finland; FR: France; HR: Croatia; IE: Ireland; IT: Italy; LT: Lithuania; LV: Latvia; ME: Montenegro; MT: Malta; NO: Norway; NL: Netherlands; PL: Poland; PT: Portugal; RO: Romania; SE: Sweden; SI: Slovenia; TR: Turkey; UK: United Kingdom.

## Figure 3.12: Status assessment of natural features reported by EU Member States under the MSFD (ETC/ICM, 2014 in: EEA 2014b)




Whether looking at species (fish, mammals, birds, invertebrates or reptiles) or marine habitats (water column, seabed), less than 20 % (often much lower) of all biodiversity features (i.e. species, habitats and ecosystems) are considered as being in Good Environmental Status, although the status of biodiversity of species in the Black Sea is unknown. The same pattern has been observed for vulnerable marine species (EC, 2008a) and habitats protected by the Habitats Directive. From 2001 to 2006, only 10 % of the marine habitats assessments were considered to be at favourable conservation status. All of these were within the Macaronesian region. The assessments also stated that conservation status was inadequate or bad for 50 % of the marine habitats. Marine species fared even worse with only 3 % of the assessments being favourable and more than 70 % being categorised as unknown (EEA, 2014b).

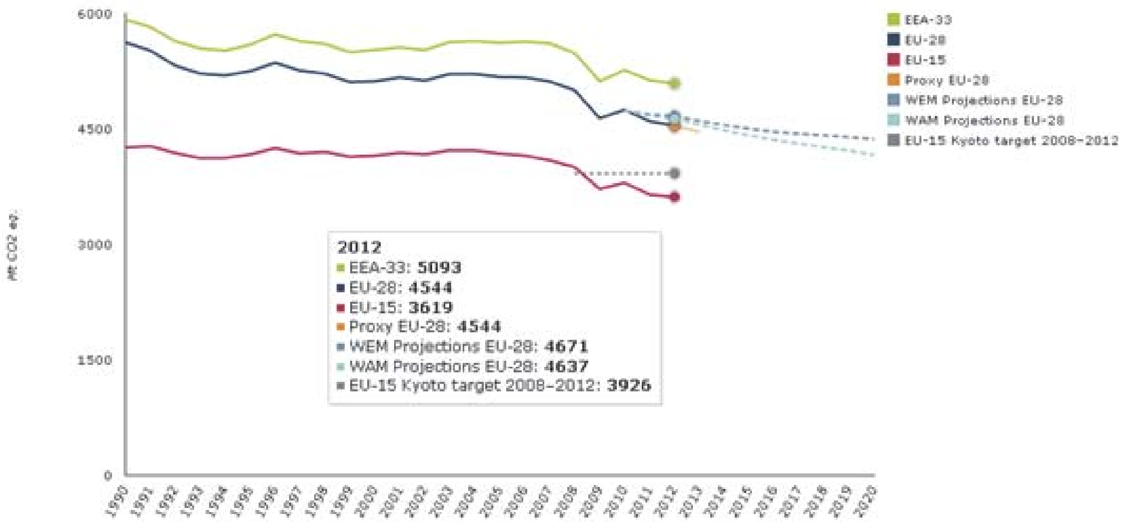
### *Climate change and greenhouse gas (GHG) emission*

Overall, changing climatic conditions are going to have direct and indirect effects on geographical regions and ecosystems in Europe. For example, the increase occurrence of extreme weather events as well as changes in the availability of water affects GHG fluxes and consequently soil-plant-atmosphere systems (Suttle et al., 2007).

Terrestrial ecosystems are undergoing transitions with global climate change which influence water-carbon-energy fluxes, which will become stronger in the coming decades and beyond. For instance, to estimate the key processes (such as plant photosynthesis, soil moisture) of carbon (C) and water exchanges between the soil, atmosphere and biosphere pools is essential under different land use and treatment to draw conclusions for the future. The use of ecosystem models is necessary which have made significant progress in terms of quantifying regional to global C and water fluxes (Jung et al., 2011).

According to the latest official data, published by the EEA in May 2014, GHG emissions in 2012 amounted to 4,522 Mt $CO_2$ eq. in the EU-28. For the EEA countries, GHG emissions in 2012 were about 5,093 Mt $CO_2$ eq. (Figure 3.13).

**Figure 3.13: Historic and projected trends of GHG emission in Europe (EEA, 2014c). WEM: with existing measures, WAM: with additional measures. GHG totals do not include emissions from Land Use, Land-Use Change and Forestry (LULUCF) and international bunker fuels.**




GHG mitigation is a priority task for the EU and Member States' GHG emission were decreased by 19.2 % in 2012 compared to 1990s level (excluding LULUCF and international aviation). Preliminary estimates for 2013 show a further fall of 80 Mt $CO_2$ eq. between 2012 and 2013 (20.7 % below 1990 levels). Moreover almost all EU-28 countries are well on track towards achieving their commitments under the first period of the Kyoto Protocol (EC, 2013a). The greenhouse gas emissions covered by the Emission Trading System (ETS) in 2013 were 19 % below 2005 levels in the EU. For six Member States, projections indicate that implementing the additional measures which were in the planning stage in 2013 might not be sufficient to reduce GHG emissions below targets by 2020 under the Effort Sharing Decision (Reichstein et al., 2013).

## 2.3.4. Food and feed

### *Introduction*

Food and feed together accounted for the majority of biomass demand (Figure 3.1 in section 3.2) at the world level in 2011. These products are generated by agriculture (including livestock), horticulture, fisheries and aquaculture. The main drivers of food and feed demand are human population growth and changes in diet. High growth in population in the next few decades will mainly occur in Asia and Africa, with any change in Europe potentially being a slight decrease. Changes in Europe's diet are also predicted to be small, with the major driver of global dietary change deriving from Asia, due to the growth in economies such as China and India and the size (and predicted economic growth of their populations Kearney, 2010). The main demand impacts on Europe, therefore, will mainly be the consequence of global trade, unless consumers respond to the efforts of governments to tackle diet and health issues (e.g., Capacci et al., 2012). Preliminary evidence of change has been shown by Vranken et al. (2014). At the global level, there are already a number of projections of the potential increase in demand for food and feeds (e.g., IAASTD, 2009; INRA and CIRAD, 2009; Foresight, 2011) but none of these considered changes in biomass demand for non-food uses. This is considered in Chapter 2.3.1. The emphasis in this section is on summarising past and present trends in technology, policies, markets and society which have, and still are influencing the demand and supply for foods and feed and the challenges and opportunities that future trends (to 2050) will present.

## *Trends in technologies*

**Past trends**

Technological advances have contributed significantly to the development of agriculture since humans first changed from being hunter-gatherers to being farmers. It was in the middle of the 20th century, however, that science was '… *harnessed to the improvements in agricultural technology*' (Blaxter and Robertson, 1995). Significant breakthroughs were made in the breeding of both crops and animals, in crop and animal husbandry and fertiliser and pesticide industries developed. The impact of some major animal diseases was much reduced, yet significant economic losses due to disease still occur (Bennett, 2003).

In low and middle income countries, growth in crop production also occurred in the 20th century, although later than in Europe and unevenly between crops and regions. Called the Green Revolution, the greatest growth in yields was seen in Asia and due both to the planting of new crop varieties and to increased inputs such as fertiliser (Evenson and Gollin, 2003).

At the same time crop production for direct consumption by humans was increasing, similar technological advances were increasing the production of feed for livestock. Livestock, like humans, require energy and protein, although, unlike humans, ruminants in particular can extract energy from crops with high fibre contents such as grass, which grows in more marginal areas. Systems of livestock production in developed regions such as Europe and particularly for pigs and poultry have increasingly intensified as demand for livestock products have increased. In these systems, livestock increasingly rely on highly concentrated feeds, bringing them into more competition with humans for energy often supplied by grains (Gill et al., 2010). In terms of protein feeds, the diverse range of sources, including fishmeal, groundnut meal, meat and bone meal, has been replaced by a high dependence across the world on soybean meal.

There have been many technical improvements in the fishing vessels in Europe, implying significant improvements in their capacity and efficiency of harvesting, storing (cooling and freezing) and even on-board processing. The increasing efficiency in fishing technology combined with the lack of sufficient international agreements for regulation of fisheries in international waters led to a situation in the 1980s and early 1990s where more than 75 % of the fish stocks were either overexploited or close to being so. After 2000, the global landings of fish stabilised at around 95 million tonnes (t) (FAO, 2014b), but these figures are based on fish being recorded as landed for marketing. As fishing for a certain target species involves by-catch of other species and catch of fish below the minimum landing size, a large amount of fish is being discarded at sea, most of them dead after having been in contact with the gear. Data for volumes of discards are unreliable as the amount is not normally recorded, but estimates go up to as much as 20 to 30 million t (Kelleher, 2005). Scientific knowledge about the genetics and ecosystems of different fish stocks, their changes (e.g., climatic) and models for prediction of future developments is important for sustainable management of fisheries resources, such as deciding on fishing quota policies to avoid overfishing of stocks and extinction of fish species. Significant progress in the scientific knowledge on the situation of fish stocks, and improvements in gear selectivity has been made over the last 10-15 years (see current trends). Some problems still exist such as illegal, unreported and unregulated (IUU) fisheries, for which an estimate of 11-26 million t has been made (EC, 2015b).

The seafood supplied from traditional fisheries is far from enough to satisfy the market needs, and as the biological production in the oceans has reached a maximum for sustainable exploitation, the pressure to increase aquaculture increased tremendously over the years when the commercial fish stocks suffered from overfishing. The total amount of fish being marketed has thus grown to above 150 million t, and aquaculture is still increasing every year. In 2014 aquaculture provided more than 50 % of the world's fish supply for the first time. Globally, non-carnivorous freshwater species make up around 60 % of production. In the EU, carnivorous species account for about 25 % of the production. The carnivorous fish demand other fish as feed, presenting new challenges to the total supply of marine biomass. However, it should be noted that poikilothermic species such as fish show higher feed efficiency than other warm-blooded farm animals for many feed sources such as marine species and some vegetable oils and protein. Further, production efficiency of farmed species has improved. For example, the use of fishmeal and fish oil per unit of farmed fish produced has declined substantially as reflected in the steadily declining average inclusion levels of fishmeal and fish oil within compound aquafeeds (Tacon and Metian, 2008). Overall, a 62 % increase in global aquaculture production was achieved when the global supply of fishmeal declined by 12 % during the 2000-08 period (FAO, 2012b). Further research and development is taking place to develop alternatives to fishmeal and fish oil in farmed fish diets (e.g., lower trophic organisms including plants, algae and insects).

Carp farming has very long traditions in Eastern Europe, but more intensive aquaculture in Europe started with the salmonid farming in the eighties. Salmon farming has dominated aquaculture in Europe in recent decades. The early development (1980-2000) of salmon farming was characterised by relatively rapid development, intensification and expansion with accompanying big challenges of diseases, parasites and negative environmental impacts. Rainbow trout, carps and marine species such as sea bass, sea bream, turbot and oyster are other important farmed species in Europe. Also, European aquaculture is characterised by farming of many different species, which makes it challenging to develop sufficient technology or know-how, market and infrastructure (feed supply, breeding programs, processing and regulations). Shellfish and algae have the potential to become increasingly important industries. While algae exploitation is at very low levels presently, shellfish currently account for 50 % of EU aquaculture production. Shellfish require no external feed to produce and provide health benefits for consumers. Expansion of both products would have mostly positive effects environmentally (water cleaning and nutrient removal effects), socially, economically (labour intensive) and for human health.

Fish farming can locally cause eutrophication and anoxia due to the surplus of organic material from feed and fish excretions, and further alter the benthic communities. Aquaculture may be a pathway for the introduction of non-indigenous species that sometimes become invasive, but alien species in aquaculture are controlled by regulations. Escapees from aquaculture farms may also have genetic impact on wild populations through escaped fish interacting with wild fish. Contamination from antibiotics may also be an issue in marine fish hatcheries. Research, development and innovation (RDI) were critical for developing the solutions to many of these problems in salmon farming. The resulting systems for monitoring and environmental impact and fighting parasites and disease by using, for example, cleaner fish, new vaccines and selective breeding have all-important measures. The use of antibiotics has been dramatically reduced in Atlantic salmon to almost zero. Similar research on antibiotic reduction, improved vaccines and specific diseases is required to make these improvements for the other species farmed. However, sea lice and escapees are still considered important challenges for further growth of the industry. Much research and development today over several species is focused towards land based recirculating systems and offshore cages to reduce problems. Aquaculture is also competing for space with other coastal activities, in particular tourism. Together with the economic recession during recent years and the relatively high number of farmed species, this may be one of the reasons why overall aquaculture in the EU has not increased significantly over recent years.

When processing fish, only 50-60 % is being used as the main product, fish fillets, regardless of whether the origin is from traditional fisheries or from aquaculture. The remaining fractions, i.e., heads, backbones, guts and skin are being used for non-food products, mainly feed, or in some cases discarded as waste. When processed on-board, most of these fractions are thrown overboard. As fish, crustaceans, mussels, etc. are perishable foods, as much as 20-25 % may be lost due to delayed chilling, preservation and transport before it reaches the consumer. Taken together, there is considerable potential for improving the use of biomass from fisheries, getting more value out of it and creating jobs.

Non-food product and material development using algae is another opportunity for utilising marine biomass, where a certain amount may be harvested (Zemke-White and Ohno, 1999). The current trend has been to use macro algae (seaweed) for direct food consumption or for production of food additives. This is likely to increase in the future and is an area for research. New developments may emerge as cultivation of both macro- and microalgae are made possible, and the products can often be of high value and high prices. Also, improvements in regulations, practice (harvesting, processing, packaging, storing) and technology for ensuring food safety and quality relies on science and technology. Furthermore, socio-economic research on markets, consumer issues, industrial economics and politics is needed to improve the economic and social aspects (e.g., employment) of the fisheries industry.

Technology also contributed to a 'revolution' in food supply chains in the 20th century. This brought benefits to consumers in terms of year-round access to fruits and vegetables (which had previously only been available on a seasonal basis) as well as a much wider range of processed products and increased shelf life (Lang, 2003). The combination of cheaper production with a more sophisticated food industry resulted in a steady decrease in food prices (FAO, 2011a) until 2007-08, when there were spikes in food prices which ended the complacency about agriculture which had resulted from the food surpluses which were present at the end of the 20th century (FAO, 2011a).

**Current trends — risks and opportunities**

The increasing recognition of the risks to agriculture from climate change (e.g., Stern, 2007) together with the food price spikes (Cohen and Garret, 2009) resulted in a number of Foresight studies being undertaken in the first decade of the new century (IAASTD, Agri-Monde, UK Foresight). These highlighted both current and future risks, and opportunities arising from recent scientific advances. Key risks, followed by key scientific opportunities are outlined below

**Risks from climate change:** The extent of the potential impact of climate change on agricultural production is unknown as the extent (and nature) of the change will depend on whether governments across the world are prepared to take action to reduce emissions (Stern, 2007). There are, however, a number of papers which have modelled the likely impacts in different regions of the world (de Sherbinin, 2014). Within Europe there may be winners (countries in the north) as well as losers (countries in the south), but overall the predictions are for a decrease in crop yields. This is particularly true for soybean (Osborne et al., 2013) and Europe is the major importer of soybean, for use as protein source for livestock feed. But e extreme weather events and sea level rise may affect the apparent 'winners' of climate change. Climate change impacts on fisheries will produce new management and harvesting complexities. It is expected that warm water stocks will move further north in the North Atlantic Area. This will lead to changes in catch levels and species habitation, new fishing patterns. A possible need to alter relatively stable shares between EU Member States may become a challenging political issue. Greater acidity of the oceans is likely to have an impact on mollusc and crustacean productivity, while predictions of an increased number of storms will make fishing more hazardous.

**Risks from limiting resources:** Climate change is one of nine planetary boundaries which were identified by Rockström et al. (2009a) in a seminal paper drawing attention to the risks to our planet from the way we are living our lives in the 21st century. Biodiversity and nitrogen cycles were highlighted alongside climate change as having boundaries that we might have already crossed. Freshwater use and land use were two more of the nine that are of key concern to food and feed production.

**Risks from slowing yield growth:** There have been a number of reports of decreasing rates of yield increase in recent years, which will create a major challenge in meeting the increased requirement for cereals and soybean meal as a protein source for livestock. Ray et al. (2012) quoted figures of 24-39 % of rice, maize, wheat and soybean growing areas where yields were not increasing.

**Risks from the nutrition transition:** It is well recognised that as countries' economies grow, the composition of the diet changes (Popkin, 2003). In many countries this leads to an increase in the consumption of livestock products (Delgado, 2005), which in turn puts pressure on the supply of grain. IAASTD (2009) forecast that an additional 1,305 million t of grain would be required by 2050, of which 553 million t would be consumed by livestock. Pigs and poultry have a much higher (more than twice) usage of concentrated feed than ruminants (e.g., Alltech, 2012) but if more intensive dairy and beef systems develop to meet growing demand, the pressure on grain from these species will also increase.

**Opportunities from plant and animal genetics:** In genomics, genotyping and high-throughput sequencing have generated an extensive and precise knowledge of the DNA and RNA of a set of crops. Ten years ago, the cost of sequencing was more than tenfold the current cost, and the time needed for sequencing has decreased by a similar extent. In parallel, the development of transcriptomics, metabolomics, proteomics and phenotyping has been rapid. In order to implement such new technologies in animal breeding, selective breeding programmes will still be needed. Hence, selective breeding programmes will also be an important prerequisite when diversifying production and developing new farm species as in aquaculture. There may be potential for yield increase through plant breeding outside the classical cash crop as many orphan and neglected crops have not yet been optimised.

**Opportunities for managing plant and animal diseases:** In spite of the negative reactions from consumers and environmental organisations, the private sector is still trying to develop new chemical pesticides. But innovation in chemical molecules is becoming more difficult, among other reasons, due to additional regulations and resulting costs. In some cases, the durability of effectiveness of a particular molecule is short, for example in fungicides when resistance to the molecules appear after mutation. Private firms focus on genetically modified crops, but strong opposition from the public in Europe forces national governments and the EC to postpone decisions. Pressure from civil society pushes governments to ban pesticides for which dangers are proven or for which there are suspicions of risks. Alternative technologies and practices such as integrated pest management or use of robotics for weed control are gaining ground. Scientific advances are also providing new opportunities for managing livestock disease, both in terms of new diagnostic methods as well as new vaccines. These should receive increased attention particularly where there are risks of zoonoses — animal diseases which can pass to humans.

**Opportunities from engineering and technology:** The machinery sector has developed new techniques like no-till farming and mulch production. New energy sources like methane are still being explored as potential fuel sources for tractors while already established for road vehicles like cars or busses. Precision agriculture and related technologies such as sensors, information and data provision systems and improved machines are increasingly accounting for the variability und uncertainty within agricultural production systems. Moreover, the optimised use of natural resources such as water and nutrients as well as the site- and culture-specific application of fertilisers and pesticides improves the economic efficiency of farming practices. More advances can be expected from the use of drones, Internet of Things applications, swarm robotics and maybe even insect cyborgs. Hydroponics, aquaponics and aeroponics are increasingly used for environment-controlled agriculture in urban settings.

**Opportunities for exploiting marine biomass — blue biotechnology:** Marine, or blue biotechnology, is the use of marine bio-resources as the target or source of biotechnological applications. The marine resources are thus used to develop products or services, but the marine environment can also be the recipient of biotechnology applications developed using terrestrial resources. In many cases marine biotechnology is understood as the use of components produced by marine micro-organisms, sponges, micro- or macro-algae or other marine organisms which have not been studied in much detail. Improved use of such resources is obtained through bio-discovery and bio-prospecting, primarily targeting the pharmaceutical market. But marine biotechnology is much more than that. The marine bio-resources can be used directly or indirectly for food and feed, nutraceuticals, cosmeceuticals, biopolymers, bioenergy, chemicals and enzymes, and may also be applied in bioremediation, terrestrial or aquatic systems. In 2010 the Marine Board of the European Science Foundation published 'A new vision and strategy for Europe' within marine biotechnology (Marine Board, 2010), in which it described how marine biotechnology may contribute to key societal challenges. The main elements have been taken up by the European Commission in the work programmes for research and an ERA NET for Marine Biotechnology (www.marinebiotech.eu) is presently working towards an improved exploitation of marine bio-resources and is performing a foresight study with the purpose of establishing a strategic road map for the area. Furthermore, the ERA-NET COFASP also works on improved exploitation of marine bioresources.

**Opportunities for alternative animal feeds:** The European animal production sector is a major part of our economy. It contributes EUR 130 billion annually to Europe's economy, accounts for 48 % of total agricultural activity and creates employment for almost 30 million people. However, Table 3.1 estimates that 58 % of the world's biomass was used for animal feedstuff in 2011 and with potential competing uses of biomass with the growth of a bioeconomy this may not be sustainable. Alternative feeds with a lesser requirement for land includes insects (van Huis, 2013), but these are not yet commercially viable while plant- and animal-based alternatives for fishmeal are already used in industrial feed for aquaculture (Naylor et al., 2009).

**Biotechnological alternatives for meat production — Artificial meat:** The potential of scientific innovations to improve the efficiency of livestock systems is not in doubt (Hume et al., 2011); the key question is how acceptable some technologies are to the consumer and how far governments are willing to invest in their development. At the extreme end, production of artificial meat by growing stem cells in a bioreactor is certainly feasible (Langelaan et al., 2010), although at present it is neither economically viable, nor shown to be acceptable to the consumer.

**Conclusion:** Technological advances have in the past supported very significant growth in the production of food and feed. Looking forward, the risks from climate change and resource limitations are considerable. Scientific advances offer many solutions and the challenge will be to prioritise which ones hold most promise, not just of success in addressing the issue but also in being economically viable and acceptable to the consumer.

## *Trends in business and markets*

### Past trends

Like agricultural production, food systems (post farm gate) in Europe also went through a period of transformation after World War II. Fruits and vegetables became available out of season, new processing methods and more global 'sourcing' of foods all contributed to changes in food supply chains (Lang, 2003). Producers organised themselves in cooperatives or different kinds of groupings. Food industries were created and rapidly concentrated. The distribution networks also concentrated leading to hypermarkets in a position of monopoly. Priority was given to the 'common market' and to European market integration.

At the world level there has been a steady increase in food consumption per person. Economic growth and increasing per capita income in past decades were important drivers of per capita food consumption (expressed in kilocalories (kcal) per capita and per day). On average, global calorie consumption per capita per day increased from 2,373 kcal to 2,772 kcal between 1969 and 2007, although per capita food consumption is very variable across countries and regions (Alexandratos and Bruinsma, 2012). During the post war period, food markets became a geopolitical stake. With the Public Law 480, the USA created food aid in the context of the Cold War. The Green Revolution began in India in 1966 and spread through Asia and Latin America, increasing its production and exports. The Marrakech trade agreements opened a new era of liberalisation of the markets giving less developed countries an opportunity to protect their food sector. The CAP was attacked and forced to liberalise and open its market.

### Current trends

The 2007/08 price hike created a new situation. The rapidly growing purchase capacity of the middle classes in Asia and a lot of new emerging countries was creating an increasing demand and on the supply side, the productive adaptation was not as strong. The Australian climate shock reduced its exports dramatically and suddenly, the market operators became aware of the deficits. The speculation on cereals grew rapidly. Many countries succumbed to panic and banned exports. Food prices increased by threefold in a few days, creating situations of revolt against the governments, which didn't have enough food stocks. A lot of these governments had been obliged previously to reduce food stocks due to e.g., high costs and corruption. In many places, yields had been plateauing since the 1990s because of the structural adjustment policy decisions several years before. This crisis created some distrust of food markets in their ability to create stabilisation of food prices and easy access to goods. It also generated a productive reaction in many developed countries such as the USA or the EU.

**Another major event occurred in the USA,** the tensions on the oil market and the risk of a price increase could put the USA in a bad situation. First, a big part of the maize production was transferred from food exports (to Mexico) to biorefineries in order to produce biofuel. Second, the exploitation of shale gas and shale oil resolved the problem of oil dependency of the USA. Maize exports grew again. The cereal markets were affected by these big changes.

**In that context the EU situation is also new:** Market evolutions have shown that we were entering a new geopolitical era where strategic manipulation of markets was replacing the liberal game that was negotiated in the trade rounds. The EU was the top world exporter of food and drink products in 2012 (FoodDrinkEurope, 2014), exporting USD 98.7 billion (20.5 % of world total) and importing USD 85.9 billion (18.1 %).

**Trends in markets for crops:** At a global level, cereals such as maize, rice and wheat contribute approximately 50-60 % to the human caloric intake today (IAASTD, 2009). Overall, the demand for cereals is projected to decline (1.4 to 0.4 % p.a.). Less cereals will be demanded by East Asia, the Pacific region (-27 kg), Latin America and the Caribbean (-11 kg). However, the cereal demand in sub-Sahara Africa is projected to increase (+ 21 kg per capita), (Hubert et al., 2010). Cereals such as coarse grains (e.g., maize) are increasingly fed to animals, which is projected to increase their demand for feeding purposes. An increasing population, especially in developing countries, will demand far more meat and dairy products, which will increase the demand for grain-based livestock production. Consequently, maize produced for feeding purpose in developing countries is projected to increase. By 2050, 60 % of the global maize demand is projected to be used as animal feed while 24 % and 16 % are used for food and biofuels, respectively (Hubert et al., 2010). In developed countries, the main purpose of maize is projected to shift towards biofuel production if current legislation and strategies remain (Kearney, 2010, Alexandratos and Bruinsma, 2012). In general, average projected growth rates of cereal production will be much lower (0.9 % p.a.) in the next 40 years compared to the past 40 years (1.9 % p.a., Alexandratos and Bruinsma, 2012).

**Trends in markets for meat products:** Economic growth will increase demand for animal proteins. The annual global consumption of meat is projected to grow from 38.7 kg per capita per annum in 2005/2007 to 49.4 kg per capita per annum in 2050, much of this being increases in poultry and pork. At current consumption patterns, additional meat production of approximately 200 million t per year would be required in 2050 (Bruinsma, 2009).

**Trends in markets for fish and seafood:** Fish is a very high quality source of animal protein for human nutrition. Consumption is dependent on the region's stage of development, trade, and the availability of aquaculture and fisheries (inland and marine) products. Today, 3 billion people meet at least 15 % of their average protein consumption by seafood (WWF, 2010). In developed countries there is a high quantity of fish per capita (22-24 kg per capita per annum) consumed, while in developing countries, consumption is 9-18 kg per capita. Since 1960, world fish consumption increased (3.2 % per annum), and per capita seafood consumption of 9.9 kg per capita per annum (live weight equivalent). Today it reaches 18.4 kg per capita per annum (FAO, 2012a, FAO, 2013). In 2012, capture fisheries and aquaculture at the world level were 156.2 million t of fish (93 million from capture, 63 million from aquaculture), from which 132 million t were used for human consumption (18.6 kg per capita per annum in 2011). But since 1980, fish production from aquaculture grew at an average high rate of 8.8 % per annum globally. Medium-term demand (2020) would need 23 million t more (FAO, 2012a). Additional demand for fish would then be supplied by aquaculture but would have to be environmentally- and animal welfare-friendly (Bostock et al., 2010; Garcia and Rosenberg, 2010; Godfray et al., 2010; EC 2011c; FAO, 2012a; FAO, 2013). Clearly, in the future, aquaculture will play a tremendous role in the supply of fish and sea food, globally.

**Price trends:** The observation of prices such as food and feed prices is a valuable indicator to predict the future of market systems. In general, rising prices of primary sources such as biomass as well as agricultural commodity products indicate an imbalance of supply and demand. Moreover, they signal an increasing pressure of scarcity such as land, water and nutrients on the market, which is driven by a growing population demanding more food, feed, fuel and materials in order to fulfil their daily needs in accordance to their rising incomes (Nelson et al., 2010). Furthermore, food and feed prices are linked to prices of other commodities such as energy or fertilisers. The short- and long-term impact of food and feed prices on markets as well as on the status of food stocks and reserves are of great interest to producers and consumers as well as to authorities and governments (Gerber et al., 2008; FAO, 2012b; FAO, 2014b). For a large part of the global population, food expenditures represent a large share of disposable income. This has a negative impact on food and nutrition security (Willenbockel, 2011). Between 1960 and 2000, real agricultural commodity prices continually declined. Major price peaks were only short-lived and these peaks were connected to global events such as the oil crises in the 1970s (FAO, 2011b). However, between 2002 and 2008, real prices of food and agricultural commodities started to increase (Figures 3.14 and 3.15).

At the same time, prices seem more volatile (Figure 3.16). The increasing prices and their volatility are increasingly driven by demographic changes (population growth), but also related to energy prices and biofuel production, bad harvests in the previous year, low levels of food stocks as well as restrictions on exports by major wheat exporting countries into the global market (i.e., Russia) (Hubert et al., 2010).

**Figure 3.14: Price trends of agricultural commodities from 1990 to 2014 based on data from FAO (2014b)**

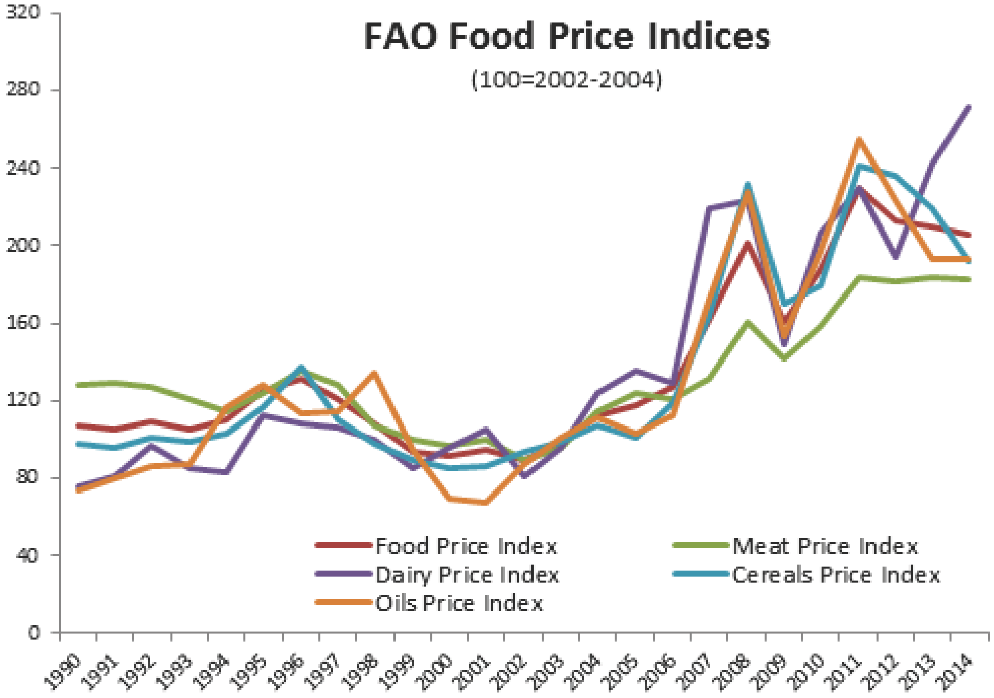



Figure 3.15: Price trends of fish and seafood from 1990 to 2014 based on data from FAO (2014c)

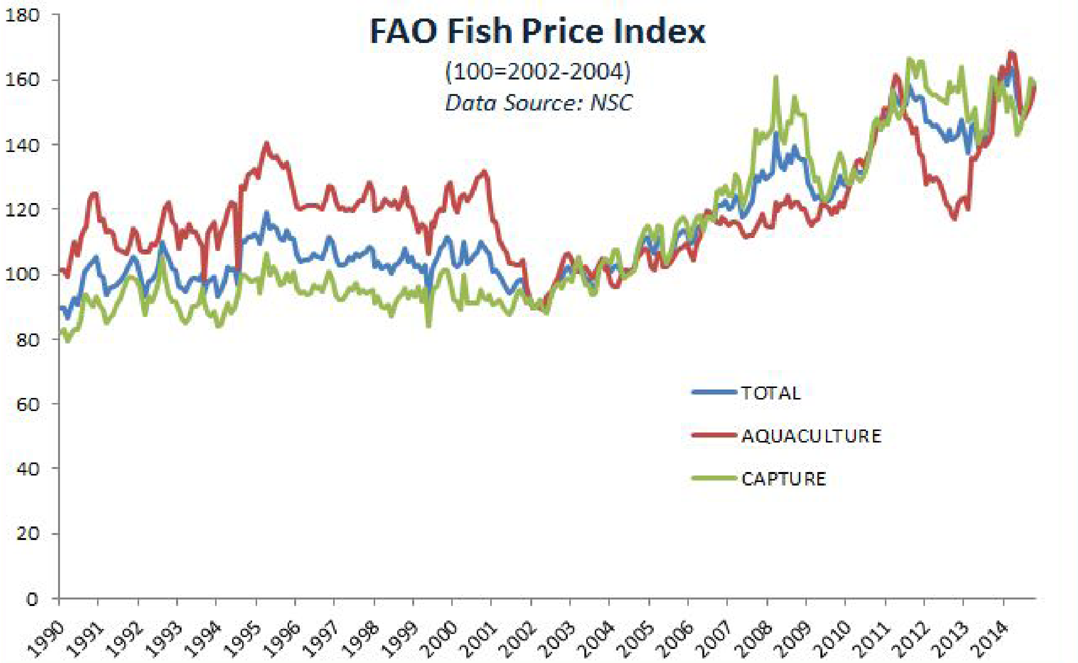
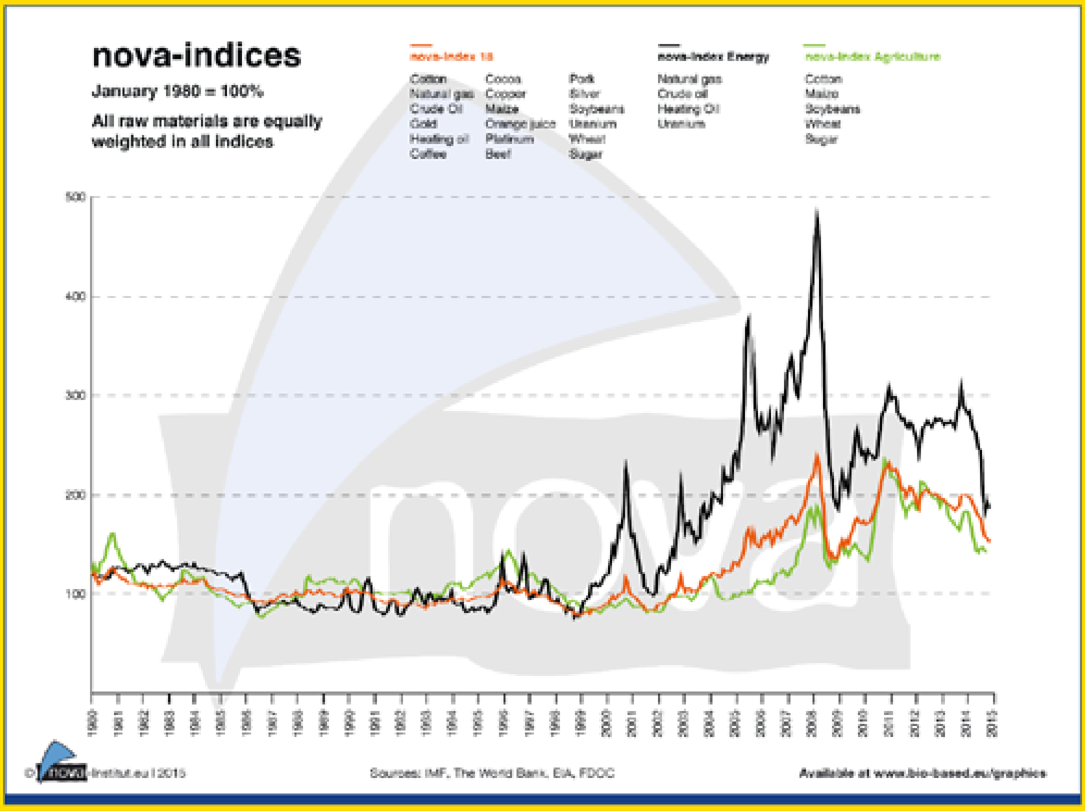


Figure 3.16: Price development based on nova price-indices (IMF, 2015; The World Bank, 2015; FDOC, 2015; EIA, 2015) (newest version at: http://bio-based.eu/graphics/).




In 2014, food and agricultural commodity (including feed) prices have not reached previous low levels as in 2002. Moreover, driven by increased pressures on natural resources, the competition with other biomass demand such as biofuels, demographic developments, the adverse impacts of climate change as well as rapidly rising incomes and dietary changes in many developing countries the increase of real world market prices for food and feed is projected to continue (FAO, 2011b; Foresight, 2011; OECD, 2013). The greatest increase of prices is expected for grain (+ 30 to 50 %) by 2050 (Foresight, 2011, Willenbockel, 2011; FAO, 2012b). Maize is projected to be the grain with largest price increases in the future. This increase will affect food and feed prices globally. Additionally, meat prices are projected to increase by about 20 to 30 % compared to today (Willenbockel, 2011; FAO, 2012b; OECD, 2013). In the future, the slowing rate of growth of the global population will contribute to a slowdown of price increases for food and feed. The progress of technology and innovation may contribute as well. However, negative impacts of climate change on yields, which cannot be mitigated can reduce the increase of productivity and, consequently, the slowdown of food and feed prices in the future (Nelson et al., 2010, Foresight, 2011). Overall, due to different demands, the rise of crop commodity prices is projected to be much slower than those of meat, fish and biofuel (OECD, 2013).

**Trends in consumption pattern:** Overall, a growing population, particularly in developing countries, and the increasing demand for meat and dairy-based food, are major global trends with regard to food consumption and related products. In addition three more specific trends at EU level can be observed (EC, 2007a; EC, 2011c). First, the variety of food and drink consumption has increased. The expansion of agro-food trade and markets as well as social and technological developments are among the major drivers. Second, habits of food consumption are changing. Food eaten away from home as well as an increasing share of convenience foods purchased can be observed as a consequence of changes in lifestyle, the changing role of women in society, changing household structures and incomes. Moreover, the supply of enriched food (e.g., functional food) is increasing and very profitable. Third, diets of the rich and the poor are increasingly different. Since calorie-dense food is available and consumed all over Europe, diet-related diseases such as obesity, type 2 diabetes, hypertension, osteoarthritis, and cancer are on the increase. Higher incomes allow richer consumers to adapt their diets and lifestyles in a manner characterised by an increase in novel and specialist foods. Here, for example, the increasing demand for vegetarian, organic, or foods for special health requirements play an important role. In contrast, the diets of the poor tend to not adapt, for example to more fruits and vegetables, due to the higher costs of non-staple foods (EC, 2007a; EC, 2011c). However, there will be a growth of middle class expectations in the developing world which includes the demand for healthy food, nutritional supplements, and different eco-label products in addition to the increasing demand for non-food products, such as chemicals, plastics and other materials for packaging, textiles, automotive and construction.

**Innovation in markets:** The renewal of the relationship between the producer and the consumer defines new 'short circuits' or 'short supply chains' with new forms of intermediation, such as urban agriculture, farm shops, weekly provision of fresh products, web contracts (e-commerce) and so on. Together with marketing opportunities through social media, this creates new opportunities for small-scale and local food producers. Supermarkets are aware that something fundamental is changing in consumer purchasing and are proposing new formulas like e-trade, 'drive' or home delivery (Mansour and Zocchi, 2012).

**Trends in processing, distribution and retailing:** Processing, distribution and retailing are intermediate steps within the food value chain. These areas are going to change partly due to consumer demand, change of global and local market structures as well as due to economic reasons. Food consumed in Europe is predominantly processed (ca. 90 %, ESF and COST, 2009). Sustainability, the improvement of the nutritional value as well as food safety aspects and the development of new and innovative products are major issues of current changes in food processing within Europe. The distribution of food and related raw materials continues to become increasingly globalised, while logistics become more efficient and just-in-time, goods are expected to travel longer distances. On the one hand, this efficiency reduces the loss and waste of food and agricultural products. On the other hand, this trend increases pressure on infrastructure such as roads or traffic and increases vulnerabilities and risk of breakdown. Moreover, it will also have negative ecological and social impact such as the increase of greenhouse gas emissions as well as landscape fragmentation by infrastructure and noise. The improvement of food packaging, which is part of an efficient as well as sustainable food value chain, is also an important trend. Today, packaging needs to be light while still protecting the products. Consumers as well as producers are increasingly demanding packaging that contributes to the demand for increased quality, food safety standards, shelf-life extension, and the increasing demand for convenience food and for information about the food product (e.g., nutritive value, presence of allergens, advertisement; Duriez, 2009, Farmer et al., 2013). In addition to processing and distribution of food and food-related products, the retailing sector is changing as well. Until 2020, multiple changes with regard to multi-channel supply are expected with regard to retail. This includes, for example, online shopping, system management and evaluation of consumer behaviour based on large data sets (e.g., payback cards, collection of points), differentiation of retail due to the increase of private-label products as well as the growth in emerging countries, which will increase the pressure on markets and prices in developed countries (ESF and COST 2009; Mansour and Zocchi, 2012). Future challenges will be the increasing demand for transparency and traceability of raw materials, inputs, food products and associated social aspects such as fair trade (ESF and COST, 2009). Compared to agricultural production, processing, distribution and retailing will continue providing a growing proportion of employment (Cohen and Garret, 2009).

**Concentration of markets**: An ongoing trend in global markets, which is also of high relevance for the bioeconomy strategy, is the increasing market consolidation and the concentration of market control (ETC Group). Agricultural markets and trade of agricultural and food and feed products are increasingly organised in global value chains. This requires each single participant in a value chain to be competitive in a market with many players. As a consequence, large transnational businesses (trading companies, agro-food processors and producers) are most competitive and, consequently, holding the corporate power. They remain key players while controlling the market by their decisions throughout the food system. However, a concentration of markets can also support the establishment of niche markets (e.g., local beer breweries), which provide products that are not relevant for global players, but still demanded by many consumers. Within the food system, a large concentration of power within relevant markets can be observed within trading, processing and retailing (IAASTD, 2009; Thompson et al., 2007). Processors such as Nestlé, PepsiCo and Kraft earned 37 % of the revenue generated in 2009, globally (ETC Group). The power of the global seed and fertiliser industry is massively concentrated. Being controlled by only five large biotech companies, the fertiliser industry (all major fertilisers) is in the hands of five countries, which are holding a share of more than 50 % of the world's production capacity (Hernandez and Torero, 2011). Both industries hold a strong strategic position in the market, since they are providing crucial inputs for agricultural production, which allows them to control and to restrict farmers' choices or access to specific goods such as seeds (Howard 2009; Then and Tippe, 2009). Together with many other actors in supply systems such as food systems, these companies and countries are affecting prices and even consumption patterns by creating dependencies (De Schutter, 2010; Hernandez and Torero, 2011).

## *Challenges, dogmas and dilemmas*

**A central challenge: produce enough food** — At the global level, producing enough food is a central question, particularly in countries that will have a population increase and do not have enough land and water to ensure food security. Therefore, the question is mainly for Asia (population increase and carrying capacity overtaken), Africa (an important demographic wave to come and yields still low), and WANA (West Asia North Africa) (dry land, water limitations and still increasing population). In these countries, the equation is: produce food, with higher yields, environmentally friendly, at low cost (producers are small holders and consumers are poor). It looks like an impossible challenge, increased research (and policy) interest in intensification based on ecological principles, in other words ecological intensification (while preventing negative socio-economic consequences) may be part of the solution. Another part is the establishment of permanent economic complementarities between countries having surpluses and countries having deficits.

**A dilemma: keeping forest vs expanding new cropping areas?** — Providing food to an increasing number of people is likely to continue to increase cropping areas. It means that fallows will be reduced and that new cropping areas will be added at the expense of forests. Forests are a common inheritance which will be indispensable in the future. If societies decide to keep forests intact, the consequence is that food production needs a tremendous increase in yields. Yield increase is therefore an essential, although difficult, part of the solution.

**A dilemma: food vs feed —** Food which is produced directly for humans and feed which is produced for animals in order to feed humans are in competition for the use of arable land. In industrial countries, more than 40 % of the land is used for feed production. Given that the production of one calorie of meat needs from 3 to 12 calories of grain, reducing the consumption of meat would save a great quantity of land for direct production of food for humans. But, societies have strong preferences for meat that are unlikely to change quickly. Research emphasis should therefore be on finding ways of increasing production of livestock in ways that also reduce the competition for land which can grow food for humans (e.g., grains). Improving the productivity of grass-fed livestock is one option; identifying alternative sources of feed is another.

**A dogma: reduction of food losses — waste is the solution** — All over the world and in industrial countries, food waste was approaching 30 % of total food purchase in 2011, but actions by governments in recent years have decreased this. Many new opportunities for using and reducing food waste have been suggested (e.g., growing insects for livestock feed or human food, van Huis, 2013) but in Europe, the outbreaks of BSE in the 1990s and Foot and Mouth disease in the UK in 2001 led to regulation limiting the reuse for food or feed purposes (EU Waste Framework Directive; EC, 2008b).

**A dogma: EU will feed the world** — The current consensus of experts (e.g., IAASTD, 2009; INRA and CIRAD, 2009) is that at the start of the 21st century sufficient food is being produced to feed the world population — the reason why ~ 800 million people still suffered from undernourishment/chronic hunger in 2014 (FAOSTAT, 2014) is due to uneven geographical distribution of food and issues of affordability and accessibility. In 2013 Europe produced ~ 17 % of the world's cereal production (FAOSTAT, 2014; FAO, 2011b).

**And climate change** is viewed as having a smaller effect on cereal production in Europe than in more tropical regions (a major threat to increasing global production, yet at the regional level, some parts of Europe are predicted to benefit from climate change (Olesen et al., 2011).

Europe is therefore likely to make a greater contribution to world food production in the future, but the forecast increase in demand for cereals of an additional 1.3 billion tonnes between 2000 and 2050 is a serious challenge.

**A dilemma: food and fuel/energy?** — Crops cultivated for biofuel and bioenergy could take a considerable and increasing share of agricultural production in the future (Table 3.1), particularly in countries where there are no fossil energy sources. It could take away land and calories from human nutrition, with the risk of increasing the prices of food commodities. Increasing energy demand and increasing world market prices for bioenergy crops could amplify the competition between the different types of use (food vs. fuel/energy) (Smith et al., 2010, FAO, IFAD et al., 2011; Lima and Gupta, 2013). Globally, EU and USA biofuel legislation will have the largest impacts on the biofuel markets (Gerber et al., 2008; Baier et al., 2009). By 2050, the percentage of cereals, vegetable oils and sugar used for biofuel production is projected to at least double: 6.1 %, 10.3 % and 1.8 % of the fuel produced respectively (Alexandratos and Bruinsma, 2012). It should also be noted that macro-algae can be used as a source of energy supply as well as solar fuels (liquid fuels from solar, water and $CO_2$).

## 2.3.5. Bio-based materials and chemicals

### *Introduction*

#### Use of biomass in material use worldwide

In 2011, 12 billion t (t) dry matter (dm) biomass from agriculture, grazing and forestry have been used for feed (58 %), bioenergy (heat and electricity, 16 %), food (14 %), material use (10 %) and biofuels (1 %) worldwide. Today, the share of biofuels might have reached 2 % (see Chapter 2.3.2). The volume of biomass used for materials and chemicals in 2011 was 1.26 million tdm. The most important application areas were:

- Construction and furniture with 522 million tdm, mainly lignocellulose.
- 444 million tdm for animal bedding, mainly by-products from agricultural and forest (lignocellulose).
- Pulp and paper with 201 million tdm, mainly cellulose, hemicellulose and starch.
- Chemical-technical industry (including polymers) with 59 million tdm, mainly plant oils, starch and sugar and rubber.
- Textile fibres with 35 million tdm, mainly cotton and man-made cellulose fibres.

The above data are based on Piotrowski et al. (2015) and are mainly derived from official datasets of FAOSTAT, CEFIC 2014 and Fibre Year 2014.

### *Trends in technologies*

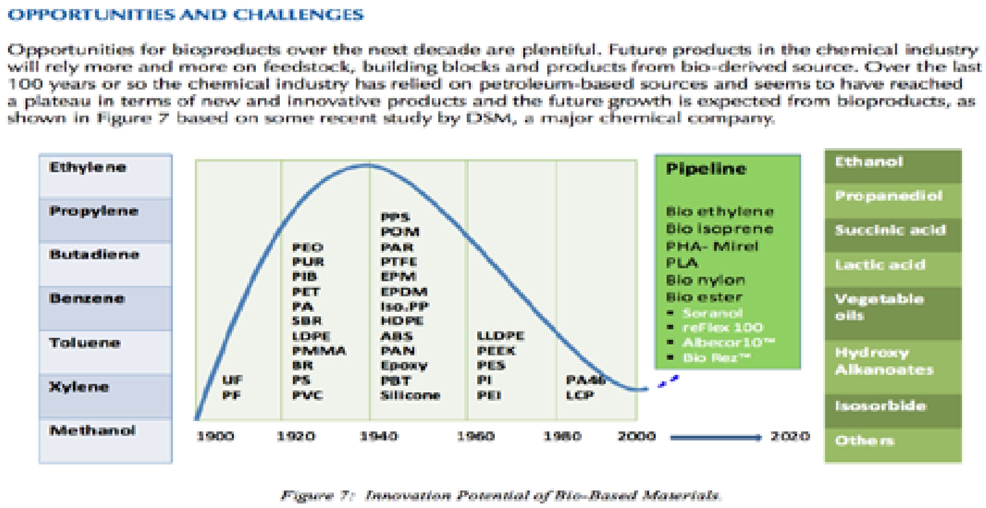
Currently, the most interesting fields of innovation in the bio-based economy are the chemical-technical industry with the pulp and paper industry and the man-made fibre industry owning the largest facilities for biomass fractionation due to their history and long-standing expertise in biomass conversion.

- The demand for biomass in the chemical-technical sector can grow from 59 million tdm in 2011 to 500-1,000 million t in 2050, based on a compound annual growth rate of 3.5 % in the whole sector and an increasing share of biomass.
- For the textile sector, there is a gap of 180 million t of textile fibres by 2050, which can mainly be filled by man-made cellulose fibres, bio-based polymer fibres or petrochemical fibres — depending on the political and economic framework.
- The worldwide demand for pulp will more or less stay constant due to an increase in packaging and a decrease in printing paper.

#### Transforming the chemical industries — the transition period

The oil-based chemical industry has matured over the past 100+ years into a central, sophisticated and advanced economic branch. The economies of scale for oil refineries, dictates the trend: the larger, the more economic. In addition, the transport cost of the starting material oil in pipelines is rather low. With regard to innovative and novel products, the petroleum-based industry reached a plateau, but further growth is expected from bioproducts (Figure 3.17, DSM, 2012).

## Figure 3.17: Innovation potential of bio-based materials building partly on classical oil-refinery product lines (DSM, 2012).


OPPORTUNITIES AND CHALLENGES

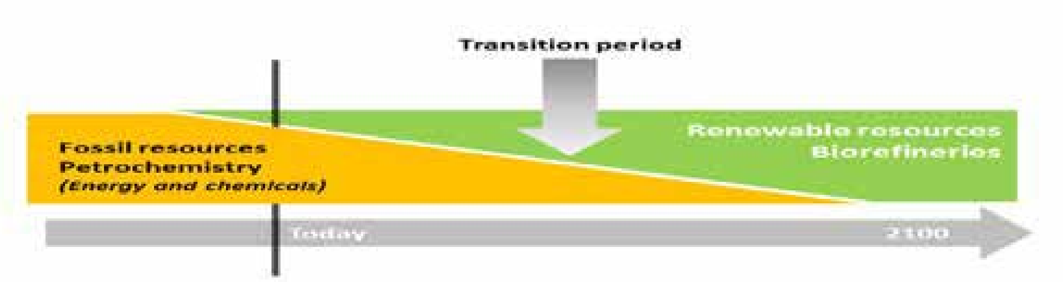
Opportunities for bioproducts over the next decade are plentiful. Future products in the chemical industry will rely more and more on feedstock, building blocks and products from bio-derived source. Over the last 100 years or so the chemical industry has relied on petroleum-based sources and seems to have reached a plateau in terms of new and innovative products and the future growth is expected from bioproducts, as shown in Figure 7 based on some recent study by DSM, a major chemical company.



*Figure 7: Innovation Potential of Bio-Based Materials*

If products and chemicals are to be made out of sustainable resources, the whole chemical industry sector has to face a transition with regard to starting materials, intermediates and processes (Figure 3.16). The combination oil and biorefinery will be a keystone for the production of sustainable materials in the near future. The necessary changes from a fossil-based refinery to a biorefinery cannot be accomplished at once, but require a transition period with oil-refineries and biorefineries running in parallel. For a biorefinery, the economies of scale differ greatly from that of an oil refinery. In addition, the transport costs for the starting biomass will be much higher for biorefineries. Hence, economic efficiency needs to be reached by different means than in traditional fossil-based refineries. This applies not only to material use of biomass but also to fuel and energy. In order to cope with the mixed mode of operation of oil and biomass as starting materials novel concepts are required which still need a lot support from basic research efforts on all levels.

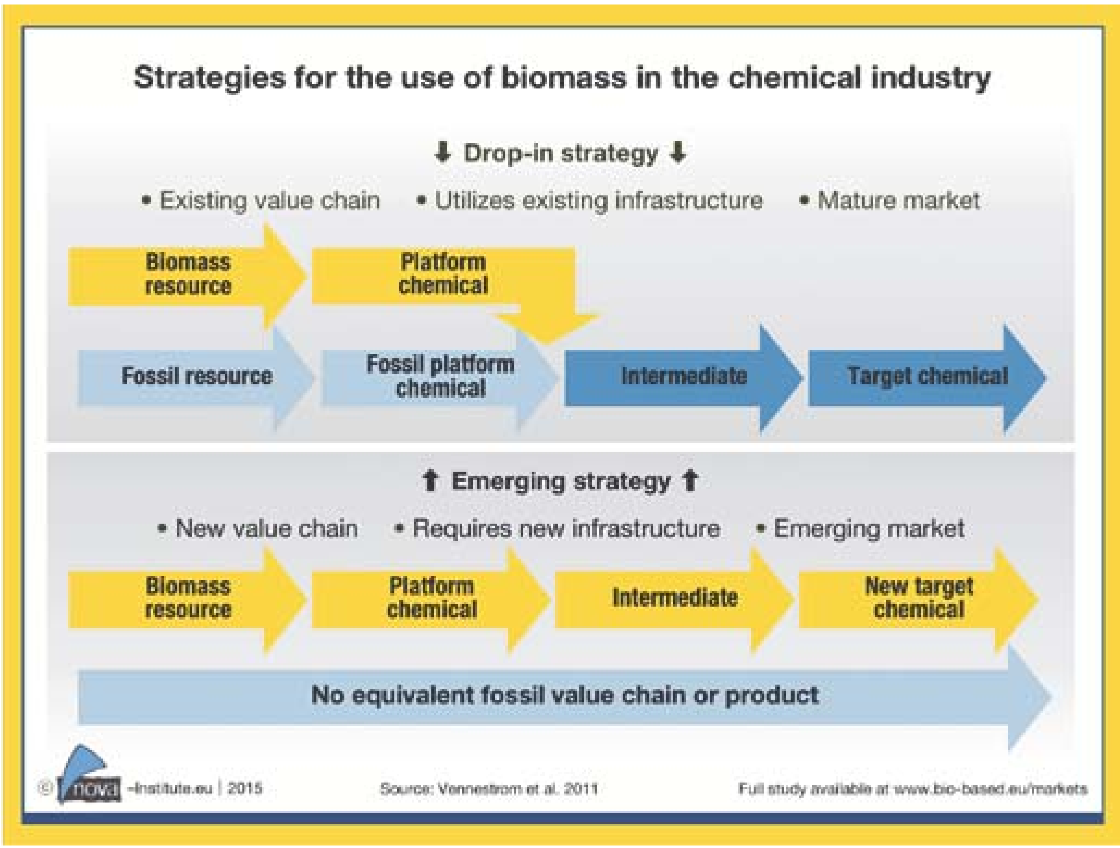
## Figure 3.18: Transition period — trends in utilisation of biomass (today — 2100).




For the transition period, different scenarios are conceivable, i.e., the production of similar starting products from bio-based resources through conversion technologies (e.g., production of furfural and other aromatics to be fed into classical oil-based production lines), the direct substitution of oil-based compounds by renewables (e.g., partial substitution of phenol by polymeric lignin, when only separation and purification but no polymer breakdown is needed) or in the best situation the direct utilisation/substitution of biomaterials at the highest level of biosynthesis (e.g., direct use as a polymer, such as cellulosic non-wovens for tissues). This often needs high-quality biomass compared to waste stream utilisation in the drop-in strategy. In the drop-in case, biomass is transformed to a platform chemical such as ethylene, methane, methanol, etc. (Figure 3.19, top) with the exact same chemical structure as the fossil-based equivalent and is fed into the existing infrastructure of the petrochemical industry. This pathway is especially useful for organic waste and agricultural sidestreams transformed to methane or syngas.

The drop-in strategies can utilise existing value and production chains and their infrastructure, but require the respective technology of isolation and purification. In many cases, cost-effective fractionation and conversion technologies are today still in their infancy, i.e., in pilot scale or demonstration scale, and once more require a high share of input from research. The advantage of the drop-in strategy is the already present, mature market for the products (e.g., bio-based polyethylene terephthalate (PET) bottles). A disadvantage is the only partial utilisation of biomass (mainly carbon and hydrogen, about 20-50 % of total biomass).

Figure 3.19: Two strategies for bio-based chemicals: Bottom: emerging; Top: drop-in.




For sugar, starch, lignin or plant oil, other dedicated pathways are more efficient, utilising not only the carbon in the biomass, but the whole biomass — carbon and oxygen, hydrogen and nitrogen. Emerging strategies imply new building blocks and chemicals, new value chains, new investment in plants and infrastructure. These new building blocks are often produced by new processes, especially by industrial biotechnology using yeast/fungi, bacteria and enzymes to produce the new chemicals such as succinic or lactic acid in a sufficient way. New emerging strategies based on biomass can take advantage of utilising higher levels of structure already provided by nature. So far, although very appealing in theory, this approach is still somewhat limited considering the vast variety of products used today.

Table 3.5 shows the different characteristics of the two strategies.

**Table 3.5: Characteristics of drop-in versus dedicated strategies**

| Criteria | Drop-in strategy | Dedicated emerging strategy |
|---|---|---|
| Value chain and infrastructure | Existing value chains and infrastructure of the petrochemical industry are used | New value chains, new processes (e.g., industrial biotechnology) |
| Implementation | Fast, low investment | Low, high investment |
| Markets | Mature markets | Emerging markets |
| Biomass utilisation efficiency | Low, 20-50 % (mostly C) | High, 50-100 % (C, O, H, N) |
| Biomass | All kinds, including organic waste and side-streams | Dedicated biomass |
| Products | Same as petrochemicals and standard polymers | New building blocks and polymers with new properties |
| Competitive price | Mostly more expensive than petrochemicals, except those from very cheap biomass | Often more expensive than petrochemicals, in special applications competitive with new properties |
| Research agenda | Not in the focus of the research agenda | In the focus of the research agenda |

**Lignocellulose biorefineries**

New strategies and chemical pathways are needed to convert biomass into the required intermediates or products. Lignocellulosic biorefineries will still be playing a special role in the coming years. The pulp and paper industry already generates side-stream commodity products, such as furfural, ethanol, acetic acid, tall oil, or new structural materials, etc. using renewable resources integrated with traditional pulp and paper products. This recently also included the partial recovery of lignin. The conversion of already existing pulp mills into advanced biorefineries means making use of existing infrastructure, expertise and permits, and hence investment costs are lower compared to emerging technologies. Still, a lot of change and transformation will be required to meet future needs. In any case, this approach requires integrated biomass harvesting and processing to address scale, transport cost and low biomass densities, and these processes must have a high energy / material conversion yield in order to be competitive. Biorefineries based on, for instance, organosolv treatments for the production of carbohydrates followed by processing to ethanol are an ill-defined concept from the economic point of view, as the structurally very complex polymer cellulose is processed into a low-value commodity. Even the production of glucose and other sugars from hemicelluloses as starting compounds for biotechnology applications remains challenging. Recent concepts focus much more strongly on the recovery and use of lignin, often to be used as a phenol substitute in different areas of application. In the lignin case, the natural synthesis effort is retained to a larger extent, but the heterogeneity of lignin bond types and building blocks in combination with changes brought about by the refining itself causes difficulties in its utilisation and will still require strong support from basic and applied research. The bottleneck here is still the lack of suitable applications for different lignin types and grades.

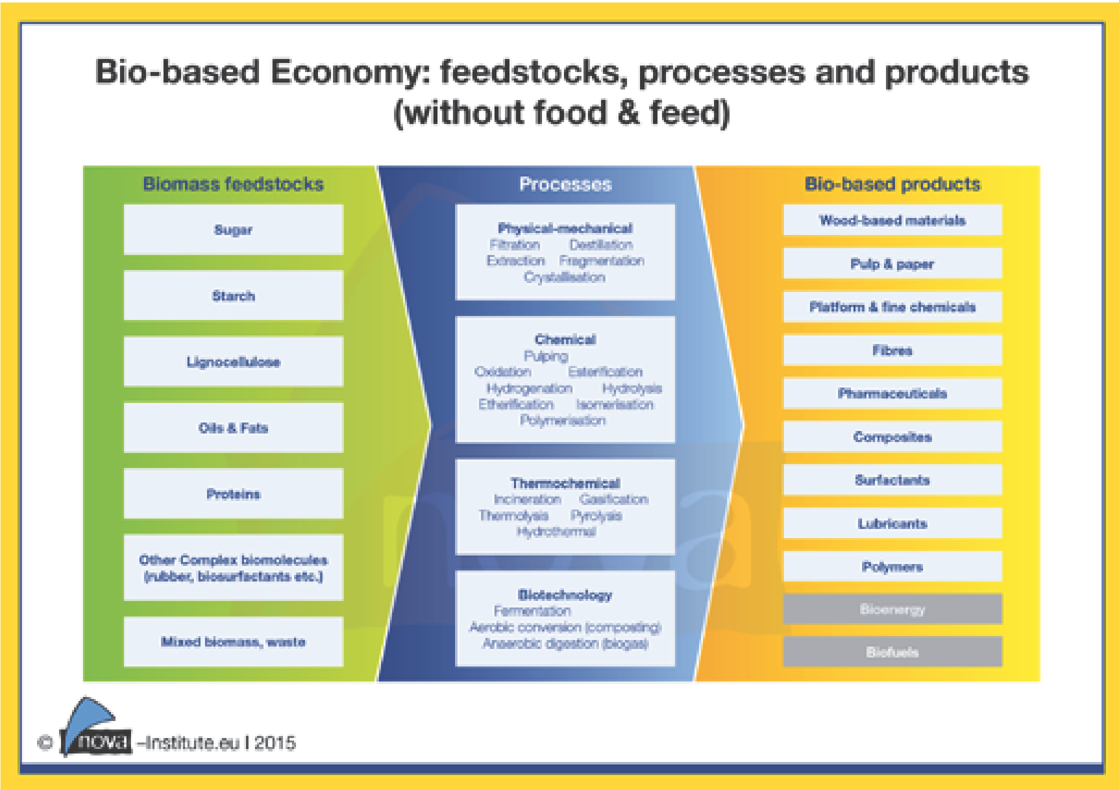
So far, only high-value applications of lignin justify the production cost of most biorefineries. Such a highly added-value product might also require a very pure lignin, e.g., free from residual carbohydrates and inorganic compounds. While the purification of cellulose is state-of-the-art in the pulp and paper industry and the producers of specialty celluloses are acquainted with the peculiarities of cellulose, large-scale isolation and purification is still insufficiently advanced in the case of lignin. Considering the overall amount of lignin in biomass (annual plants 9-18 %, wood up to 30 %), both a high added value application and utilisation in larger amounts as a commodity is required. In any case, energetic utilisation of lignin should be minimised in the future.

Future needs are an increase in yield and value from the same amount of raw material. Besides conversion and adaptation of existing infrastructure, emerging new concepts and technologies are on the way, many of them operating in pilot or small scale units already. The major target is an effective destruction and separation of biomass of various origins into the major building blocks to allow a further conversion into chemicals and products, fuels and energy. Emphasis is currently placed on low-cost technologies and utilisation of fewer chemicals.

#### Utilisation of biomass

Figure 3.20 presents the interplay between different kinds of biomass, different processes and different applications. Based on the numbers given earlier, the major raw material currently is wood. It accounts for by far the highest share of lignocellulose. In the long run, biomass should not be used as fuel or energy, or only at the very end of a cascade utilisation chain.

**Figure 3.20: Bio-based economy: feedstock, processes and products (Piotrowski et al., 2015).**




#### Industrial Biotechnology

Industrial biotechnology is an important biomass transformation technology: highly specific transformations can be accomplished under mild reaction conditions with often very high yields. However, currently only 5-10 % of all processes for biomass transformation in the chemical and material sectors are conducted according to biotechnological approaches, although the tendency is strongly increasing. The sector is still dominated by combinations of physical pre-treatment and subsequent chemical conversions at high temperatures and/or pressure. The typical production processes applied in industrial biotechnology are fermentation steps. Here, carbohydrate feedstock — mainly sugar monomers from hydrolysed starch or lignocellulosic biomass —

are converted into different products by micro-organisms (bacteria, yeasts) or by isolated enzymes. Enzymatically catalysed transformations are highly specific, and can reach high output and purity. Metabolic engineering of the bacteria or yeasts also offers the possibility of producing complex molecules that are not easily available from fossil-based processes. This is mainly important for complex, high-prized molecules used as precursors for the pharmaceutical industry, but to some extent also as building blocks for polymers.

The main disadvantage of biotechnological processes is the often energy-intensive product recovery from the fermentation broth and the extensive downstream processing, which can lead to very high costs. Addressing this, a lot of work today focuses on improving and optimising downstream processing.

Industrial biotechnology has a special importance for the future bio-based economy as an innovative field with a great number of opportunities to produce platform chemicals, building blocks for a variety of polymers as well as molecules for fine chemistry and pharmacy. Over the last few decades, such technologies have been developed and upscaled from the lab scale to demonstration and even production scale in several areas.

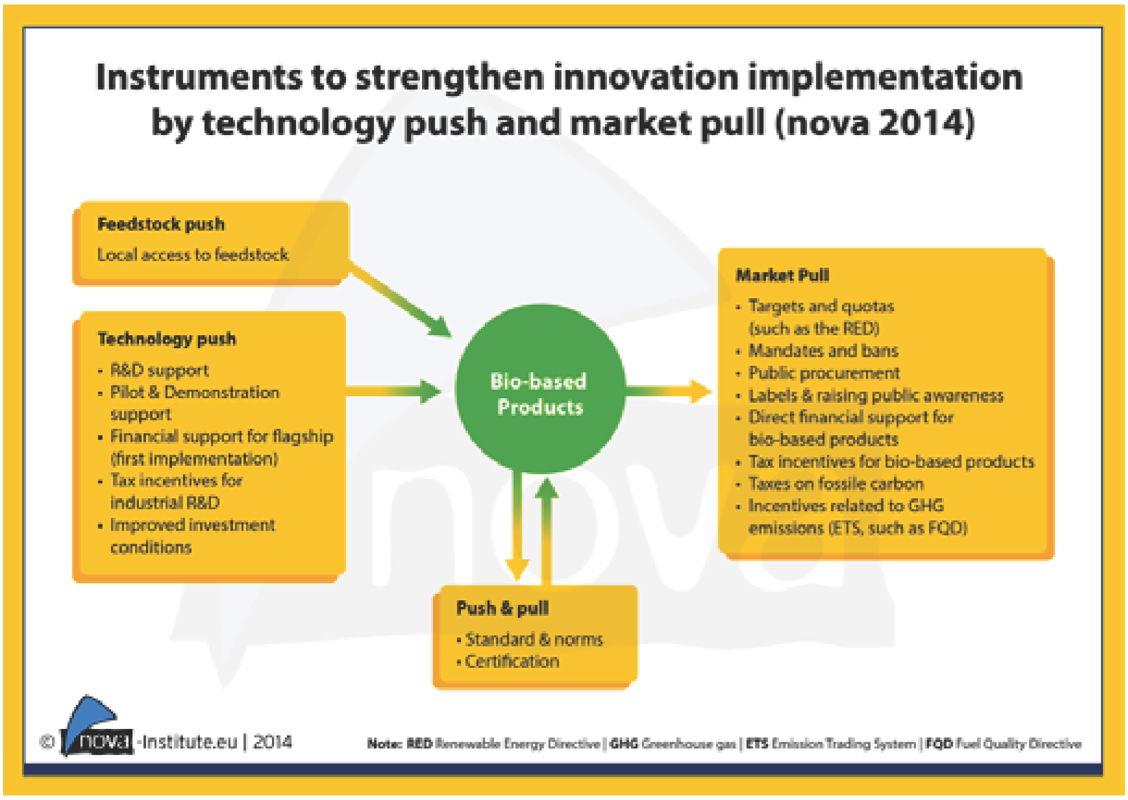
In recent years, most of the higher scale applications for industrial biotechnology processes have focused on the biofuels sector, especially on the production of bioethanol and biogas. In the material use sector, industrial biotechnology has been focusing on several building blocks for bio-based polymers, but also on lubricants, solvents and surfactants.

## *Market policies*

### Push and pull

According to a widely accepted market theory, innovative products are placed on the market either through technology (or feedstock) push or through market pull. Policies can have an important impact on market pull through different measures. Within the bio-based market, only the bioenergy and biofuels sector enjoys politically created market pull, based on the European Commission's Renewable Energy Directive (RED). For bio-based chemicals and materials, there is no such support, even though there are several possibilities to introduce measures. The following picture shows a list of all measures that are theoretically possible as means to introduce bio-based chemicals and materials (Figure 3.21).

Figure 3.21: Instruments to strengthen innovation implementation — push and pull (Carus et al., 2014a).



One example is to use mandates and bans on certain products to promote environmentally friendly innovation. Mandates and bans should be used as strong instruments based on sound environmental and health reasons in order to tap the full positive potential of bio-based products. They should create a long-term market pull, being future orientated, market proven and consistent.

Another strong market pull instrument could be a reform of the Renewable Energy Directive into a Renewable Energy and Materials Directive (Carus et al., 2014b) in order to change the current distortive market pull only focused on energy.

DG Energy is not the appropriate body to create a market pull also for bio-based chemicals and materials. This needs to be initiated by DG GROW, DG Environment and/or DG Climate Action. The newly introduced structure of the European Commission could be helpful to bring the different bodies together, since the newly appointed Vice-Presidents are supposed to lead task forces for important topics, combining the different working areas of the Commission.

This is especially important as other parts of the world — most importantly the US, Latin America and Asia — are actively improving the framework conditions for bio-based industries in the field of bio-based chemicals and materials. In order to stay competitive, Europe needs to guarantee supply security of biomass and market demand to high value industries, such as production of chemicals and materials, in order to prevent them from leaving Europe and taking their value and employment with them.

### *Trends in business and markets*

Current trends to utilise biomass target the market with the highest volume. As the market volume of plastics is by far the largest of any single sector within the chemical industry, a share of bio-based products especially in this business is the aim of several companies and other stakeholders which are moving from petrochemical to renewable feedstock.

As described in section 3.5.2, polymers can be synthesised according to the drop-in strategy, i.e., by substitution of starting materials with bio-based chemicals. In the case of bio-based polymers, the largest recent production aims at bio-based polyethylene as a drop-in solution based on bioethanol production. Also from bioethanol, ethylene glycol is produced for the production of polyethylene terephthalate (PET), mainly driven by brand activities such as those undertaken by Coca-Cola Ltd. which has started to use a bio-based PET for their beverage bottles.

Also the emerging strategy (see section 3.5.2) is already in place with the production of polylactic acid (PLA), a novel polymer within the classical assortment of polymers used in food containers. PLA is produced from lactic acid, which is derived from the fermentation of glucose by bacteria. Hence, PLA is a fully bio-based polymer with no petro-based equivalent. Other organic acids, such as succinic acid or itaconic acid, together with alcohols, such as 1,3-propanediol, 1,4-butanediol and several more, are at demonstration scale by now and commercial production should follow in due course. Other potentially large-scale products based on biotechnological production will include acrylic acid, terephthalic acid, levulinic acid and others. Werpy and Petersen (2004) assessed a set of the 12 most promising new top value added chemicals, derived from biomass, on the basis of some selection criteria to meet the growing bioeconomy with a focus on the US markets. Bozell and Petersen (2010) revisited the 'Top 12' based on real trends and provided a new list of top 10 bio-based chemicals from carbohydrates with a slightly different focus in 2010 (Table 3.6).

**Table 3.6: Most promising new top value added chemicals in 2004 and 2010**

| Werpy and Petersen, 2004 | | Bozell and Petersen, 2010 |
|---|---|---|
| 1 | Succinic, Fumaric and Malic acid as 1,4-diacids | Ethanol |
| 2 | 2,5-Furan dicarboxylic acid (FDCA) | Furans (HMF, Furfural, FDCA) |
| 3 | 3-Hydroxy propionic acid (3-HPA) | Glycerol and derivatives |
| 4 | Aspartic acid | Biohydrocarbons (Isoprene and others) |
| 5 | Glucaric acid | Lactic acid |
| 6 | Glutamic acid | Succinic acid |
| 7 | Itaconic acid | Hydropropionic acid and aldehyde |
| 8 | Levulinic acid | Levulinic acid |
| 9 | 3-Hydroxybutyrolactone | Sorbitol |
| 10 | Glycerol | Xylitol |
| 11 | Sorbitol | |
| 12 | Xylitol and Arabinitol | |

Comparing these science-based forecasts to the real markets, the congruence seems to be quite high (see figures) — especially for ethanol (and ethylene and monoethylene gycol (MEG) as follow-up chemicals) as a leading bio-based chemical during the last decade and several other molecules. Lactic acid and succinic acid are rising in capacities and applications as well as furans, aiming at a new bio-based polymer called polyethylene furanoate (PEF) that can substitute PET in packaging applications (bottles). Smaller shares of other chemicals are not as big as suggested in Figure 3.22 and 3.23, but all mentioned top 10 chemicals are in use or seen as future molecules for the bioeconomy. Not included in Werpy and Petersen (2004) or in Bozell and Petersen (2010) lists are the bio-based diols propanediol and butanediol and adipic acid that are supposed to play a role in a bio-based future, too.

**Figure 3.22: Most important new bio-based building blocks, cumulated capacities worldwide 2011 to 2020 (Aeschelmann et al., 2015).**

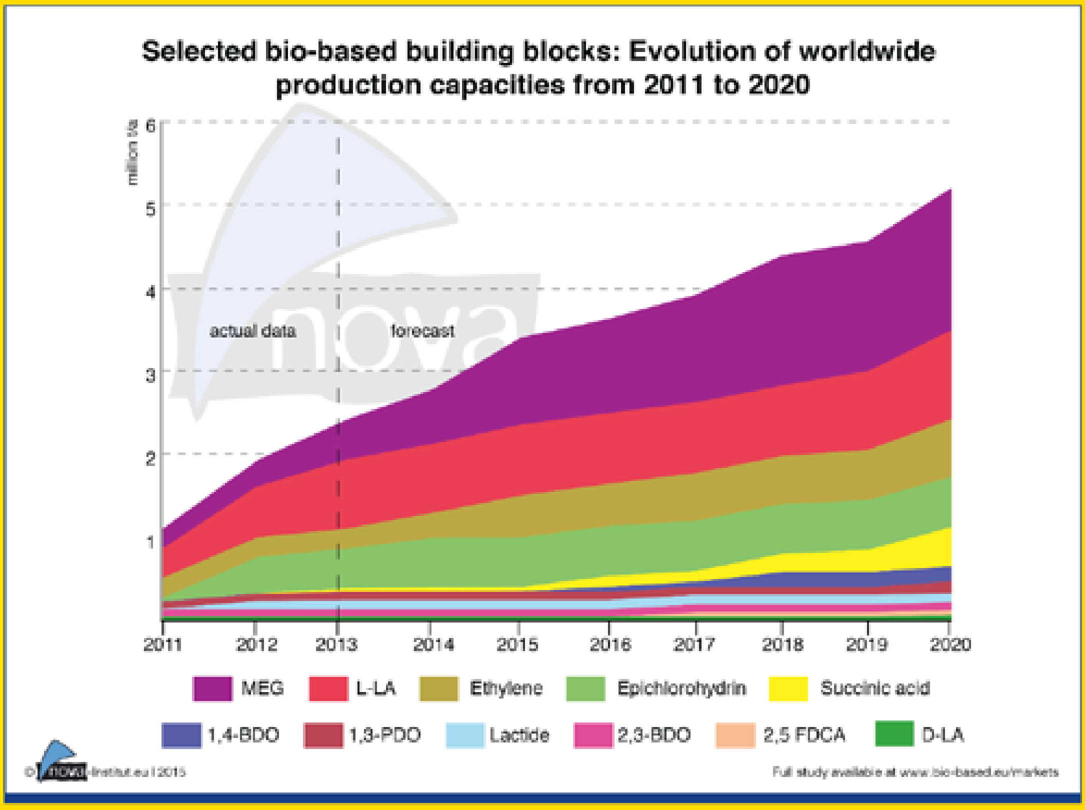
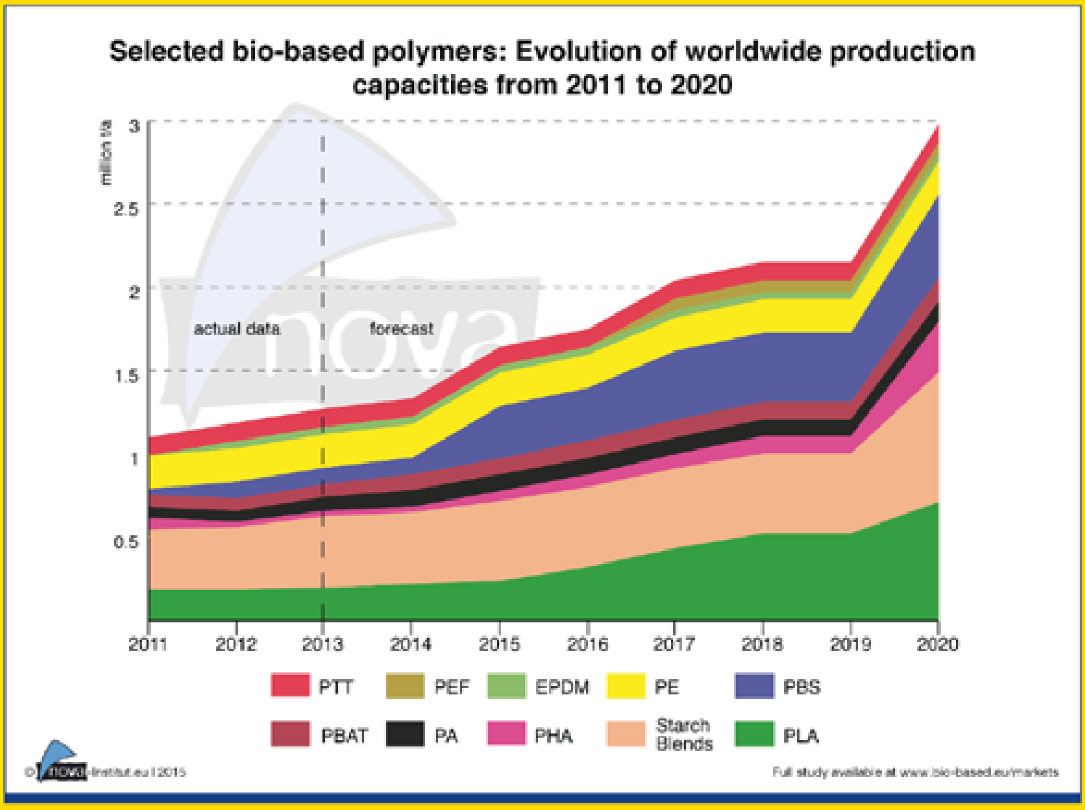


**Figure 3.23: Most important bio-based building polymers, aggregated capacities worldwide 2011 to 2020 (Aeschelmann et al., 2015).**




The overall worldwide development of bio-based polymers appears encouraging, but the growth is still very different for different regions in the world, and Europe falls behind most other regions. The data compiled in cooperation with the Institute for Bioplastics and Biocomposites and the Nova-Institute show that the bioplastics production capacity is to increase from around 1.6 million t in 2013 to approximately 6.7 million t by 2018 (only new bio-based polymers). Bio-based, non-biodegradable plastics, such as bio-based PET, are increasing most significantly. PLA is a major growth driver in the field of bio-based and biodegradable bioplastics. Flexible and rigid packaging remains by far the leading application field for bioplastics.

With a view on regional capacity development, Asia will expand its role as major production hub. About 75 % of bioplastics will be produced in Asia by 2018. In comparison, Europe will be left with roughly 8 %. 'We urge the EU legislator to consider the immense growth and job creation potential of our industry — an important sector of the bioeconomy. The EU needs a comprehensive framework to stay competitive in the field of bioplastics' concluded François de Bie, chairman of European Bioplastics (Press release European Bioplastics, 2014-12-02).

In the field of lubricants, surfactants, pharmaceuticals and other fine chemicals, the products mainly concerned will usually not be produced at a large scale, but for a high price. In these areas, the main activities for biotechnology are in the identification and modification of production routes for tailor-made products, for example for bio-surfactants, such as alkyl glycosides.

**Extractables from biomass side-streams and waste**

Biomass can be used in many different ways. Besides conventional processing steps i.e., for pulp production, recent research agendas focus mainly on the destruction of biomass to smaller fragments or by transforming polysaccharides of lignocelluloses into fermentable sugars. This current approach requires to some extent a change of thinking and a different strategic orientation wherever possible in order to acknowledge and use the already present high structural complexity of biopolymers. The biopolymers should be utilised primarily at their highest structural level. In concrete terms the polymer level should be favoured over generation of monomers or fragments.

From several biomass sources, waste streams and residues side-products are partly already utilised. For example, limonenes from citrus peel and residues can be used as aroma, perfume, cleaning agent, pharmaceuticals or polymers. Large amounts already result from side-stream processing during cellulose production. Tall oil is a valuable side product from Kraft pulping of softwoods; acetic acid and furfural are available from sulphite pulping of hardwood. In all examples, the compounds isolated are of high value and can be used in several utilisation areas.

In general biomass can be utilised in many different ways. Recent research agendas mainly focus on break-down of biomass to smaller molecules or in transforming lignocellulose in fermentable sugars. But also the extraction of high value complex biomolecules is an important utilisation pathway, which can often be processed before or parallel to other pathways of utilisation. From several biomass sources, waste streams and residues extractable compounds are available and partly already in use. Table 3.7 gives an overview of some important extractables partly already available in high amounts. This is especially true for pine chemicals from wood residues and waste streams from the pulp and paper industry (mainly tall oil). In all examples the extractable compounds are of high value and can be used in several utilisation areas (Table 3.7).

To have an idea about the volume of these streams a few data on grape residues are given in Figure 3.22 as an example. The total production of grapes is ~65 million t worldwide, the main producers being China, Italy, the US, France and Spain — so three of the main global producers are located in Europe.

Grapes are mainly produced for wine production and human consumption. A large amount is processed in the wine industry, so high amounts of by-products, mainly pomace, are available. The grape pomace after processing for wine or juice is about 10-15 % of wet grapes; it contains up to 60 % skin and pulps and 40 % seeds. The seeds can be used for the production of high quality grape seed oil, the pomace contains very diverse yields of polyphenols and tannins, from 50 to 200 mg/g dry pomace or marc as a mixture of resveratrol, polyphenols and tannins in different ratios. The price of resveratrol depends on purity and lies between 100 and 400 €/kg. The rest of the pomace can be used for fodder, fertiliser or for the production of biogas.

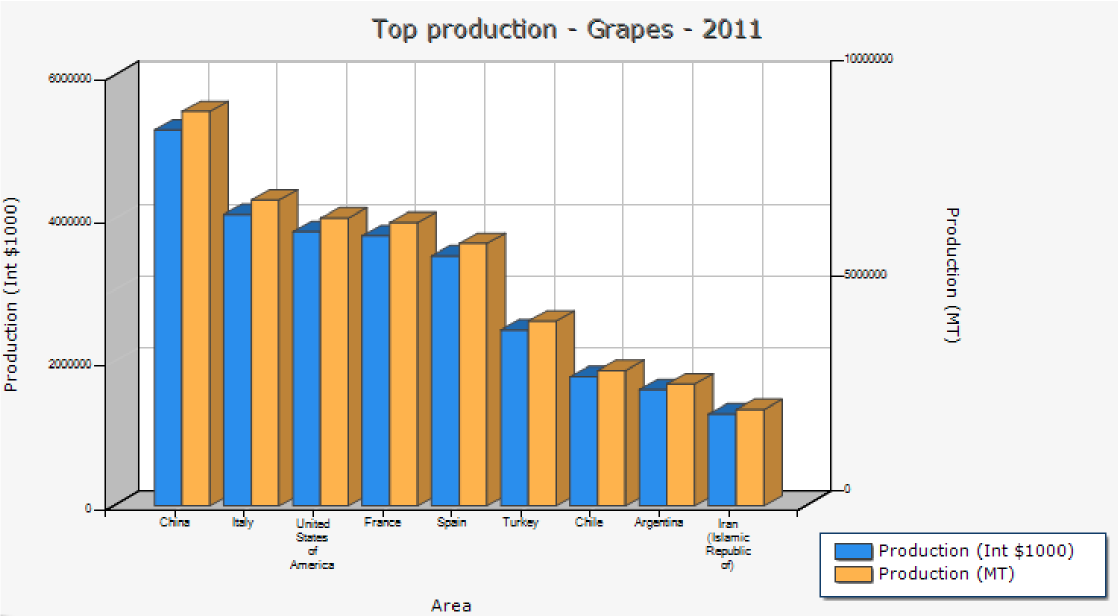
Marine biomass integrated bio-refineries are also able to develop a range of value added products for example from functional healthy food additives such as peptides to cosmetics and pharmaceuticals such as wound healing products.

**Table 3.7: Biomass side-streams and waste — Extractables and potential uses.**

| Biomass side-streams and waste | Extractables | Potential uses |
|---|---|---|
| Wood (tall oil) | Colophony | Cleaning agent, lubricant, paints |
| | Turpentine | Solvents, cleaning agent, … |
| | Other pine chemicals | Chemical base materials, paints, adhesives, others |
| Bark | Tannins | Tanning agents, PUR foams |
| Citrus peels and residues | Limonene | Aroma, perfumes, cleaning agents, pharmaceuticals, polymers |
| Grape residues, pomace | Resveratrole, Poly-phenoles, Tannins | Paints, tanning agents, nutraceuticals |
| Cashew residues | Cashew Nutshell Oil (Cardanol, Cardol) | Coatings, PU, flame retardants, adhesives |
| Fruit residues in general | Essential oils, Pectines, Tannins | Aroma, perfumes, cleaning agents, pharmaceuticals, polymers, tanning agents, others |
| Olive residues (Pomace) | Phenols: Tyrosole, Hydroxytyrosole, Oleuropein | Pharmacy, food ingredients, nutraceuticals |

| | | |
|---|---|---|
| Olive leafs | Tannins | Tanning agents, polymer cross-linker |
| Coffee residues | Behenic acid, Cafestol, Kahweol | Pharmacy, cosmetics |
| Tomato residues<br>(Green, Pomace) | Tomatine, Flavonides | Pharmacy, nutraceuticals, aroma |
| Sugar beet molasses | Betaine | Functional Food (protein), nutraceuticals |

Figure 3.24: Production of grapes in different countries (FAOSTAT, 2013).




**Forestry**

With regard to forestry, the future trend is to prepare the forestry sector for a multifunctional, better use: energy, fuels and chemicals, construction, furniture, landscape, recreational activity and other ecosystem services, such as water regulation, biodiversity and carbon storage. Platform and specialty chemicals from biomass gain more importance relative to the established uses in the pulp and paper and material sector. Forestry is directly affected by major changes in the chemical industries, where whole production lines are adjusted to cope with an increased share of the (partly) new starting materials from forestry. The pressure to operate high-value utilisation modes—in particular of non-polysaccharide components (lignins, pectins, extractives)—will increase. Energy considerations will disfavour utilisation paths that rely on far-reaching destruction of biomass (pyrolysis, syn-gas) against biotechnological conversions and direct usage of less fragmented components. Boosting the forest sector by genetically engineered trees may play a role in the future. These technologies aim at high quality biomass and improved disassembly of woody biomass with significantly lower energy consumption at constant or even better product properties. In addition, new tree species will be tested for their ability to cope with climate change and to secure resilience of the forest. An efficient nutrition management equivalent to that in place for agricultural systems is needed in forest management. More diversified ways of generating the raw material should be established. Wood harvesting in a soil-preserving way is an issue (e.g., no stump extraction). This is in-line with a more extensive and effective utilisation of used wood (extension of cascades, longer life cycles, inhibiting the aging of biopolymers), both from post-consumer and industrial sources.

Increased inter-weaving with other industries leads to an inter-linked and cross-sectorial industry (energy, chemicals, textiles, food). Some countries will stop producing forest products at today´s scale, but new services connecting to new products and the forest as such could over-compensate this trend. Payments for ecosystem services (including biodiversity, carbon, green health, rewarding carbon capture and LCA of forest) will be a new means to support forests. Still forests have to cope with pests, pathogens and natural catastrophes. Advanced materials based on lignocellulosics could enter completely new markets and will be a main pillar in forest economics (Hetemäki, 2013).

## *Challenges, dogmata and dilemmas*

### Challenges

Compared to classical oil refineries, biorefineries face high transport costs of biomass and/or low biomass availability. Currently the only large biorefineries available are pulp mills, but exploring their full potential with regard to biorefining is only at the very beginning. So far, they generate commodities such as ethanol, acetic acid, furfural, new structural materials, etc. using renewable resources integrated with traditional pulp and paper products. In order to transform the available biomass, cost effective fractionation and conversion technologies are needed on large scale to feed the demand or more likely for Europe a complete change of concepts towards smaller units with an optimum size adapted to local conditions, which are not comparable to classical oil refineries where the raw material is pumped in pipelines at very low cost. This approach requires integrated biomass harvesting, collection and processing to address scale and transport cost barriers.

When fractions of biomass are fed into established processes of the petrochemical industry, they usually have to be of constant quality and reactivity. Both demands are challenging as we cope with biological variation and lack of appropriate analyses. The overall reactivity of lignocellulose and its components is badly understood.

The lignin challenge: Most of the lignin separated today in pulp mills is used to satisfy the energy demand for the overall wood separation and recovery process for chemicals. About 15 %+ of the lignin can be immediately removed from a classical mill scenario and used for different applications. In future scenarios, lignin as fuel should be completely avoided, as lignin offers in principle multiple ways to serve as biopolymer and starting compound for platform chemicals. However, the technology for this is largely missing. Recently, at least strategies to precipitate lignin from black liquor have become commercially available (Lignoboost™ technology), which offers a solid kraft lignin to the market. In addition, lignin can be partially returned as organic matter to soil to prevent carbon depletion of soil organic matter. Supply and monitoring of constant lignin quality and reactivity are a further problem to be addressed by research.

Another major challenge feeding bio-based intermediates and products into current oil-based refineries and chemical production (drop-in strategy) is often their chemical incompatibility. While oil-based refineries to a large extent work in apolar systems, most of the bio-based products have a low compatibility in those solvents. The higher the natural synthesis level, the more pronounced this problem becomes. In addition, the required analytical techniques ensuring quality and performance are currently immature.

For the transition period scenario we need to use existing infrastructure on the largest possible scale, expertise and permits with processes utilising different kinds of biomass feedstock. The know-how currently available largely lies with fibre, pulp and paper producers as they have technologies to separate biomass on a large scale (biggest single line pulp mill uses 3 Mt ODM/y wood) into major fractions, purify those components and further process them, e.g., into fibres.

### Dilemma — best use of biomass

This chapter already illustrated one of the most pressing challenges in order to create a strong bio-based chemicals and materials sector: the best allocation of biomass to the different applications. A workshop among the SCAR experts has resulted in the following list of criteria that should determine the priorities of biomass allocation:

- **Markets**
  - Food: Guaranteed food security (plus quality and local diet and cultural habits) — at least no distortion of the global food markets
  - Supply and demand. Biomass should be utilised where the most ‘pressure’ from demand and supply is. Adaptability and resilience towards future changes in demand and supply (also climate change)

- **Supply:**
  - ‘Best use’ with a strong link between processing and applications/products on the one hand and the production of biomass on the other hand: Sustainable land use, soil, water and biodiversity — balance between yield intensity, the ecological capacity of

the regional production system (water, soil) and recycling of nutrients, provision of other ecosystem services and economic viability. Utilisation and valorisations of almost all waste, co- and by-products.

- **Economy:** Increased/highest value-added creation, maximise value of outputs.
  - Economy and social:
  - Increased/highest employment generation.
  - More investment in bio-based economy in Europe — new production lines in the EU.
- **Social:** Acceptance from policy and society, social acceptance.
- **Environment:** Increased climate protection — lowest carbon footprint.
- **Efficiency:**
  - Increased resource and conversion efficiency — circular economy, coupled production and cascade use.
  - 'Atom economy — biomass utilisation efficiency', keep the functionality of the biomolecules, utilise the complexity — maximum value creation from biomass (employment).
- **Technology:** Strengthen innovation; as the forest products production including pulp and paper is slightly declining in Europe and production has shifted to Asia and to Latin America, the European Forest Product sector is facing a severe challenge with the production capacities being in decline for years (Hetemäki, 2013). This negative trend can be effectively buffered by innovation and intelligent product developments and diversification of products by European producers. As we will not meet the economy of scale easily in Europe, novel fundamental approaches are needed to become competitive again.

This list of priorities has several impacts on research agendas and policies. If the best use of biomass is to be achieved, the following points need to be considered and implemented:

- **Technology:**
  - Utilisation and valorisation of waste, co- and by-products from all organic sources (agriculture, forest, food sector, organic waste streams)
  - Finding different ways of combining production of biomass.
  - ... and Environment: How to intensify, increase yields with less impact on soil quality and environment, how to achieve sustainable growth in yields in agriculture and forest production?
  - ... and Policy: Implementing cascade use and coupled production in a smart way.
- **Economy:**
  - How to integrate in the existing structures of chemical (and other) industries?
  - Research on future demands and supply, where will the pressure be?
- **Social:**
  - How to create acceptance for promising innovations?
  - Identify the positive aspects and future solutions contributed by bio-based economy.
- **All sectors:**
  - Strategic research agenda, future scenarios: imagining 'Biomass-based societies' — what are the key parameters to achieve success?
- **Evaluation:**
  - Better impact evaluation in an early stage and continuously; monitor side effects on markets, environmental and socio-economic impacts.
  - Better data collection and monitoring, knowledge transfer.

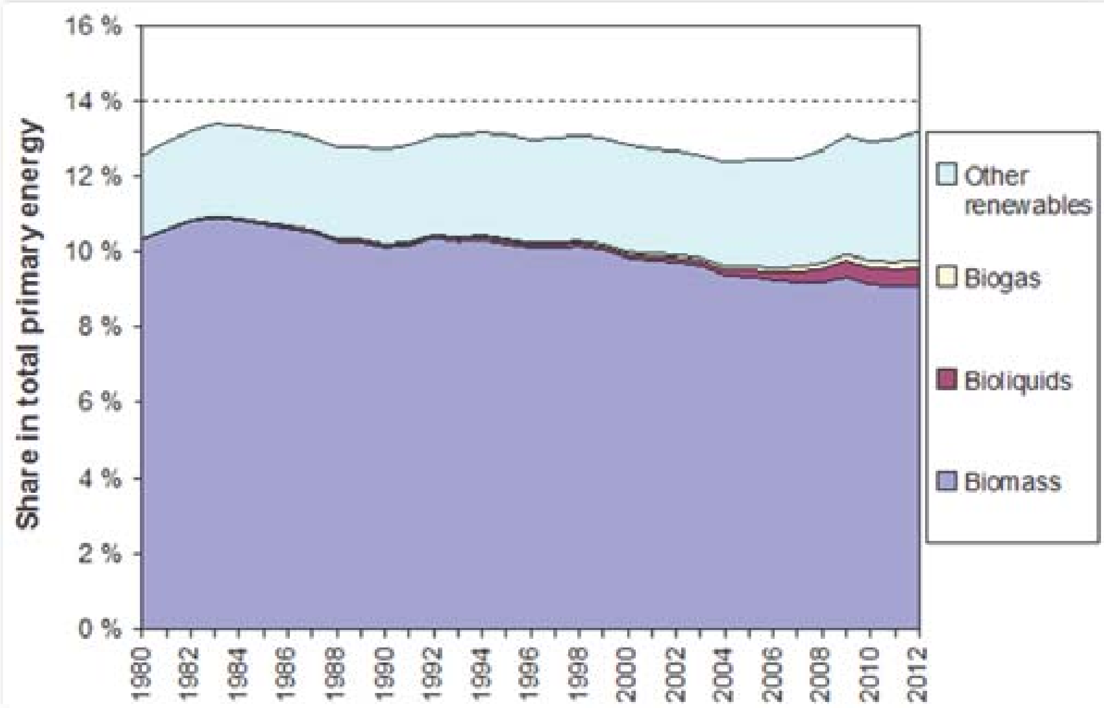
## 2.3.6. Bio-energy

### *Introduction*

The current energy system is still highly dependent on fossil fuels (oil, coal and natural gas) and nuclear energy. According to the IEA Energy Statistics, bioenergy has accounted for roughly 10 % of global total primary energy supply since 1980 (IEA, 2014a). Between 1980 and 2010 bioenergy supply increased from 31 to 55 EJ (690-1200 Mtoe), along with the increasing global energy demand and new policies and measures to increase the use of renewable energy sources in both OECD and non-OECD-countries. In 2012, renewable energy accounted for only 13 % of the world primary energy supply. Solid biofuels represented 69 % of all renewable energy, and wood accounted for about 65 % of the solid biofuels. The largest share of solid biofuels is traditional wood used for heating and cooking in developing countries. According to IPCC estimates, in 2008 traditional firewood and charcoal still accounted for about 74 % of global bioenergy use. Even in Europe, firewood still accounts for about 45 % of all wood biomass used for energy. Liquid biofuels, mainly for the transport sector, represented about

4 % of renewable energy in 2010, and biogas only about 1.5 %. Liquid biofuels and biogas have been the highest growing components of the primary bioenergy supply (IEA, 2014a).

Figure 3.25: Renewable energy share in global primary energy 1980-2012 (IEA, 2014a).



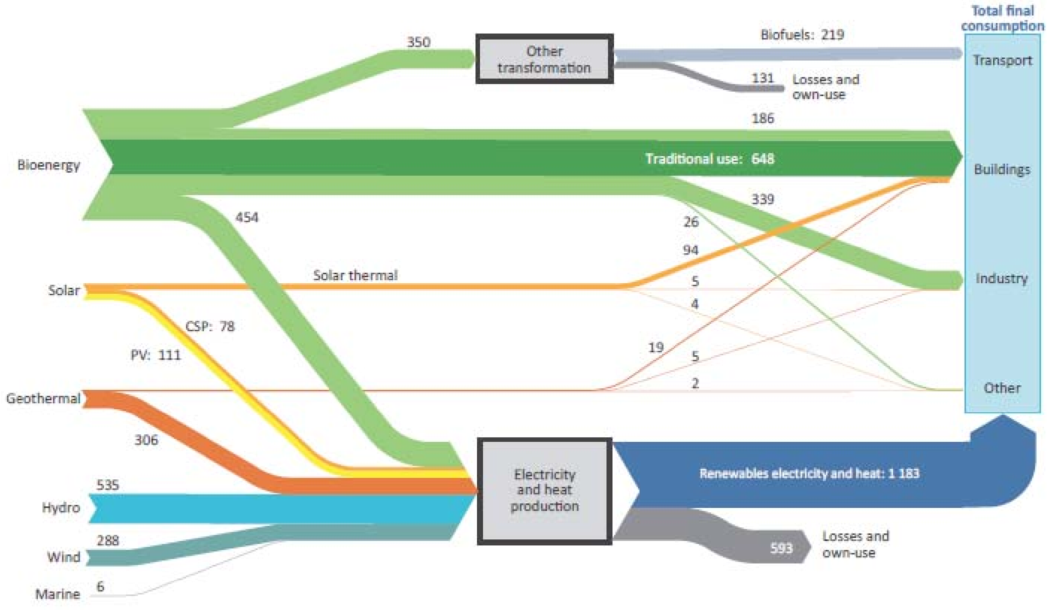

## *Trends in technologies and global bioenergy demand*

Reducing our dependence on fossil fuels requires a significant shift from using technologies based on transformation of fossil fuels towards using technologies based on renewable electricity, heat, and fuels in all end uses: industry, transport (electrical vehicles, synthetic fuels, biofuels), buildings (heat pumps, solar and other renewables), etc. As a result, bioenergy and biofuels will play a double role: first as a transition fuel as long as electrification is not yet fully implemented and second for those applications for which electrification will be difficult to implement (MacKay, 2008).

In its *Technology Roadmap — Bioenergy for Heat and Power*, the International Energy Agency (IEA, 2012) envisages that by 2050 bioenergy could provide up to 7.5 % of global electricity generation, 15 % of final energy consumption in industry and 20 % in the buildings sector. Key to this development is the deployment of large-scale biomass power plants (> 50 MW) to generate electricity efficiently and at low cost on the one hand and the development of small-scale, high-efficiency conversion technologies on the other.

In figure 3.26, the world renewable energy balance in the IEA WEO New Policies Scenario is shown. The New Policies Scenario corresponds to approximately 3.6 °C global temperature rise (IEA, 2014b) meaning that in the 2 °C mitigation scenario the share of renewables should be even higher. It can be seen that bioenergy is expected to have a major role in future energy systems compared to other renewables and that the traditional biomass is assumed to represent the largest share among other end uses even though its share would be decreasing.

**Figure 3.26: World renewable energy balances in the New Policies Scenario, 2040 (Mtoe) (IEA, 2014b).**




Notes: Other transformation includes bio-refining (processing of bioenergy to make biofuels). CSP = concentrating solar power; PV = photovoltaics.

The range of feedstock that can be used for bioenergy and biofuel production (i.e., for heat and electricity and liquid and gaseous biofuels) is large. The largest share of biomass is wood and agro-biomass (i.e., energy crops and residues), but also sewage sludge, animal wastes, organic liquid effluents, the organic fraction of municipal solid waste are used as feedstock. However, these biomass feedstock need to be pre-treated and systems processing biomass have to be designed to avoid fouling and corrosion. This is due to the higher oxygen, chlorine and alkaline content, lower bulk density, higher moisture content and lower caloric value of biomass compared to fossil fuels. Pre-treatment technologies aimed at upgrading the energy density of feedstock include drying, pelletisation and briquetting, torrefaction, pyrolysis and hydrothermal upgrading. Biomass combustion for heat production are based on burning stoves, incineration or gas combustion and are available at both small scale for individual house heating and at large scale. Biomass is converted into power using steam turbines, thermal gasification, engines or biorefineries. (IEA, 2012). One option considered also is the thermal conversion of biomass into biomethane that then can be injected into the natural gas grid but in this option biomass raw material should come from low value wastes and/or side products.

Biofuel technologies are categorised into first, second and third generation depending on the type of biomass used and the production processes adopted. Each generation presents a series of advantages and concerns:

- The production of **first generation biofuels** utilises edible products as biomass and adopts established technologies that are cost-effective in terms of yields (Naik et al., 2010). First generation ethanol technologies are based on starch and sugar fermentation, while biodiesel is based on transesterification, which transforms oils and fats into fatty acid methyl esters. These processes have varying productivity and do not always meet with greenhouse gas (GHG) emission reduction targets (de Vries et al., 2014; Sawangkeaw and Ngamprasertsith, 2013). Processing and transportation costs can be high and impact on energy use (Fiorese et al., 2014). Soils can be damaged, e.g., erosion, carbon (C) balance, waste and residues from fertilization (de Vries et al., 2014). Moreover, in the case of tropical oil plants used as biomass, geographical location of production can impact supply and distribution on a global level, while land use changes and competition with food and feed production can drive up costs and food prices (Naik et al., 2014).

- **Second generation technologies** can make ethanol from cellulosic feedstock — such as grass, wood, and crop residues. There are two processes being developed: biochemical and thermochemical. The biochemical process implies breaking cellulose into sugars after a pre-treatment, which separates cellulose from other constituents, and sugars are fermented into ethanol. Separated lignin is used to produce energy ([4]). It should be noted that also the 2nd generation biofuels compete with land use, which means that also with the 2nd generation biofuels the origin of the raw materials should be carefully considered. Therefore, refineries should diversify processes to recirculate more products to be used as biomass feed stock, e.g., using by-products and waste from other industries. However, some woody species used as biomass are invasive, hence the need for implementation of environmental assessment and monitoring systems (Smith et al., 2013). The technologies also need investment to improve the cost-efficiency of upstream and downstream processes to attract commercialisation (Kim and Kim, 2014; Tunå and Hulteberg, 2014). However, there are still large uncertainties related to costs of 2nd generation biofuel production until the first large scale demonstrations have been realised.

- **Third generation technologies** can turn algae/microalgae, which are rich in lipids, into several types of fuels. The microalgae can be converted to biofuels by either bio-based chemical or a thermochemical conversion process, like previous generation biofuels (Dutta et al., 2014). The possibility to tailor the characteristics of feedstock through genetic modification opens the door to fourth generation technologies (Dutta et al., 2014). For example, genetic modification can make algae produce oils that can be easily refined into butanol, which is far better than ethanol as it is very similar to gasoline. Advantages of the production of biofuels from algae include the potential for such processes to work as carbon sinks and the by-products of these technologies could be used in other industries, such as pharmaceuticals and nutraceuticals (Ribeiro and Pereira da Silva, 2013; Naik et al., 2010). Third generation technologies at the present stage are expensive and have high but inconsistent productivity, leaving large-scale production not energy efficient (Leite et al., 2013), so there are doubts on the current state of the art that algae can be turned economically into fuels.

## *Trends in business and markets*

The liquid biofuels produced today are mainly for road transport. Normally they are blended (about 5 %) with traditional petrol or diesel. However, there is an increasing pressure on aviation and marine transport industry to reduce GHG emissions ([5]).

According to the Clean Energy report 2014 (Clean Edge, 2014), the global production and wholesale market value of ethanol and biodiesel has been USD 97.8 billion in 2013. It forecasts that the global markets for both ethanol and biodiesel will grow on average 4.5 % annually in the next 10 years with biodiesel prices falling and ethanol pricing remaining stable. According to the IEA (IEA, 2014c), global biofuel production should reach 140 billion litres in 2018 from the 113 billion litres in 2013, thus undershooting the volumes required to reach 2 °C mitigation targets. Globally, operation of advanced biofuels capacity was 5.4 billion litres in 2013, an increase of over 1 billion litres compared to 2012. According to the IEA, global advanced biofuel capacity could reach 8.7 billion litres in 2018, which is also below the 2025 target to reach the 2 °C mitigation.

According to AEBIOM, in Europe the total estimated turnover for biofuels for 2011 was 14,685 million EUR (AEBIOM, 2013). Biodiesel has a share of 79.1 %, bioethanol 19.9 % and biogas and vegetable oil about 0.5 % each.

E2, a US think-thank, provides an overview of the critical points of the value chain of advanced biofuels (Bernhardt et al., 2014):

- **Feedstock.** This industry consists of waste management companies, algae producers, biomass owners and agricultural commodity traders. Weyerhaeuser and PowerStock are examples of biomass owners. Bunge is a giant trader involved in advanced biofuels.

- **Technology and Process Development.** Technology from enzyme developers, such as Novozymes and DuPont, as well as plant genomic companies, such as Mendel and Syngenta, are increasingly utilized at commercial scale facilities.

([4]) The thermochemical conversion is based on production of syngas through heating. Syngas is mixed with a catalyst and reformed into ethanol. These technologies are not considered cost-effective yet (Alvira et al., 2010; Bhalla et al., 2013). Advantages of this type biofuels are the lack of competition with food production, the reduced land-use change impact and the potential for GHG emission reduction (Limayem and Ricke, 2012; Timilsina and Shrestha, 2011).

([5]) http://www.biofuelstp.eu/spm6.html and http://www.ecofys.com/en/publication/biofuels-for-aviation/

- **Engineering and Equipment.** In this segment companies that provide the engineering platforms and equipment necessary to operate a biofuel plant are considered. E2 identifies providers such as Biodico and Chemtex.

- **Distribution.** Leading energy companies, such as Shell, Chevron, Exxon and BP are all investing in advanced biofuels. Other companies such as Propel are focusing on renewable fuel terminals.

Incentives for biofuels have encouraged massive investments. According to Govindji (2013) there are two types of investors in the biofuel sector:

- Financial investors, who invest in biofuels primarily to derive a financial return;

- Strategic investors are companies who invest to preserve or create longer-term strategic opportunities. In the biofuels industry, they include feedstock owners, engine manufacturers, process technology vendors and refineries.

At the moment, investments tend to go to first generation biofuels, while advanced biofuels are mainly the object of venture capital, as the financial risk associated with them is still high ([6]). The high level of subsidy to first generation biofuels is considered a constraint to further investments in the sector (Govindji, 2013). On the other hand, investors in first generation technologies claim that changes of regulation undermine a rising industry.

## *Challenges, dogmas and dilemmas*

**Sustainability assessment** — The 2009 Renewable Energy Directive (RED) identifies stringent sustainability requirements of the feedstock, setting progressive minimum thresholds for saving of $CO_2$ and encouraging certification schemes. The assessment of Indirect Land Use change (ILUC) is also recommended. On this basis, in December 2010 the European Commission released a report on indirect land use change related to biofuels and bioliquids. The report acknowledged that indirect land use change can reduce greenhouse gas emissions savings associated with biofuels, but recognises that '*a number of deficiencies and uncertainties associated with the modelling, which is required to estimate the impacts, remain to be addressed, which could significantly impact on the results of the analytical work carried out to date*' (EC, 2010).

In 2012, the European Commission released a proposal of directive (COM(2012) 595 final) wherein a revised methodology for assessment of ILUC was proposed. However, the debate over the methodology of assessment is still very intense. Land use changes are particularly difficult to assess. Reasons are multiple and include the methodologies available and the reporting of direct and indirect effects of land use changes (Overmars et al., 2011; Panichelli and Gnansounou, 2014; van Stappen et al., 2011), the uncertainty of the data available to policy-makers, in particular modelling data, leading to the risk of considering as certain, data that is instead uncertain (Di Lucia et al., 2012).

A major methodological issue for assessing ILUC is related to the boundaries of the system analysed. When measuring indirect effects, in fact, the range of impacts may be limitless. A recent study commissioned to Ecofys by the European Oilseed Alliance (EOA), the European Biodiesel Board (EBB) and the European Vegetable Oil and Protein Meal Industry (FEDIOL) highlighted that in order to assess sustainability of biofuels, also unconventional oils such as extra heavy oil and bitumen (tar sands), kerogen oil (oil shale), light tight oil (shale oil), deep sea oil and synthetic products (gas-to-liquids and coal-to-liquids) should be taken into account. These unconventional oils have a higher carbon footprint than conventional ones because of the type of production processes involved. Ecofys' report estimates that biofuels have a greater effect in displacing the production of unconventional oils rather than fossil fuels. As a result, the impact of biofuels in terms of net GHG emission reduction is now thought to be greater than previously estimated (Ecofys, 2014).

Other authors claim that social changes and impacts are not addressed, reflecting the lack of research on social vulnerabilities of the development of the bioeconomy (Esteves Riberiro, 2013). The main problem remains the multi-scale, multi-sector and multi-institutional character of the development of the bioeconomy, which needs an enhanced adaptive capacity and flexibility of the system (Hunsberger et al., 2014) and integrated sustainability assessment and certification models (Gnansounou, 2011; Scarlat and Dallemand, 2011; Silva Lora et al., 2011).

Among positive social impacts of biofuel income generation, the diversification of farm incomes,

([6]) Reuters (2014) signals that energy companies such as France's Total have manifested its intention to invest into second generation biofuels.

the reduction of rural-urban migration with rural employment opportunities and the creation of jobs at all stages of the value chain are suggested (Hunsberger et al., 2014; Kaphengst et al., 2012). However, there is little evidence of long-term benefits in terms of employment and rural development (Gasparatos et al., 2011). Jaeger and Egelkraut (2011) claim that current positive estimates are based on static regional models, not on dynamic general long-term models, and that although fossil fuels are used in the production and processing of biofuels, LCA models do not take into account behavioural responses and market effects, possibly overestimating the benefits from biofuel production and influencing public perception.

**Governance patterns** — It is claimed that social impacts of biofuels within Europe are mostly perceived as positive, for example through the creation of new jobs, the diversification of income opportunities for European farmers, or the reduction of energy dependency in rural communities (Ribeiro et al., 2008), while most negative impacts are evidenced in feedstock exporting countries. There is clear evidence that biofuel policies have an impact on labour, land rights, access to water, energy security. This asymmetry raises issues of governance. Governance structures and infrastructures, as well as private infrastructures, capacity building and financial investments, which influence greatly the efficacy of laws and policies. Some developing countries producing biofuels may lack government infrastructure, e.g., community consultation, smallholders' rights.

Negative externalities are usually offset to developing countries that are producers and exporters of biofuels, where governance is weak. Issues that arise in such countries are linked to the uneven distribution of the benefits from biofuels production between investors and growers and between large-scale and small-scale producers, linked to the type of production (Florin et al., 2014; German et al., 2010). Labour rights are weak and land transfer agreements are not transparent and legally binding (Obidzinski et al., 2012). Large producers tend to rely on short-term employment, with a negative impact on rural development, income stability and social equality, fostering social conflict (Kaphengst et al., 2012). Smallholders are priced out of markets (i.e., price of feedstock crops), have limited access to land (i.e., land value), technology and training needed to boost production and add value to their products (i.e., processing plants), consequently bearing higher social costs, linked to the loss of income, than large producers that retain greater production, financial and negotiating powers, in particular in emerging value chains like Jatropha (Florin et al., 2014; German et al., 2011; Tessler, 2012). The formulation and implementation of the successful sustainability criteria should cover the above issues and thereby restrict the use of unsustainable biofuels, like in RED.

Another governance issue is related to the market power of involved actors. Market power of energy producers depends on the size of their production and benefit from the linkages between the energy market and emissions market. According to Dormady (2014), policy-makers need to ensure that carbon markets adequately support the expansion of future capacity in order to avoid the risk of larger producers exercising greater influence on energy and emission prices, artificially inflating or suppressing emission prices and ultimately reducing the effectiveness of carbon markets and energy policies.

Implementation of sustainability schemes can act as a driver to improve governance coherence in Europe and adopt uniform regulations and certifications to incentivise developing countries to move in the same direction and improve their infrastructure, legal framework and law enforcement; e.g., Government of Mozambique invested in compliance to EU standards to expand the market.

**Policy paradoxes: the 'energy paradox', the 'green paradox' and the 'Jevons' paradox'** — Energy policies are increasingly faced with the 'energy paradox', the 'green paradox', and the 'Jevons' paradox'. The energy paradox is a situation in which consumers undervalue the cost of future energy cost over the current purchasing price, and thus are not willing to pay for more efficient technologies (Parry et al., 2014). This paradox discourages investments in efficient technologies. Conversely, conditions creating the so-called 'green paradox' occur when reduction in fossil fuel demand following GHG mitigation agreements leads to a reduction in fossil fuels prices, which in turn leads to an increase in fossil fuel use from countries that do not adopt GHG mitigation policies (Grafton et al., 2014). Thirdly, the 'Jevons' paradox', also known as 'rebound effect', is related to an increase in total consumption as a consequence of efficiency gains. The Jevons' paradox is now recognised by the International Energy Agency (IEA) and the United Nations Intergovernmental Panel on Climate Change.

These three paradoxes show that a mix of policies should be taken in consideration and aligned to overarching goals. Mazumder (2014), for example, claims that in order to reduce energy consumption a combination of taxes and subsidies is more effective than a subsidy system alone in incentivising the reduction in gasoline use and achieving energy security (i.e., higher gas tax, lower biofuel subsidy and lower tax on income). Others suggest refining demand-side policies to encourage most efficient technologies while keeping income effects of efficiency increase unaltered.

### 2.3.7. The policy framework of the European bioeconomy

The current policy framework of the European bioeconomy consists of a multitude of regulations, incentives and strategies from several policy areas. In this section we highlight the main policies related to agriculture, forestry, food, fisheries, bioenergy and bio-based materials.

#### *Agriculture and Rural Development*

The Common Agricultural Policy (CAP) became effective in 1962 as one of the first common policies of the European Economic Community. It was developed to reduce dependency on food imports. The aim was to increase food production through ensuring good prices for farmers. It offered a stable policy framework with high internal prices, import taxation and export subsidies. The success in terms of production was fast but it produced food in excess (for example cereals and dairy products). Obliged to export the surplus food, the EU was accused of trade distortion. In 1992, there was the first major reform of the CAP with the emphasis shifting from price support to direct aid to farmers. Further changes took place during the early 2000s as the EU enlarged, with an increasing emphasis on payment for rural development and environmental services (EC, 2013b).

European agriculture is facing some strategic problems that will need decisions in the years to come. Agricultural production has a macroeconomic role to play. One aspect is maintaining employment in rural areas. In line with the EU's growth strategy 'Europe 2020' and the overall CAP objectives, the EU's rural development policy aims at '*... a balanced territorial development of rural economies and communities including the creation and maintenance of employment*' as one of its three long-term strategic objectives (EC, 2015c). The other is trade. This sector can produce more and export more to make a greater contribution to the common trade balance. The EU was the world's largest exporter of wheat and barley in 2014 (USDA, 2015) and is also a major exporter of industrial food and processed products, exporting more premium quality products than low cost and basic quality products.

There are three long-term objectives for the CAP at this stage in its history: viable food production, sustainable management of natural resources and climate action and balanced territorial development. The 2013 reform has addressed these issues. The reform has introduced important changes, such as the abolition of milk and sugar quotas and the introduction of 'greening' measures (rewarding farmers for the provision of environmental public goods), but has maintained non-targeted subsidies, which represent the largest part of the 'first pillar'. The expected reports on CAP performance and the negotiations for the new Multi-annual Financial Framework (MFF) will probably be occasions for further reforms. CAP expenditures of the EU policies have been declining sharply, from 43 % of the EU budget in 2007 to about 36 % planned in 2020, and the prospects beyond 2020 do not allow us to expect a reversal of a trend. As farmers' incomes in many countries are heavily dependent on subsidies, further reduction could generate pressure to structural change.

#### *Forestry*

The Treaties for the European Union make no provision for a common forest policy. However, there is a long history of EU measures supporting certain forest-related activities, coordinated with Member States mainly through the Standing Forestry Committee. The EU Forestry Strategy adopted in 1998 puts forward as its overall principles the application of sustainable forest management and the multifunctional role of forests. The Strategy was reviewed in 2005, and the Commission presented an EU Forest Action Plan in 2006. In May 2014 a new forest strategy was adopted by the EU agriculture ministries under proposal of the Commission (COM(2013)659). The strategy develops and implements a common vision of multifunctional and sustainable forest management in Europe. The principles to which the strategy aspires are a) Sustainable forest management and the multifunctional role of forests b) Resource efficiency, optimising the contribution of forests and the forest sector to rural development, growth and job creation; c) Global forest responsibility, promoting sustainable production and consumption of forest products defines action priorities and targets.

The strategy addresses the issue of the growing demand for raw material for existing and new products (e.g., green chemicals or textile fibres) and for renewable energy, arguing that this poses a significant challenge for sustainable management and for balancing demands. The strategy also introduces a 'forest information system' to be set up and for Europe-wide, harmonised information on forests to be collected. It would carry out a review of the new strategy by 2018.

### *Fisheries and aquaculture*

The Common Fisheries Policy (CFP) sets quota for the amounts of each type of fish which Member States are allowed to catch. Total allowable catches (TACs) or fishing opportunities are catch limits (expressed in tonnes or numbers) that are set for most commercial fish stocks. In the Mediterranean Sea, fisheries management is based mainly on regulating fishing effort, and only bluefin tuna is managed by TACs and quotas. The amounts are fixed at levels to protect the fish stocks that have been severely affected by fishing above capacity. The fisheries sector still employs more than 140,000 fishermen and the fleet had 97,000 vessels in 2007, but competition from large vessels reduces employment and the activity of small-scale fishermen. The EU has to import fish. The consumption of seafood in EU is dominated by marine finfish products (13.9 kg per capita in 2009 with little annual variation). Corresponding figures for freshwater and shellfish products were around 3.4 kg and 1.7 kg, respectively. Consumption of freshwater products has increased steadily from 1.6 kg in 1990 (Hofherr et al., 2012).

As a consequence of this situation, Europe's fisheries policy was in urgent need of reform. With two-thirds of North Atlantic stocks now overfished, the fishing industry is experiencing smaller catches and facing an uncertain future, and the reform was implemented in 2014 to make fishing environmentally, economically, and socially sustainable. By bringing fish stocks back to sustainable levels, the new CFP aims to provide EU citizens with a stable, secure and healthy food supply for the long term (EC, 2009). It seeks to bring new prosperity to the fishing sector, end dependence on subsidies and create new opportunities for jobs and growth in coastal areas. From now on, EU fisheries will be managed by multi-annual plans and governed by the ecosystem approach and the precautionary principle. To safeguard resources and maximise long-term yields, scientific data on the state of the stocks will be more reliable, and the fishing industry will have a better and more stable basis for long-term planning and investment. EU Member States are entrusted with collecting, maintaining and sharing scientific data about fish stocks and the impact of fishing at sea-basin level. Fisheries data collection programmes (e.g., BITS, MEDITS) were established several years ago and national research programmes will be established to coordinate this activity.

Discarding of fish catches will be phased out. This practice of throwing unwanted fish overboard differs significantly between different gears, areas and target species, and is estimated at 23 % of total catches. Fishermen will be obliged to land all the commercial species that they catch. This will further lead to more reliable data on fish stocks, support better management, and improve resource efficiency. It is also an incentive to avoid unwanted catches by means of technical solutions such as more selective fishing gear. Decentralised governance and introduction of a system of transferable fishing concessions for vessels over 12 m long are new policies to give the fishing industry a long-term perspective, more flexibility and greater accountability, while reducing overcapacity. However, small-scale fisheries will be exempt from the transferable fishing concessions scheme. The financial instrument for fisheries will further support small-scale fisheries and help local economies adapt to the changes.

For fisheries policy, the future trend is to manage in a sustainable way the fish stocks for the European area and to adapt the fleet keeping an acceptable level of employment for small-scale fishermen.

The new framework for aquaculture in the EU aims to increase the production and supply of seafood in the EU, reduce dependence on imported fish and boost growth in coastal and rural areas. Member States will draft national strategic plans to remove administrative barriers and uphold environmental, social and economic standards for the farmed-fish industry. The policy further aims to empower the aquaculture industry by simplified rules and decentralised management. Producer organisations are expected to play a greater role in collective management, monitoring and control. More informed consumers through new marketing standards on labelling, quality and traceability can probably also contribute better to support sustainable fisheries and aquaculture.

In EU's Blue Growth agenda, blue energy, aquaculture and blue biotechnology were identified as areas where additional effort at EU level could stimulate long-term growth and jobs in the blue economy (EC, 2012c).

Increasingly, greening measures are also being introduced. For instance, in Norway so called 'green licences' have been introduced to promote a green growth of the salmon farming. Here, salmon farms can exchange a conventional licence for two 'green licences' with special requests for innovative and environmental friendly farming.

### *Food*

#### **Competitiveness and food quality**

European current policy challenges with regard to the market for agricultural and fisheries products are mainly related to trade and to the position of European exports in international markets. The future free trade agreement between the USA and EU (Transatlantic Trade and Investment Partnership) seems to be rejected by important sectors of the European population for several reasons. First, there is fear of increased unemployment, and second, the possible renunciation of European norms and standards in production and processing as well as an obligation to accept beef treated with hormones or GMO-feed and food, which is not properly labelled.

European agriculture is distinct and has a long history, which has led to a very diverse and small-scale agricultural as well as livestock and fisheries sector (including aquaculture). This is not conducive to competitiveness in international commodity markets, but has led to a new business model that creates jobs and value added by developing niche markets for high quality products. For this reason, the food sector has competitive advantages for both quality and safety of the products. Competitiveness and quality are of high priority in current EU policies. For example, the EU agricultural product quality policy aims at guaranteeing quality to consumers and a fair price for farmers by improving regulations and establishing new quality schemes for agricultural products and feedstuff. These schemes are intended to provide guarantees for protected designations of origin and geographical indications, traditional specialties or other optional quality term (organic products or mountain farming) (EC, 2015d). Additionally, production is related to highly diverse landscapes and rural cultures that give the products a cultural environment that is part of the image of increasing rural development and competiveness.

#### **Food and feed safety**

Globalisation and rapid economic growth are major drivers of the challenges associated with food and feed safety issues. Scandals such as horse meat in lasagne or aflatoxins in forage maize in 2013 not only indicate that there are still gaps with regard to food safety, but they also reduce consumers' trust in the food industry and in the responsible authorities (Henning et al., 2014). This happened despite the EU having passed legislation on the traceability of beef in 2000 and the creation in 2002, of the European Food Safety Authority. In the same regulation (178/2002) the European Parliament established the general principles and requirements of the Food Law, and laid down procedures in matters of food safety across all food chains (EC, 2002). Moreover, the safety of food and related policies are required to address aspects of animal health and welfare. Diseases such as brucellosis, salmonellosis and listeriosis are zoonoses, which can be transmitted to humans by contaminated food. That is one reason why strategies such as the European Union Animal Health Strategy (2007-2013) placed a focus on animal health (EC, 2007b).

Food and feed safety policies also have to consider the consumption of genetically modified organisms (GMOs), even though there is no evidence that they harm either animal or human health. For some decades, the application of biotechnology in order to artificially modify characteristics of plants and animals has been hotly debated, particularly in Europe (Martin, 2013). Policies are required to ensure transparency for European consumers, i.e., to ensure that people know when they are purchasing food that has been 'genetically modified'. Policies are also in place to reduce the potential ecological risk, e.g., through transfer of genes to wild plant populations (EC, 2001). Finally, policies and regulations such as the Regulation (EC) No 1829/2003 of the European Parliament and of the Council are required to protect the interests of stakeholders along food and feed value chains, for example by assuring the traceability and labelling of GMOs and the traceability of food and feed products produced from GMOs (EC, 2003).

The agreement reached in the Council on June 2014 will allow a Member State to restrict or ban

GMO cultivation in their territory on a wide range of reasons such as: environmental or agricultural policy objectives, town and country planning, land use, socio-economic impacts, avoidance of GMO presence in other products, or public policy. This may result in a diversification of development pathways of European agriculture.

**Sustainable food systems**

In 2010, European Commissioner Barroso launched the Commission's Europe 2020 strategy for smart, sustainable and inclusive growth that included the goal of moving to a more resource efficient Europe. The document included a commitment that '*healthier and more sustainable food production and consumption will be widespread and will have driven a 20 % reduction in the food chain's resource inputs.*' In the document, the Commission pledged to '*a) further assess how best to limit waste throughout the food supply chain, and b) consider ways to lower the environmental impact of food production and consumption patterns (Communication on sustainable food, by 2013); c) develop a methodology for sustainability criteria for key food commodities (by 2014)*' (EC, 2011b). In 2013, the Commission has launched a consultation in view of the publication of the Communication on sustainable food, but so far, the document has not been published.

## *Renewable energy*

The Renewable Energy Directive (RED), governing the market of energy products from renewable feedstock, was created before a backdrop of both increasing awareness of a pressing need for worldwide climate protection as well as steeply increasing prices of fossil energy, which made the dependence of Europe on energy exporting countries clearer than ever.

With the RED (2009), the EU committed itself to the 20-20-20 targets, with a cut in the energy demand by 20 %, a 20 % reduction in EU greenhouse gas emissions from 1990 levels and raising the share of renewable resources to 20 % from final energy consumption. In addition a minimum goal of 10 % renewables of final energy consumption in the transport sector to be supplied by renewable energy (including electric cars running with renewable electricity) sources was formulated. On the basis of this Directive, individual Member States were to launch national action plans for 2020 to increase the share of renewable energy sources from final energy consumption (i.e., in transport, buildings, and industrial sector). An important focal point in the EU for reaching these goals is increased research on renewables, in order to maximise the potential of the domestic energy sources. For the EU, apart from strategies to increase the share of renewable energy sources, energy efficiency is another path towards maintaining capability to answer to energy demand, but in the 2020 policy framework the 20 % energy efficiency targets were not set as a binding targets as for renewables. In 2012 the share of renewables in final energy consumption had increased to 14.1 % from 8.7 % in 2005 (EC, 2013c).

The RED held solutions for both these issues: The EU's obligatory reductions of greenhouse gas emissions from energy (electricity, heat, fuels) by 20 % compared to the 1990 emission level exceed the reduction targets of the Kyoto Protocol, while at the same time, the alternative ways of locally and regionally producing energy from indigenous renewable energy sources seemed to offer some degree of independence from energy imports. These circumstances helped to find a broad consensus for necessary action.

Even a third purpose was served with the energy support programmes. Since the 1990s, new market opportunities for agricultural products had been looked for in order to support the struggling agriculture sector, which produced too much and faced a continuing decline of prices and employment. Energy served as a very attractive outlet for these biogenic materials. Thus, the RED was able to generate massive effects with relatively few mechanisms and within a relatively small amount of time: In 2012, energy from renewable sources was estimated to have contributed 14.1 % of gross final energy consumption in the EU-28, compared with 8.3 % in 2004, the first year for which this data is available (EC, 2013c; Eurostat, 2014).

However, it has become clear by now that the RED has had some adverse effects on bio-based chemicals and materials, which could offer more value-adding and innovative contributions to the bioeconomy, by creating increased prices for biomass and even supply bottlenecks in some EU countries (Carus et al., 2014c). Contrary to the situation in the 1990s, biomass is not an overly abundant resource, but is becoming more and more scarce and valuable. However, there is still unused potential of low value biomass raw materials, which may be used as a feedstock for bioenergy and biofuels for transport.

In January 2014, the European Commission (EC) proposed the 2030 policy framework for climate and energy to make the EU's economy and energy system more competitive, secure and sustainable. This long-term framework also seeks to create regulatory certainty for investors. Some of the proposed new targets for 2030 are: (1) reduction of greenhouse gas emissions by 40 % compared to 1990 emission level in order to reach the 80 % goal set for 2050; (2) increase the share of renewable energy to a minimum of 27 % from final energy consumption and; (3) increase energy efficiency by 30 % (EC, 2013c). The main difference compared to the 2020 climate and energy framework will be the absence of binding national quotas for renewables to fulfil, with only the overall EU quota that will have to be kept. With regard to transportation quotas, the European Parliament has just approved a 7 % cap to biofuels being fulfilled by first-generation fuels. The final deal agreed also includes a clause that will see indirect land use change (ILUC) emissions reported — but not mandatorily counted — and a 0.5 % non-binding target on so-called advanced biofuels (Maler, 2015).

Currently the emissions and removals of these sectors are treated in different parts of the EU's climate policy. Non-$CO_2$ emissions from agriculture are treated in the Effort Sharing Decision (i.e. national non-ETS targets) while $CO_2$ emissions and removals related to land use, land-use change and forestry are excluded from the EU's domestic reduction target but are accounted for under international commitments. The Commission has proposed that to ensure that all sectors contribute in a cost-effective way to the mitigation efforts, agriculture, land-use, land-use change and forestry should be included in the GHG reduction target for 2030. However, the architecture of the implementation of these sectors is still open and further analysis will be undertaken with the aim of assessing the most appropriate policy approach. The new LULUCF policies on a EU level could have an impact especially on the production of the wood based materials and energy, especially if there would be new incentives to increase forest sinks instead of using domestic wood. The final decisions of the EU 2030 climate and energy framework, including nationally binding targets for greenhouse gas emissions of the non-emission trading sector, will not be decided before the results of the United Nations Framework Convention on Climate Change (UNFCCC) negotiations in Paris are known.

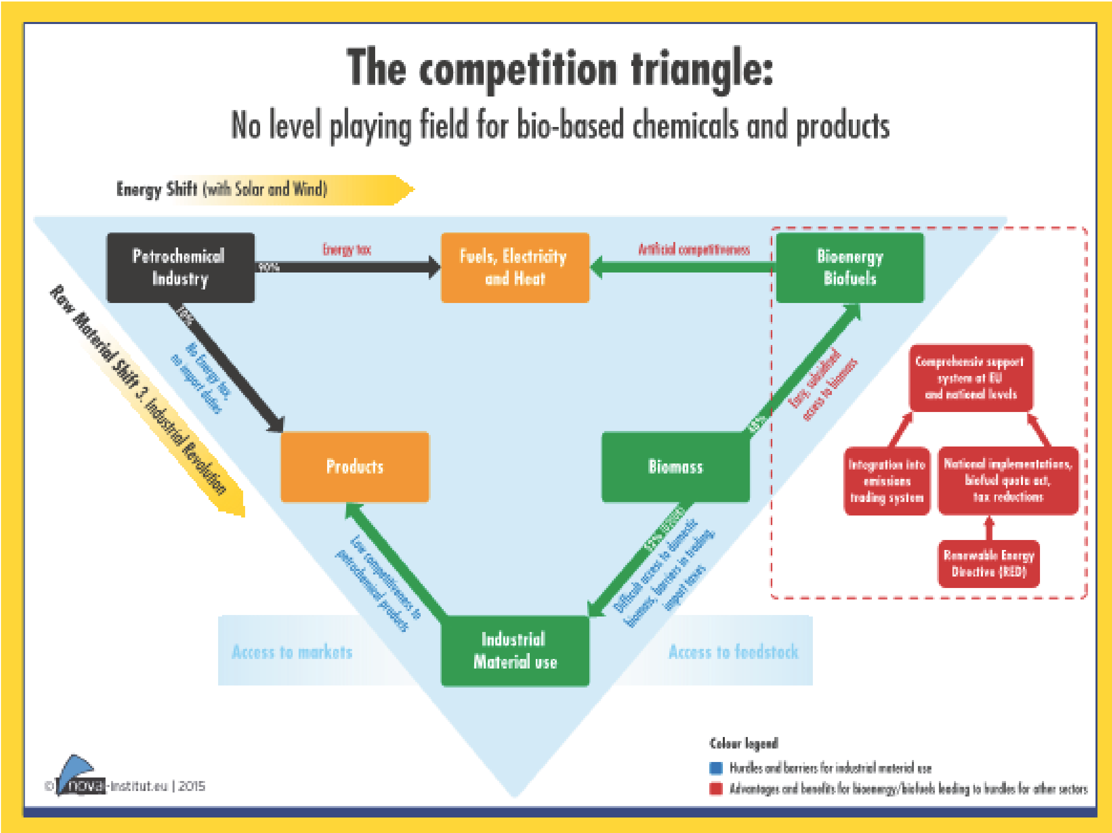
From the debate generated by these issues, it emerges clearly that sustainability criteria is an area where policy decisions and scientific advancement are strongly connected to each other, as the object of research is highly uncertain and there are different — and conflicting — interests at stake. Addressing sustainability criteria in a proper way will need a specific focus of research on how to develop appropriate inter- and trans-disciplinary approaches and methods.

### *Bio-based materials and chemicals*

Overall, the discussions about the renewable energy framework rarely take into consideration the way in which it influences the industrial material use in a more general sense, since this sector is completely out of the focus. For example, the currently discussed annex defining 'wastes and residues' that are to be counted double or quadruple if the ILUC proposal gets approved, contains many feedstock that are valuable for the chemical and material sector (Carus et al., 2014c). This is also shown in the agreement for the EU's climate and energy framework until 2030. It is not clear either whether the EU 2030 climate and energy policies will have any additional or reduced impact on the bio-based materials and chemicals sector.

The whole framework of policy in the European Union creates a difficult market position for bio-based products that can be summed up in the 'competition triangle' (Figure 3.27) below. Each side is explained briefly.

Figure 3.27: The competition triangle: petrochemicals — bioenergy/biofuels — material use of biomass (Carus et al., 2014c)




**Right side: Bioenergy/biofuels and material use competing for biomass**

Material use is competing with bioenergy for biomass that is not used for food or feed. As a result of the comprehensive support system for bioenergy and biofuels in many EU Member States, which was ultimately created by the EU RED, the prices for biomass and land have greatly increased. This makes access to biomass for material use much harder and more expensive, but this is not compensated for by support measures. This market distortion hinders the competitiveness of producers of materials from biomass. Different concrete examples can be found in the appendix of Carus et al. (2014b).

**Left side: petro-chemical products competing with bio-based products**

The bio-based chemistry and plastics industries are exposed to full competition from chemical industry products. Without any accompanying measures, new, bio-based industries must be developed that can prove their viability in the face of the well-established and long-optimised mass production of the chemical industry. Then there are high biomass prices resulting from the promotion of energy use, which are not counteracted by taxes on fossil carbon sources as a raw material for the chemical industry. All of this creates an extremely tough competitive environment.

**Upper side: fossil energy competing with bioenergy/biofuels**

Due to the national support systems based on the target of the RED and introduction of the EU's emissions trading system the use of biomass for energy has increased its competitiveness compared to fossil energy sources during the last decade. Furthermore, the latter are subject to a substantial energy tax and at the same time there was a long period of high fossil prices, which have made bioenergy and biofuels more attractive.

With the CAP, there has been considerable progress during the last revisions in terms of a level playing field between crops used for energy and crops for industry. While the latter faced disadvantages in the first pillar until 2008 (unequal treatment of set-aside land and the energy crop premium) and in the second pillar until 2014 (much higher requirements for sustainability when applying for financial assistance), these do not exist anymore. Effective from 2017, there will not even be any quota on European sugar production anymore, which is expected to lead to much greater availability of domestically produced sugar for industrial use.

In order to strengthen the access to markets for bio-based products, the EU is currently working on developing standards, certification and labelling for these products. These measures would make communication — both business-to-business and business-to-consumer — easier, thus creating confidence in the industry and with end consumers, hopefully increasing demand and market pull. The Technical Committee 'Bio-based products' of the European Committee for Standardisation (CEN/TC 411) is developing horizontal standards on bio-based products, while some other Technical Committees are working on more specific product-related norms. DIN CERTCO and Vinçotte already provide labelling for bio-based products, while for example the EU Ecolabel has included a minimum bio-based content on their criteria list for lubricants in order to be recognised as an environmentally friendly material. It is currently being researched in several European projects how labelling and other communication activities can further improve the market access of bio-based products.

Another major issue coming up on the policy agenda will be the Circular Economy Package. It is expected that this legislative package will influence bio-based materials and they should be considered as one priority area already during deliberations. The cascading-use principle, (where biomass should first be used in the most value-adding way and only later go to low-value applications such as energy), could be a valuable tool in order to ensure the most efficient use of renewable resources and should play a significant part in the package. The principle is being discussed in the European policy area, since it could be a powerful mechanism for the allocation of resources.

## *National bioeconomy strategies*

Several other policy initiatives exist that are more specifically dedicated to the bioeconomy. The German Bioeconomy Council recently published an overview of the Bioeconomy Strategies of the G7 countries that is summarised in Table 3.8. This list shows that a significant majority of the policy measures is focused on research and development, while issues such as commercial implementation, access to feedstock and access to markets are not strongly represented.

**Table 3.8: Overview on bioeconomy policy in the G7, including the EU (Bioökonomierat 2015)**

| Member | Name of Strategy | Main Actors | Key Funding Areas |
|---|---|---|---|
| Canada | Growing Forward | Ministry of Agriculture | R&D on renewable resources and biobased materials, Bioenergy |
| EU | Innovating for Sustainable Growth | DG Science, Research, Innovation | Research & Innovation (Horizon 2020), Public-Private-Partnerships |
| France | bundle of BE-relevant policies | Ministry for Ecology, Ministry for Research | Bionergy, green chemicals, clusters, circular economy |
| Germany | 1. Research Strategy BE<br>2. Policy Strategy BE | 1. Ministry for Research<br>2.Ministry for Agriculture | R&D on food security, sustainable agriculture, healthy nutrition, industrial processes, bioenergy |
| Great Britain | bundle of BE-relevant policies | Parliament, Depts: Energy & Climate, Environment, Transport, Business | Bioenergy, agri-science and -technology |
| Italy | no specific BE policy | – | Participation in EU programmes |
| Japan | Biomass Utilization and Ind. Strategies | Cabinet, National Biomass Policy Council | Research & innovation, circular economy, regional development |
| United States | 1. Bioeconomy Blueprint<br>2. Farm Bill | 1. White House<br>2. USDA | 1. Life Sciences (Biomedicine)<br>2. Agriculture (multiple areas) |

The EU's Horizon 2020 research and innovation programme will have almost EUR6 billion dedicated to research for energy efficiency, clean and low carbon technologies and smart cities and communities. In addition between 2014 and 2020, EUR 23 billion will be available under the European Structural and Investment Funds for its Thematic Objective 'Shift to low-carbon economy' (EC, 2013c).

# 2.4. Scenarios

## 2.4.1. Scenario approach

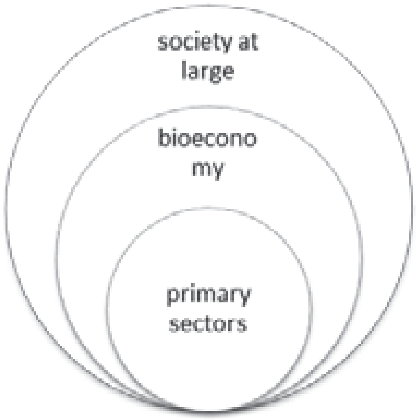
In order to develop a robust research agenda to tackle future challenges and opportunities, one faces the difficulty that the future is unknown. What can be done is to identify the most important uncertainties influencing agriculture, forestry and fisheries and aquaculture (the primary sectors) and then to explore what will, can and should happen in the alternative futures defined by these uncertainties. We identified two critical uncertainties:

- the **demand growth for biomass for materials and energy**. This variable depends on population and economic growth, the relative scarcity of classical resources (e.g., fossil fuels) that will be available, the evolution of bio-based technologies (influencing conversion efficiency) and the evolution of non-biomass based technologies.

- the **supply growth of biomass**. This variable depends on the development and implementation of new technologies in the primary sectors.

These uncertainties are themselves influenced by uncertainties external to the bioeconomy—external drivers that form the background to the bioeconomy scenarios. Hence, we follow a layered approach, as sketched in figure 4.1. At the core are the primary sectors—that is, agriculture, forestry and fisheries and aquaculture. Developments in the primary sectors are influenced by evolutions in the materials and energy sectors that together with the primary sectors form the bioeconomy. The bioeconomy in turn is influenced by a set of external drivers.

Figure 4.1: A layered approach towards SCAR4 Scenarios




Section 4.2 discusses some of the main external drivers that form the background or *décor* for the bioeconomy. Section 4.3 describes the main features of a limited number of future scenarios. Section 4.4 concludes by discussing some implications of these scenarios, as explored in the third workshop.

## 2.4.2. Main external drivers

The long-term images of the future of the European bioeconomy sector depend on many drivers. The three main drivers that will likely create the background or *décor* for the bioeconomy scenarios are:

- the evolution of climate change
- the evolution of economic growth
- the evolution of the geopolitical situation.

Climate change can be faster or slower than expected, more brutal or relatively soft, more discontinuous or continuous. The nature of the evolution will have a strong effect on public and government awareness and then on policy decisions. The sooner decisions are made, the less damage to the biosphere. The sooner investments in R & D are made, the better the solutions that will be deployed. Solutions might be, for example: policy rules for efficient carbon conservation in soils and forests, fast reduction of fossil energy use, fast transition to alternative energies, etc.

The evolution of global economic growth will depend on the evolution of economic globalisation and the evolution of the world population. Population will mainly grow in Asia and Africa, while economic globalisation will depend mainly on the evolution of the world crisis. Old industrial countries will look for re-industrialisation and for a new wave of growth. Emergent countries will likely try to internalise their external growth mechanisms, and Africa will try to emerge as being the new competitive world industrial area. Two extreme situations are possible. First, a poverty scenario could happen with a lasting crisis in old industrial countries (continuing economic dullness in Europe), a slow growth in emerging countries resulting from a misfire of the growth internalisation process or economic accidents (Chinese banking system fragility, stranded assets, a next digital bubble…), and no take off in

Africa resulting from too slow a demographic transition and a fast increasing population. Second, and at the opposite extreme, a favourable growth scenario is possible with a successful internalisation of growth in Asia—particularly in China—combined with a take-off in Africa, and new growth based on the energy transition in Europe, Japan and North America. In that case, each continent could perhaps privilege internal growth and trade preference mechanisms.

The evolution of the geopolitical situation will be important. The economic history of the 20th century has been strongly influenced by the access to oil of industrial countries (political influence), by the cold war opposition and by the protection of 'lifestyles' of the developed countries. The 21st century may be more influenced by possible scarcity of energy, some raw materials and food. Countries being in situations of dependence and looking for political influence to ensure their access to resources could be aggressive. Europe will have to define a geopolicy to ensure energy supply more independently than nowadays. Climate change could also create conflict. And there is a lot of social and economic uncertainty in Middle-Eastern countries (reduction of oil production, reduction of tourism associated with civil uprisings).

The combination of the evolution of the climate and of economic growth could create diverse contextual situations:

- A **slow evolution of climate change** would give time for societies to invest in the energy transition (post-peak oil) and to mitigate against and adapt to climate change. Political contradictions between old industrial countries accused of having historically created climate change, and other countries (emerging and developing) would more easily find burden-sharing solutions. But if growth is low, the situation would not change. It would create a **business as usual situation.** On the contrary, if growth is high, investment in transitions would be easier and would reinforce the growth rate. It would create a context of **opportunities**

- **A fast evolution of climate change** would add costs coming from catastrophic events (hurricanes, flood, droughts, severe food shortages, etc.). The cost of international solidarity would be high. Population migrations could increase. **If global growth is low**, investments will be insufficient and poverty could rise. It would be a **dangerous context**. Countries would probably have to finance the transitions and the damages creating a new wave of inflation. If global **growth is high** and if the big countries have anticipated investments for transitions, the situation could be less tight and international relations less strained. But the need to act rapidly would create a **difficult situation**.

### Table 4.1: Four options for the *décor* of bioeconomy scenarios

| | | Climate change | |
|---|---|---|---|
| | | **Fast** | **Slow** |
| **Economic growth** | **Low** | **Danger**<br>High costs of climate change and transitions<br>Risks of funding shortage<br>Risks of conflicts and rising of poverty | **Business as usual**<br>Incentive to low change |
| | **High** | **Difficulty**<br>High costs of climate change and transitions<br>Acceleration of investments for mitigation, adaptation of climate change, and for energy transition | **Opportunity**<br>Opportunity for anticipation<br>Big investment in energy transition and climate mitigation and adaptation |

Such *décor* options are of course too simplistic. To come closer to reality, intermediate situations would have to be explored. For example, the following could happen:

- The option for climate change is not exactly to happen 'faster or lower' than expected. But a succession of striking climate events could create more awareness and willingness to act, while a more continuous evolution could lead societies and governments to be less aware and defer action. Therefore, the time succession of climate change events is likely to be an important variable in the global system.

- World growth could be neither low nor high, but could fluctuate. Whatever it might be, the need for investment will certainly be large: investment in energy reduction in industrial plants, buildings, transports; carbon sequestration in biomass; adaptation of agriculture to drought, investment in precision agriculture, investment in water control and storage, investment in landscape ecology, in population migration because of rises in sea level… These investments could create very different macroeconomic situations depending on the level of growth it would induce and of the rate of inflation (resulting from savings capacity and budget deficits).

Other drivers could also play a role in setting the *décor*, but with less intensity:

- The energy transition: The first aspect is the price evolution of oil. After peak oil, prices will rise (with geopolitical fluctuations). It will be a strong incentive to change. The response through time to the new technologies will depend on their availability and on the shape of the learning curves. Numerous different situations could be possible for the biomass option. For example, biomass could have a major long-term role if new technologies appear late; it could have an intermediate role while waiting for the promising solar-hydrogen alternative; or it could have a role limited to rural areas and agricultural uses with current technologies. The date of availability of the solar- hydrogen solution is certainly a key for the development—or not—of the 'energy from biomass' pathway.

- A Malthusian period: The combination of rapid increase of world meat and feed demand, as well as food, with a severe yield plateauing of crops, and a strong demand for biofuel produced from biomass could create a period of relative scarcity and high prices for biomass. There would then be an incentive for defining energy alternatives to alleviate the pressure on the biosphere productive capacity.

All these drivers can be considered as main 'external' drivers for the development of bioeconomy scenarios. They all have an impact on supply and demand of bio-sourced goods and services. This impact, as it is at present, will create fluctuations in prices and propensity—or not—to invest in technological alternatives. But behind the fluctuations, we could have several types of situation for the biomass economic status, depending on a **strong or weak supply and a strong or weak demand**. As a consequence, scenarios have to be built on the basis of the demand and supply levels for biomass, and these scenarios can be referred to as the 'framing scenarios' (*décor*) given by the main drivers' situation.

### Table 4.2: Relation between décor scenarios and biomass supply and demand

| Décor scenarios (context) | Situation of biomass supply and demand |
|---|---|
| **Danger**: low growth and rapid climate change | Supply of biomass for the bioeconomy sector would be limited by the economic conditions and the mobilisation of the macroeconomic saving capacity for climate adaptation<br>**Low supply and low demand for biomass**<br>**A ' bio-modesty"** |
| **Business as usual**: low growth and low evolution of the climate | The frame is not an incentive to change<br>**Low supply and low demand for biomass**<br>**A 'bio-modesty"** |
| **Difficulty**: high growth and fast evolution of climate change | Growth would create good conditions for biomass supply and for demand too, even if the macroeconomic scenery appears to be difficult to manage<br>**High supply and high demand**<br>**A 'potentially booming' situation or**<br>**An insufficient supply to feed the demand creating a 'bio-scarcity'** |
| **Opportunity**: high growth and low evolution of the climate | This frame creates conditions for a virtuous evolution, but not in an obligatory way.<br>**High supply and high demand — a potentially 'booming situation' ('bio-boom') or,**<br>**High supply is possible but demand take-off is low creating a stagnation situation for bioeconomy ('bio-scarcity').** |

## 2.4.3. Bioeconomy scenarios

*Scenario framework*

Two critical uncertainties were identified to form the scenario framework. The first is the **demand growth for biomass for materials and energy**. This variable depends on population and economic growth, the relative scarcity of classical resources (e.g., fossil fuels) that will be available, the evolution of bio-based technologies (influencing conversion efficiency) and the evolution of non-biomass based technologies. The second is the **supply growth of biomass**. This variable depends on the development and implementation of new technologies in the primary sectors. Assuming low, medium and high levels of each uncertainty yields nine possible futures. For the sake of manageability, we selected three scenarios:

| | | Supply growth of biomass | | |
|---|---|---|---|---|
| | | Low | medium | high |
| Demand growth for biomass for materials and energy | low | | A | |
| | medium | | | |
| | high | C | | B |

The scenarios are supported by quantitative simulations towards 2050 that are provided in Annexes 3 and 4. Scenario A corresponds to the Business As Usual (BAU) scenario, Scenario B to the strong bioeconomy scenario and Scenario C to the LOW supply growth scenario. In what follows we describe each of the scenarios, linking them with external drivers (see also table 4.3).

All these scenarios take a food-first approach, that is, in all scenarios, the amount of food and feed produced and consumed in 2050 corresponds to the projected numbers estimated by FAO. However, the increase in demand is being offset by a decrease in food losses (from 30 % to 20 %) and an increase in feed efficiency from 0.4 % p.a. to 0.6 % p.a. As a result, the total amount of food and feed produced and consumed in 2050 is projected to be 10.6 billion t dry matter (see Annexes 3 and 4).

**Scenario A** assumes that the growth in demand for biomass for materials and energy is relatively low. In this scenario, it does not matter so much whether the supply growth is low or high, so here we only assume a medium level of supply growth. We call this scenario **BIO-MODESTY**. The total amount of biomass that can be produced is 18.2 billion tdm. This creates the opportunity to increase the use of biomass for bio-based chemicals and materials from 1.24 bio t to 2.4 bio t, while the amount that can be used for biofuels may increase to 1.0 bio t.

Scenario B and C assume that growth in demand for biomass for materials and energy is relatively high. We distinguish between two situations: one in which biomass supply growth is relatively high (scenario B — BIO-BOOM) and one in which biomass supply growth is relatively low (scenario C — BIO-SCARCITY).

In **Scenario B**, the total amount of biomass that can be produced in 2050 is 23.9 bio tonnes. This amount of biomass allows the use of biomass for bio-based materials and chemicals, bioenergy and biofuels to increase even more than in scenario A: 5.7 bio t, 4.3 bio t and 3.5 bio t respectively. We therefore call this the **BIO-BOOM** scenario—a scenario in which a high demand for biomass coming from the non-food bio-based economy is met by supply.

In **Scenario C**, we assume that the same driving forces leading to high demand for biomass to be used for non-food applications apply. However, the total amount of biomass that can be produced in 2050 is only 13 bio t. As a result, when taking a food-first approach, the amount of biomass available for bio-based materials and chemicals and bio-energy is lower than it is now (and even 0 for biofuels). However, when the food-first rule cannot be enforced, high demand will increase prices for biomass considerably, as biomass is a scarce commodity. We thus call this scenario **BIO-SCARCITY**.

### Table 4.3: Biomass supply and demand of the world 2011 and 2050 in different scenarios (Piotrowski et al. 2015, no final data), Billion t dry matter

| Sector | Status 2011 | SCENARIO A: BIO-MODESTY | SCENARIO B: BIO-BOOM | SCENARIO C: BIO-SCARCITY |
|---|---|---|---|---|
| **Food** | 1.75 | 2.2 | 2.2 | 2.2 |
| **Feed** | 7.06 | 8.3 | 8.3 | 8.3 |
| **Bio-based chemicals and materials** | 1.24 | 2.4 | 5.7 | 1.0 |
| **Bioenergy** | 2.98 | 4.3 | 4.2 | 1.5 |
| **Biofuels** | 0.15 | 1.0 | 3.5 | 0 |
| **Total supply of biomass** | **12.18** | **18.2** | **23.9** | **13.0** |
| **Total demand for biomass** | **12.18** | **18.2** | **23.9** | **23.9** |

### *Scenario narratives*

**Scenario A: BIO-MODESTY**

The BIO-MODESTY future is characterised by a low growth in the demand for biomass for materials and energy. In other words, the pressure to use bio-based innovations is relatively low. This could be made possible as a result of one or more of the following circumstances:

- solar, wind and other clean energy technologies take off
- companies boost eco-efficiency
- the implementation of circular economy principles reduces organic waste in a substantial way
- technology development does not make bio-based industries competitive with non-bio-based industries
- a transition in mobility behaviour and reduced transport needs of goods, etc. (e.g., 3D printing takes off) reduces the demand for transportation fuels

Medium biomass supply growth will be made possible by current trends in intensification (see Annexes 3 and 4). However, the same trend will have very different outcomes in relation to policy variables.

**Scenario B: BIO-BOOM**

The BIO-BOOM future entails high growth both of demand and supply. An increase in demand for biomass for energy and materials may be due to one or more of the following circumstances:

- solar and other new technologies are not yet fully developed and deployed, such that biofuels are needed to mitigate greenhouse gas emissions
- technology development makes bio-based industries competitive with non-bio-based industries
- mobility behaviour or the need to transport goods does not change increasing the demand for transportation fuels

At the same time, supply follows demand. Circumstances that may lead to this future are:

- breakthrough innovations occur meeting less resistance in society, for instance, by tapping into new sources of biomass (e.g., marine, insects);
- development of African agriculture takes off, as a result of relative political stability.

Prices remain stable, but the pressure on the environment remains high. This is a future with more cross-continent collaboration, resulting in a relatively stable investment environment.

**Scenario C: BIO-SCARCITY**

The BIO-SCARCITY future is characterised by a high growth demand for biomass for materials and energy, but supply cannot follow demand. The same factors increasing demand for biomass apply as in the BIO-BOOM scenario, but low biomass supply growth may be the result of a lack of innovations breaking through. This may be because of lack of investment or because of opposition in society. In addition, the negative consequences of climate change and resource degradation are influencing production.

In this future the competition for biomass is great, leading to more land grabbing and high prices for agricultural commodities. As a result, geopolitical tensions increase even more. Governments are under pressure to regulate biomass markets, to keep food prices low.

## 2.4.4. Implications

In the third workshop, stakeholders explored the three scenarios and investigated the implications of these scenarios for food and nutrition security, environmental quality and socio-economic well-being. They further explored what would be the research needs specific to each scenario. In this way, no-regret strategies can be defined. These are issues that are common in the three scenarios. Strategies that are specific to one scenario are less attractive, because of the uncertainty of that future occurring. In what follows, we list the various implications and research needs by stakeholders, and we conclude by identifying common and specific issues that will be further translated into recommendations in Chapter 2.5.

The BIO-BOOM scenario pushes primary production systems to their limits. New opportunities are created with new areas of primary production (e.g., artificial photosynthesis) resulting in new types of industrial farming and infrastructure as well as new types of resources, products, materials, etc. It is expected that large-scale primary producers and landowners will benefit as also will big harbour areas that are hotspots for the bioeconomy because of their role in international flows of bio-based resources and products. However, pushing the system raises concerns as to whether environmental boundaries related to P, N, biodiversity and water can be respected. For fisheries, the harvesting level is set by Maximum Sustainable Yield (MSY) levels — a function of wild fish biology and environmental constraints. Hence, the scope for increasing production from existing fisheries is very limited. Large-scale systems based on monocultures may be more vulnerable to climate change, but also to epidemics and zoonoses. A high degree of regional differentiation is expected (see e.g. harbour areas). It is also not clear what would be the impact on small-scale producers and on peripheral and water-scarce regions.

Research needed to tackle the potential negative consequences of the BIO-BOOM scenario relates to

- the development of new types of plants, animals and production systems (e.g., algae, insects, new cropping systems)
- information systems, traceability, logistics, communication between primary producer and biomass transformers
- sustainable packaging
- nutrient cycles to keep soil organic matter high, such as alternative fertilisers, rural-urban cycles, impact of stump/crown removal, etc.
- how technologies, policies and business models can be developed to include also small-scale and diverse production systems
- the role of skilled and unskilled labour
- risk management strategies to deal with increased pressure on ecological and social systems
- the impact on rural areas, culture and heritage
- governance and political decision-making to ensure an inclusive bioeconomy

In the BIO-SCARCITY scenarios, competition for biomass is the highest. High prices are positive for primary producers (and for ensuring the continuation of farming, forestry, fishing). However, whether effects will be beneficial for primary producers will depend on where they are located. Regional differences can be large, with different impacts in different regions. There is a high risk of overexploitation of soils, forests and marine ecosystems. Biomass quality needs to be high, have a longer lifetime and by-products will become increasingly important. Food security is a major concern.

Research needed to tackle the potential negative consequences of the BIO-SCARCITY scenario relates to:

- the development of multifunctional use of biomass, including products that do not require harvesting of the whole plant/tree, how to slow down aging of biomaterial in order to increase life cycle, cascade utilisation, etc.;
- breeding more resource efficient plants and animals;
- neglected crops;
- increase overall efficiency and quality (management approach, precision agriculture, transformation technology, high degree of co-productions, resource efficient consumption/living;
- industrial photosynthesis, artificial leaves;
- products based on multiple feedstock in order to eliminate the constant quality; problem of biomass;
- using waste and by-products more efficiently, integrated bio-refineries
- keeping soil organic matter to a sustainable level while fostering recycling in forest soils;
- linking research to society, involve different stakeholders (decision on research (topics) not only by scientists, different way of evaluation);
- better adaptation to climate change;
- research innovation for Africa and Asia to help develop their own bioeconomy;
- urban agriculture;
- territorial approach on land use, how to make a multifunctional landscape more sustainable;
- research into how society can be reorganised to save biomass; e.g., research into a more sustainable way of living, lower demand for biomass, social innovation;
- policy development and governance of the bioeconomy to ensure a food first approach, sustainability, etc.

The BIO-MODESTY scenario most closely resembles the current situation of the primary sectors and the bioeconomy. It takes an intermediate position between the BIO-SCARCITY and the BIO-BOOM scenarios.

To conclude, similar research topics appear in all scenarios, but their relative importance differs across the scenarios. For example, governance needs to make sure that a proper implementation of the bioeconomy strategy is inclusive with respect to small-scale and diverse systems, while in the BIO-SCARCITY scenario the focus of governance research is much more on mitigating the negative side effects of competition for biomass. Climate change research is much more pressing in the BIO-SCARCITY scenario. Employment issues appear in all scenarios.

# 2.5. Recommendations

## 2.5.1. Introduction

The purpose of this report is to identify emerging research questions and to anticipate future innovation challenges resulting from potential weaknesses and opportunities following the implementation of the EU's Bioeconomy Strategy. To do this, it has explored the conditions leading to a sustainable bioeconomy (Chapter 2.2), it has summarised the state of play in the various sectors of the bioeconomy (Chapter 2.3) and it has explored the implications of several future scenarios related to the development of the bioeconomy (Chapter 2.4). Our recommendations result from all these analyses.

The aim of the report is not to formulate a full research and innovation programme, but rather to highlight new insights following the exploration of what the bioeconomy may mean for agriculture, forestry and fisheries and aquaculture. Hence, it is useful to repeat the main messages of the Third Foresight Exercise that was published in 2011 (see box) in order to see whether these messages are still valid or even have to be reinforced.

The recommendations are structured in three sections:

- *Principles* that underpin a sustainable bioeconomy and that also should underpin research and innovation towards a sustainable bioeconomy, are discussed in section 5.2. These are cross-cutting issues that all research themes related to the bioeconomy should address.
- *Emerging themes* for the research and innovation agenda are discussed in section 5.3. In this foresight exercise it is clear that the scope of research and innovation is broadened significantly, which will not only influence what themes should be programmed, but also how research themes should be addressed.
- *Organisational principles* guiding how research and innovation systems should operate and should be structured are discussed in section 5.4. These principles may form the basis for a new research and innovation policy underpinning a sustainable bioeconomy.

Main messages of SCAR's Third Foresight Exercises (EC, 2011c)

1. The increasing scarcity of natural resources and destabilisation of environmental systems represents a real threat not only to future food supplies, but also to global stability and prosperity, as it can aggravate poverty, disturb international trade, finance and investment and destabilise governments.

2. Many of today´s food production systems compromise the capacity of the earth to produce food in the future. Globally, and in many regions including Europe, food production is exceeding environmental limits or is close to doing so.

3. Drastic change is needed in regard to both food demand and supply. In an era of scarcity, the imperative is to address production and consumption jointly in order to introduce the necessary feedbacks among them and to decouple food production from resource use. The narrative of "sufficiency" opens opportunities for transition into sustainable and equitable food systems by a systemic approach that deals with the complex interactions of the challenges founded on a better understanding of socio-ecological systems.

4. The average Western diet with high intakes of meat, fat and sugar is a risk for individual health, social systems and the environmental life support systems;

5. Coherence between food, energy, environmental and health policies is needed with a new quality of governance based on a substantial contribution by the state and civil society and supported by social science research.

6. Diversity and coordination are key for increased efficiency and resilience of the future agro-food systems. This diversity has to be maintained or diversification must be fostered, between different regions and farming systems. Diversity in research directions will keep all options open for reacting to surprises.

7. Research, innovation and agricultural knowledge systems must be fundamentally reorganised to speed up transitions, tighten and actively integrate: (1) multiple disciplines, (2) research, innovation and communication, (3) farmers, food retail, technology, industry and agricultural research, and organise research and innovation as learning processes.

8. Make Europe a world leader in efficiency and resilience research of food consumption and production. Ensure public research, in particular to guarantee a better understanding of the underlying processes of ecosystem services and the interactions among the scarcities.

9. Sufficiency-oriented research, innovation and communication must become the priority. Explore new opportunities and ecological approaches to boost research and innovation on efficiency in resource use in agricultural production, including new farming systems that balance the three dimensions of sustainability, and food processing (including cascading uses) and waste reduction. Address consumer behaviour and supply chain strategies in favour of healthy sustainable diets that save food and feed resources and can help curb the increase in global food demand.

10. A radical change in food consumption and production in Europe is unavoidable to meet the challenges of scarcities and to make the European agro-food system more resilient in times of increasing instability and surprise. Now, the agro-food sector has an opportunity to positively take the challenge and be the first to win the world market for how to sustainably produce healthy food in a world of scarcities and uncertainty.

## 2.5.2. Principles

In order for the bioeconomy to achieve its multiple goals of food security, environmental care, energy independence, climate change mitigation and adaptation and employment creation, it needs to be implemented according to a set of principles. In Chapter 2.2, we started by discussing four principles—food first, sustainable yields, cascading approach and circularity. We repeat these principles here, but following the workshops we have added the principle of diversity.

*1. Food first*

In a food-first approach to the bioeconomy, attention will be focused on how to improve availability, access and utilisation of food for all in a global view. Applying this principle entails appropriate governance tools. Relevant policies, such as agriculture, food, environment, health, energy, trade and foreign investments should be checked through a food security test, and direct and indirect impact assessment should become common currency.

*2. Sustainable yields*

Users should consider the renewable nature of biomass production and apply economic rules that govern their exploitation, such as the sustainable yield approach that prescribes that the amount harvested should not be larger than the regrowth possible before the next harvest. For example, MSY is an important function for deciding on harvesting level in fisheries. This should be regarded from a holistic view, which takes all biomass into account, including that in the soil. An important indicator here is soil fertility, including the amount of organic matter and microorganisms in the soil.

*3. Cascading approach*

To avoid potentially unsustainable use of biomass, the concept of cascading use of biomass should be followed to ensure that biomass is first used for the option with the highest 'value', then for the second highest, and so on. Cascading use of biomass (i.e., first material use and only then energy use) contributes to the rational utilisation of biomass as a natural resource, since material use in bio-based products comes before a raw material is 'lost' through burning. Therefore, the cascading use of biomass increases the resource efficiency and the total availability of biomass. This needs to be tackled at a global level.

*4. Circularity*

The cascading approach, based on the principle that any matter can be reused or recycled, addresses the dilemma of best use of biomass, but it does not address the issue of waste reduction *per se*. A circular economy implies designing durable products maximising recycling and reuse and minimising waste.

*5. Diversity*

Production systems are diverse, using context-specific practices at different scales and producing a diversity of outputs. As polycultures and diversity are both key to resilience, innovations in the bioeconomy should be developed to foster polycultures rather than limit them.

### 2.5.3. Research themes and scope

*Scope*

The Scientific Steering Committee of Expo 2015 identified seven research themes to support global food and nutrition security: (1) improving public health through nutrition, (2) increasing food safety and quality, (3) reducing losses and waste, (4) managing the land for all ecosystem services, (5) increasing agricultural production sustainably, (6) understanding food markets in an increasingly globalised food system, and (7) increasing equity in the food chain. These themes are in line with the current Horizon 2020 programme as well as most national programmes. However, the Bioeconomy Strategy as well as the ongoing paradigm shift towards a much broader innovation space made up of continuous improvements, problem-solving adaptations, tailored solutions etc. (Esposti 2012; see also Section 5.4) ask for broadening the scope both horizontally and vertically.

The horizontal broadening of the scope refers to the need to simultaneously consider all sources of biological resources used for food, feed, chemicals, materials and fuel: agriculture, forestry, aquaculture and marine resources. The reason is that technological advances have made it possible to transform all types of biological resources into all types of uses. Technologically, it is possible to make fuel out of food, food out of wood, chemicals out of organic waste streams, etc. In other words, biological resources or biomass streams are increasingly becoming intertwined, leading to both opportunities and threats. Opportunities mainly mean that, at least technologically, it is possible to use, re-use and recycle all biological resources, thus potentially increasing resource efficiency significantly. Threats refer to the danger that using biological resources for non-food purposes may endanger both food security and the environment when not governed properly.

The vertical broadening of the scope means that increasingly upstream sectors (ecosystems, inputs, machinery) and downstream sectors (processing, retail, consumption) should be integrated into research addressing agriculture, forestry, aquaculture and marine resources. To optimally use and govern the streams of biological resources (both main streams and waste streams) in a circular economy requires a holistic approach that entails the coordination and integration of all actors and activities along the entire supply chain, including the consumer and beyond.

*Themes*

As mentioned earlier, the purpose of this report is not to make proposals that replicate existing research programmes that already cover relevant themes, but to draw attention to emerging research themes that, based on our analyses, may currently be receiving insufficient attention. These themes refer both to technological areas and to the non-technological aspects of the bioeconomy, as well as to the main challenges to be tackled by the bioeconomy, including food security, climate change, natural resource management resource dependency and growth and employment.

1. New production paradigms for primary production based on ecological intensification

Ecological intensification entails increasing primary production by making use of the regulating functions of nature. Its practices range from the substitution of industrial inputs by ecosystem services to the landscape-level design of agroecosystems. Research is needed to underpin ecological intensification, to shift from the study of individual species in relation to their environment to the study of groups of organisms or polycultures in relation to each other and their environment (Tittonnel, 2014). More specifically, more insight is needed into the synergetic effects of combinations of ecosystem service processes, as current research mainly addresses how single service processes work in isolation (Bommarco et al., 2013). Functional ecology and community ecology are key scientific disciplines that need to be further developed to support what could be called precision ecology. These disciplines can be strengthened by recent advances in digital technologies and approaches both at the molecular level (supported by the various -omics platforms) and at the landscape level. Research is also needed on new species or organisms, their cultivation (e.g., aquaculture) and potential interactions with ecosystems and wild relatives or species, and how the outputs of multifunctional systems can be exploited in the best way.

2. Emerging enabling technologies: the digital revolution

The digital revolution refers to the rapid advances in Information and Communication Technologies. Sensor technology, remote sensing, etc. contributing to precision techniques in the primary sectors have great potential to improve resource efficiency. However, combined with other advances in technologies (e.g., factories of the future, mechatronics, photonics, robotics, additive manufacturing), the digital revolution fundamentally transforms the way science operates, as well as manufacturing, retail and even consumption (see e.g., Poppe et al., 2013). These developments will have far-reaching effects on the bioeconomy as a whole. Research should further investigate how the digital revolution will affect primary production and their food and non-food supply chains, and how these developments can help sectors address the diversity of production systems and their outputs (food, feed, fibre, fuel) with different qualities thus contributing to the realisation of a circular economy.

3. Resilience for a sustainable bioeconomy

A resilient bioeconomy encompasses systems that are able to deal with different types of hazards. Hazards can be both the result of immediate shocks (e.g., temperature peak) and the result of long-term changes in important driving forces (e.g., increase in ambient $CO_2$ concentration). The bioeconomy and particularly the circular economy entail an increased coordination and integration of different sub-sectors. Combined with the increasing pressures from various driving forces, such as climate change and economic globalisation, this may have significant effects on animal, plant and human health hazards as well as on adaptation and risk reduction strategies tackling these hazards. Research should investigate the impact of the bioeconomy on resilience, but should also develop new solutions and systems that are more resilient, from a biological and technological point of view as well as a social perspective. Research should also explore how changes in consumption could create opportunities for the bioeconomy.

4. The new energy landscape

The transition to a new energy landscape involves abandoning fossil fuel-based technologies in favour of renewable electricity and heat generation technologies. This will have an enormous impact on primary production that currently still heavily depends on fossil fuels, particularly the production of inputs, such as fertilisers and pesticides. The extent to which organic matter will be solicited for non-food purposes will depend on the speed with which renewable energy will develop. Fast development of low-cost renewable technologies will reduce the pressure to use organic matter for energy generation, such that it can be used for high value applications such as food and bio-based materials and chemicals. Research should investigate how this transition affects agriculture, forestry, aquaculture and marine resources, identify the needs of these sectors related to these changes and develop appropriate solutions.

5. Business and policy models for the bioeconomy

A bioeconomy that is based on the concepts of circularity and cascading presents a particular challenge to making the economics work. Circularity implies new ways of designing and manufacturing products, new relationships between economic actors, new ways of recycling components and waste, etc. In other words, actors and activities will be reassembled in time and in space. In addition, different production models in terms of scope and size should not only be able to co-exist, but also capture the synergies between them. Public sector involvement is needed for these new business models to work, as public goods are generated in the circular economy but often not remunerated by the market. Research should support the development of these business models.

6. Socio-cultural dimensions of the bioeconomy

Sustainable bioeconomy governance implies that knowledge about social impacts of technology and mechanisms of social change should progress as fast as technology itself. All actors and stakeholders (primary producers, processors, consumers, citizens, etc.) should be fully involved in the governance of the bioeconomy. Science may also radically change food production and consumption patterns, with the potential to reduce pressure on ecosystems, through changes in diet, the multifunctional use of land and aquatic resources, urban-rural nutrient cycles and the production of alternative proteins for animal feed and human consumption. However, this may break established routines and create resistance and anxieties, which need to be understood better. In addition, these approaches have legal implications that need to be understood and addressed by research.

7. Governance and the political economy of the bioeconomy

The outcomes of the development of the bioeconomy through the implementation of a circular economy will depend on the rules put in place to regulate the system. The development of bio-based materials and bio-energy may create pressure on natural resources and on social inequalities in a scarcity-dominated world. Moreover, the bioeconomy is more than a set of bio-based activities. It involves both positive and negative externalities influencing the future of the biosphere and the ways in which societies will use it. So bioeconomy governance is critical. Research should help develop a framework aimed at fostering the bioeconomy; it should consist of policies and sustainability and safety standards that are coherent, create a level playing field, generate employment, avoid the overexploitation of natural resources and foster a diversity of practices with small environmental impacts.

8. Foresight for the biosphere

Current foresight is mostly using forecast-based modelling platforms, with comparative-static approaches and within a limited set of structural features. Currently, efforts are being made to expand these platforms into the non-food dimensions of the bioeconomy (see M'Barek et al., 2014, for an overview). However, research should also expand foresight capacity by integrating data and dynamic and flexible tools, in order to avoid lock-ins and monitor the sustainability and resilience of the bioeconomy and the biosphere as a whole.

### 2.5.4. Knowledge and innovation systems

Research and innovation are built upon a *knowledge and innovation system* that develops and diffuses knowledge, inspires and identifies opportunities, mobilises resources, helps manage risks and forms markets, legitimises activities and develops positive externalities (Bergek et al., 2010, quoted in EU SCAR, 2012). Over recent years, the European Commission has taken several initiatives to strengthen knowledge and innovation systems, such as the Europe 2020 strategy, that includes the Innovation Union and the European Innovation Partnerships. These initiatives support the transition towards a system in which knowledge is co-produced by all actors that engage with each other in processes of learning and even co-evolution (EU SCAR, 2012). The Scientific Steering Committee of Expo 2015 identified five cross-cutting structural issues that reinforce this vision (1) stimulating foresight and futures' research; (2) stimulating interdisciplinary and strategic research and action; (3) investing in aligning research; (4) transferring knowledge into innovation and practice; and (5) investing in education and communication to the public.

Following the first and the second SCAR Foresight Exercises, the AKIS report was inspired by the concept of 'Mode 2' science, introduced by Gibbons et al. (1994) in their seminal work *The New Production of Knowledge: The Dynamics of Science and Research in Contemporary Societies*. When revisiting the concept a decade later, they argued that:

> *The old paradigm of scientific discovery ('Mode 1') — characterized by the hegemony of theoretical or, at any rate, experimental science; by an internally-driven taxonomy of disciplines; and by the autonomy of scientists and their host institutions, the universities — was being superseded by a new paradigm of knowledge production ('Mode 2'), which was socially distributed, application-oriented, trans-disciplinary, and subject to multiple accountabilities (Nowotny et al., 2003, p. 179).*

This resonates strongly with the interactive innovation model implemented in the European Innovation Partnership 'Agricultural Productivity and Sustainability' (EIP-AGRI).

In formulating recommendations for a new knowledge and innovation system that supports the implementation of the Bioeconomy Strategy, we build upon the five characteristics suggested by Nowotny et al. (2003) that should shape a Knowledge and Innovation System (KIS) for the bioeconomy (KIS) ([7]) and we add a sixth one that refers to the skills and capacities in the KIS that are needed to implement the other characteristics.

#### *Challenge-oriented*

Rather than only being driven by scientific curiosity, the KIS should also be challenged-oriented ([8]). The KIS should find a right balance between basic and applied research. Orientation is currently provided by the Europe 2020 strategy and more specifically the Grand Challenges for the bioeconomy which are to ensure food security, manage resources sustainably, reduce dependence on non-renewable resources, mitigate and adapt to climate change and create jobs and maintain competitiveness (see Chapter 2.2). These are translated into national research programmes and European research programmes, such as Horizon 2020, the FACCE Joint Programming In-

([7]) Esposti (2012) calls it the Knowledge and Innovation System for Bioeconomy (KISB).

([8]) We prefer to use the word challenge to the word application that was used by Nowotny et al. (2003).

itiative and several ERA-nets. These challenges provide a framework for research and innovation. Tackling these challenges requires the development of innovative solutions and applications but also knowledge that supports the use of these solutions and applications by society.

### *Trans-disciplinary*

The KIS should be trans-disciplinary, that is, multiple theoretical perspectives and practical methodologies should be used to tackle challenges. Trans-disciplinarity goes beyond interdisciplinarity as it transcends pre-existing disciplines (Nowotny et al., 2003). Creswell (2013), among others, refers to pragmatism as an emerging scientific worldview that integrates qualitative and quantitative approaches and focuses on 'what works'. However, pragmatism does not mean, for instance, using the humanities and social sciences only to ease the adoption of innovations that are meeting with resistance in society. Rather, the humanities and social sciences should help in acknowledging and respecting the multiple values inherent in society (see section 2.2.2 in Chapter 2.2).

### *Socially distributed*

Knowledge should be diverse and socially distributed in the KIS. Communication barriers have been largely lifted, such that knowledge is created in diverse forms, in diverse places and by diverse actors. However, at the same time a lot of barriers still exist and hamper co-creation of solutions. Knowledge is increasingly being protected by intellectual property rights, which hinder the inclusive and public-good character of knowledge (Nowotny et al., 2003). We recommend open access and open innovation to guide knowledge production as much as possible. A second barrier is the lack, or non-inclusion, of knowledge on costs and cost structures in production systems. Cost issues greatly influence uptake of new knowledge and its application potential, but information on costs is often protected or withheld. Particular attention should be devoted to social innovation and the inclusion of socially disadvantaged actors and regions.

### *Reflexive*

Rather than an 'objective' investigation of the natural and social world, research has become a process of dialogue among all the actors involved, following its application-oriented, trans-disciplinary and socially distributed nature. As a result, new knowledge emerges in a process of co-creation between researchers and other actors and its consequences are an integral part of the research process (Nowotny et al., 2003). The KIS should devote sufficient attention to these reflexive processes, both within the boundaries of a research project and at the meta-level of organising and programming research. Current efforts of stakeholder engagement in projects and in programming are steps in the right direction. Examples include the stakeholder consultation of Horizon 2020 and the EU rural networks (ENRD and EIP-AGRI).

### *New rewarding and assessment systems*

Quality control transcends the classical peer review as trans-disciplinarity makes old taxonomies irrelevant. In addition, the integration of different actors (brokers, extensionists, users, etc.) also broadens the concept of quality into multiple definitions of qualities (Nowotny et al., 2003). As a result, assessment/rewarding systems relating to researchers (impacting their careers), research projects and programmes (assessing impacts), research institutes/bodies (their outputs, but also including for instance efficiency of the organisation as regards their systematic and purposeful networking with stakeholders and actors), other actors (non-researchers' contribution to solutions), education (teaching students how to co-create solutions in projects), and even the organisation of regional/national/international KIS (policies and funding) need to change. This makes the research and innovation process more uncertain from a traditional perspective on research.

### *Competencies and capacities*

Taking a pragmatic, solution-oriented approach in a trans-disciplinary and reflexive way and being accountable to different constituencies requires a new set of skills and competencies that researchers, other actors as well as other stakeholders in the KIS need to acquire. These new skills and competencies imply important challenges for all actors and stakeholders in the KIS. Institutions of higher education in particular can play a key role by integrating these skills and competencies into their curricula. In addition, trans-disciplinarity requires diverse disciplines to contribute to the research process. However, many disciplines have been reduced or have even disappeared. Finally, the capacity to engage in KIS not only depends on the aforementioned competencies, but also on resources that need to be invested by actors and stakeholders.

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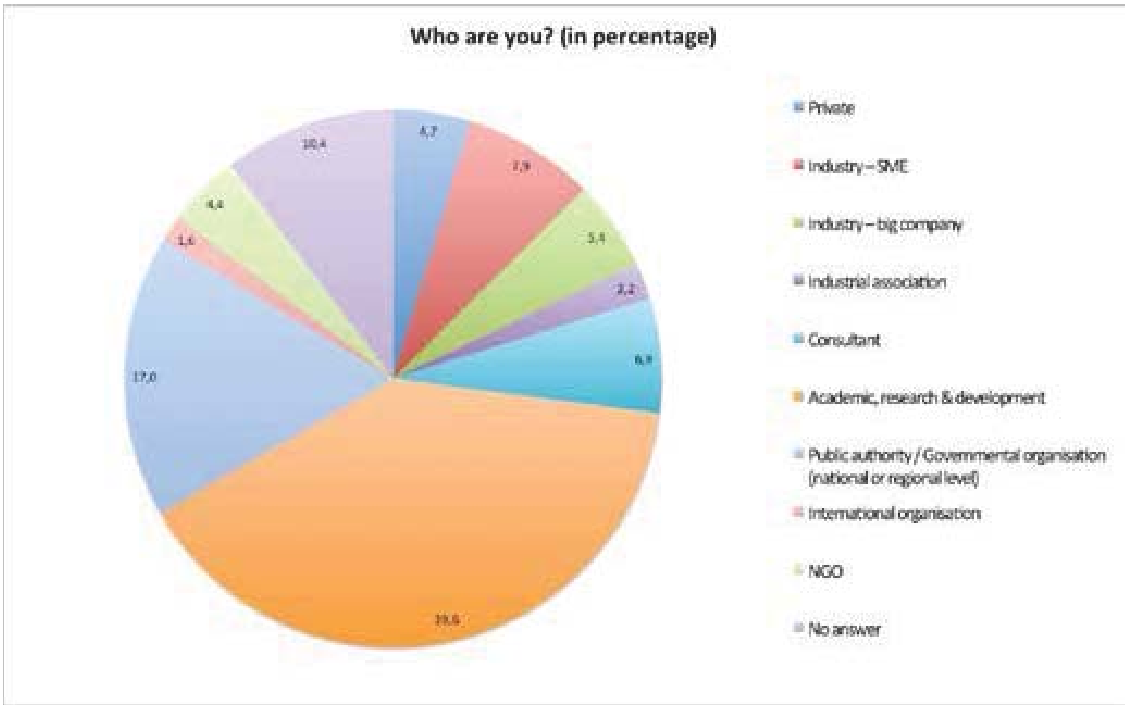
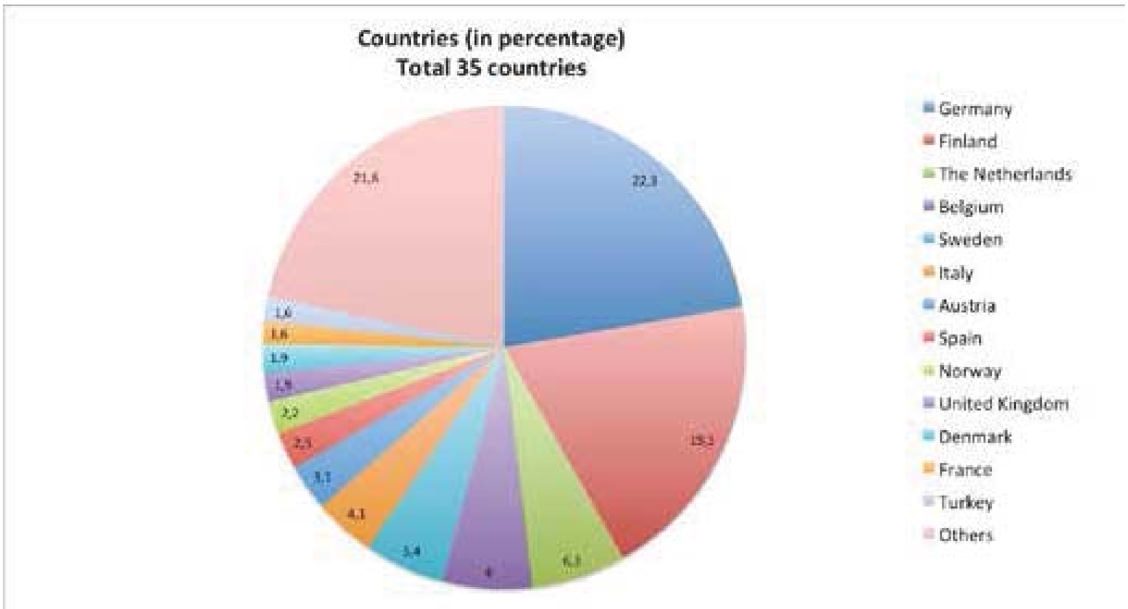
# Annex 1: Survey results

An online questionnaire was sent to about 60,000 experts. The total number of respondents between 7 October and 7 November 2014 was 435. Out of these 435, 221 questionnaires were complete and 214 questionnaires were completed partially.



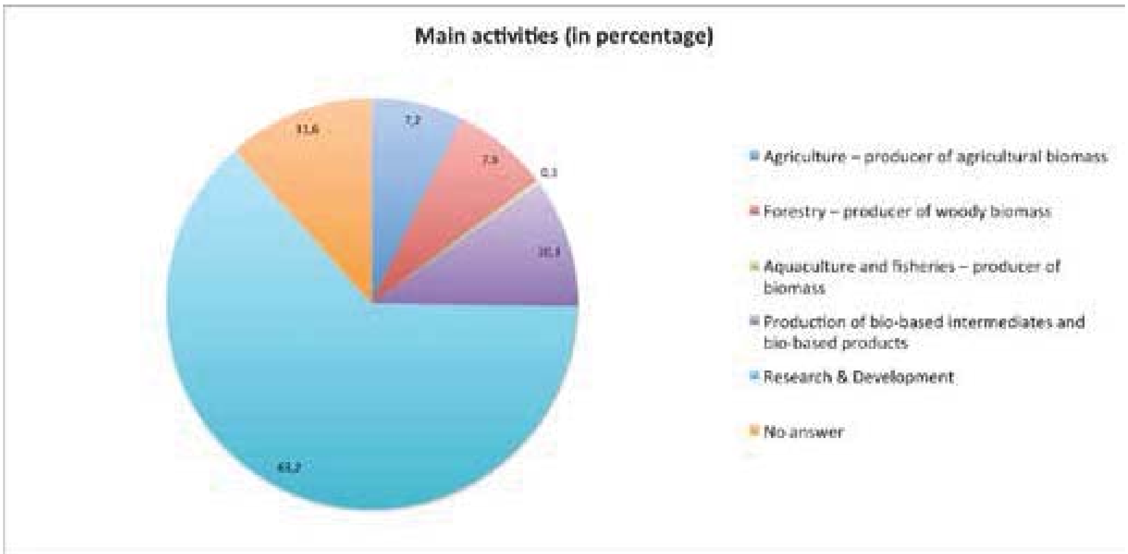

**Comments**:

- High percentage 'Academia, research and development'
- 'Public authority, governmental organisation'
- Private means 'private person'



**Comments**:

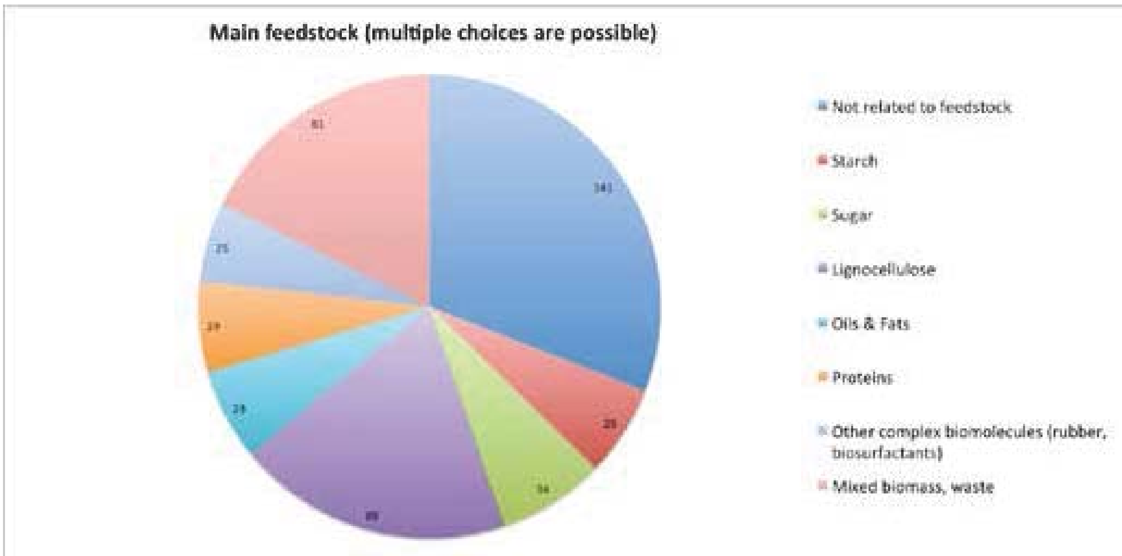
- Relatively high share for Finland (and Sweden, Norway and Denmark)
- Relatively low share for France.
- Participants from 35 countries incl. non-European countries




**Comments**:

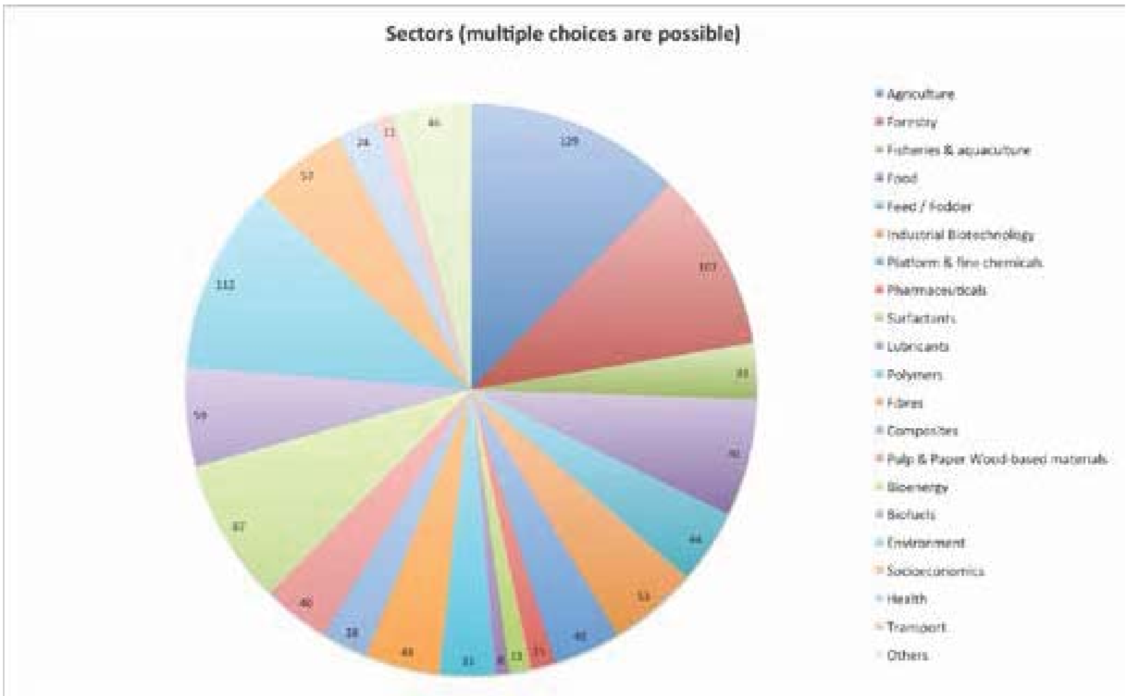
- But the share of 'Research & Development' is very high at 63 % — this includes R & D both in academia and in industry.
- Shares of 'Agriculture', 'Forestry' and 'Production of bio-based intermediates and products' are evenly distributed.

**Your main biomass feedstock (multiple choices possible)**




**Comments**:

- High share of 'Lignocellulose' because of the high share of Scandinavian countries.
- The high share of 'Mixed biomass, waste' is linked to the high share of 'Academia, research & development' and 'Public authority, governmental organisation'.




**Comments**:

- All sectors of the bio-based economy are covered well.
- Participation was highest for the 'Environment' sector.

## Rate on a scale from 1 (unimportant) to 10 (very important) to what extent you consider the following dilemma to be important

| Consider the following dilemma to be important | All | All except academia (159) | Only Industry (49) |
|---|---|---|---|
| Economy vs. ecology | 7.7 | 7.7 | 7.1 |
| Production efficiency vs. Biodiversity | 7.4 | 7.3 | 6.5 |
| Centralised, large and global vs. decentralised, small and local | 7.1 | 7.1 | 6.6 |
| Economic vs. social policy objectives | 7.0 | 7.2 | 6.6 |
| Food vs. fuel | 6.8 | 6.8 | 6.2 |
| Food vs. feed (meat production) | 6.4 | 6.7 | 6.3 |

**Comments**:

- The differences between 'All' and 'All except academia' are small.
- 'All except academia': Ranking of 'Economic vs. social policy objectives' is higher than it is compared to 'All'.
- 'Industry representatives' (SME, big companies and industrial associations) show a lower overall rating (dilemmas are overall seen as less important), but the differences in ranking compared to 'All' are small.

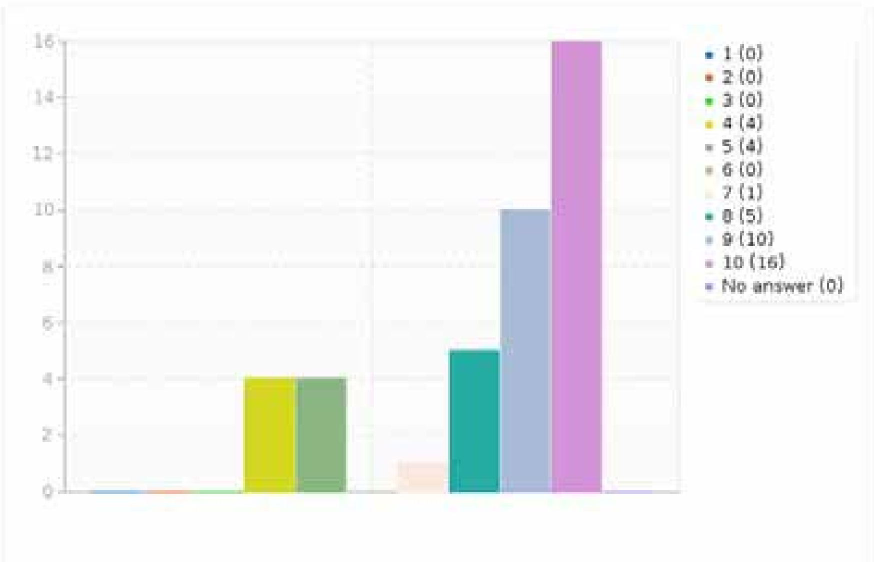
## Rate on a scale from 1 (unimportant) to 10 (very important) to what extent you consider the following problems to be a constraint

| Problems to be a constraint | All | All except academia (159) | Only Industry (49) |
|---|---|---|---|
| Non-coherent policy | 7.9 | 8.2 | 8.3 |
| Increasing scarcity of clean freshwater | 7.5 | 7.3 | 6.9 |
| Increasing degradation of soils | 7.4 | 7.6 | 7.0 |
| Decline in biodiversity | 7.3 | 7.4 | 6.9 |
| Land and water grabbing | 7.0 | 7.2 | 7.1 |
| No level playing field for material use and bioenergy | 6.9 | 7.2 | 7.8 |
| Government investment | 6.4 | 6.5 | 6.3 |
| Phosphorus (as fertiliser) scarcity | 6.3 | 6.5 | 5.9 |
| Sustainability certification of bio-based feedstock | 6.1 | 6.2 | 6.6 |
| Trade barriers | 5.7 | 5.9 | 6.5 |

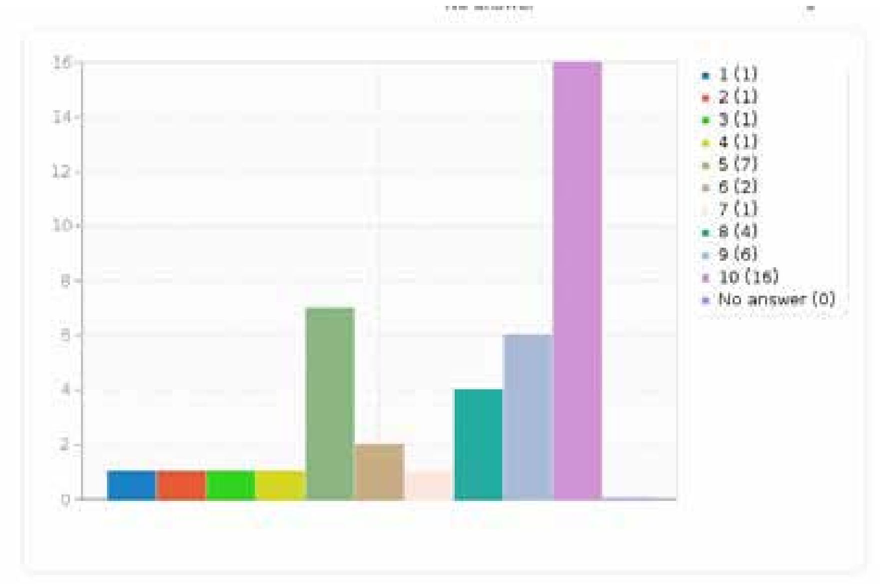
**Comments**:

- The differences between 'All' and 'All except academia' are small.
- '**All except academia**': In general higher rating than 'All', especially for 'non-coherent policy' and 'no level-playing field for material use and bioenergy'.
- '**All except academia**': Ranking of 'freshwater', 'degradation' and 'biodiversity' a little different compared to 'All'.
- '**Industry representatives**' (SME, big companies and industrial associations) show a different ranking than academia, public authorities and NGOs (main differences in red):
  - 'No level playing field for material use and bioenergy' is second place in importance (for 'All' it is number 6); behind 'No-coherent policy'.
  - Soil, water and biodiversity show lower rating.
  - Sustainability certification and trade barriers show higher rating.

**Industry ranking on 'no-coherent policy'**



**Industry ranking on ‘no level-playing field for material use and bioenergy’**




**Comments**:

It is interesting that industry sees different problems to that of academia, policy and NGOs:

- The latter focus on impacts and risks (‘freshwater, soil, biodiversity, land and water grabbing’) before the bio-based economy even starts on a big scale;
- While the industry focuses clearly on the fact that under the given circumstances, the bio-based economy will not take off at all (‘non-coherent policy’ and ‘no level playing field’).

For the industry, the political framework (‘non-coherent policy’ and ‘no level playing field’) is clearly a bigger problem than the research agenda (‘Government investment’).

With a view on these circumstances, some people lament the loss of „innovation culture’ in Europe, more and more observing a ‘culture of concerns’. Risk assessments are the focus of every debate and these are more and more ‘danger assessments’ without being ‘opportunity assessments’. Keeping the balance will be the crucial point: If sustainability requirements are set too high (which seems likely at the moment), developments will stand still. However, requirements need to be a bit higher than those for fuels in order to get environmentalists on-board.

# Annex 2: Employment and turnover in the bioeconomy

The following paragraphs present an estimation of employment and turnover in the European bio-based economy mainly based on available statistical information from Eurostat. Apart from an overall assessment we present a comparison of energy and material uses of biomass based on the same amount of biomass by taking the effects generated by biofuels and the material use of biomass in the chemical industry as an example.

## A2.1. Overall assessment

The following two figures show the total employment and turnover of the bioeconomy in the EU-28 in 2011. These two figures are almost entirely based on available Eurostat data (Eurostat 2013a — d). Most of the sectors can be regarded as fully bio-based (agriculture, forestry and fishery as well as the manufacture of food products, beverages, tobacco products, paper and paper products, forest-based industry and biofuels).

Only for two of the sectors (the textile industry and the chemical and plastics industry) were estimations for the bio-based shares necessary. For the textile industry, we assumed a bio-based share of 40 % which is the share of natural fibres in total world fibre market (The Fiber Year, 2014) and for the chemical industry we assumed a bio-based share of 5 % which is the estimated share of renewable raw materials in total material consumption of the European chemical industry according to the European Chemical Industry Council (CEFIC 2014; Piotrowski et al. al., 2015). These estimates could be further broken down to product level and refined in the future.

**Figure A2.1: Employment in the EU bioeconomy in 2011 (Several Eurostat datasets; Agriculture: Agricultural labour input statistics; Forestry and Fishery: Employment by sex, age and detailed economic activity; Other sectors: Annual detailed enterprise statistics for industry; own estimations)**

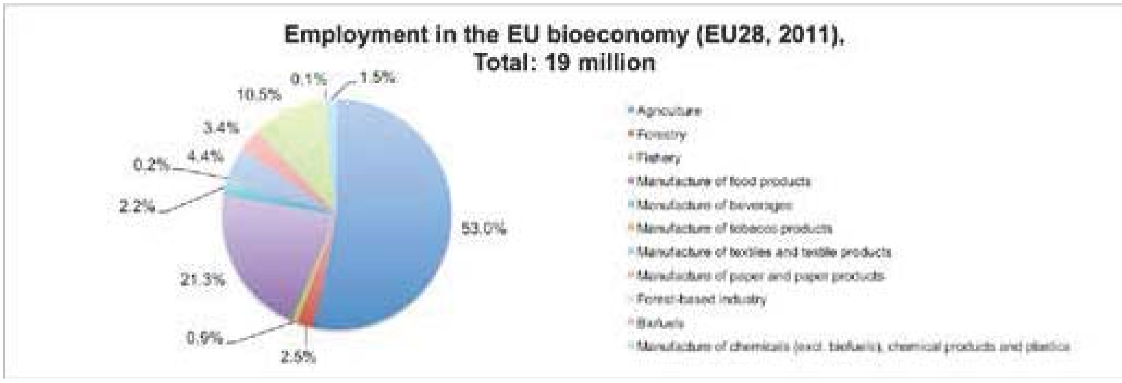
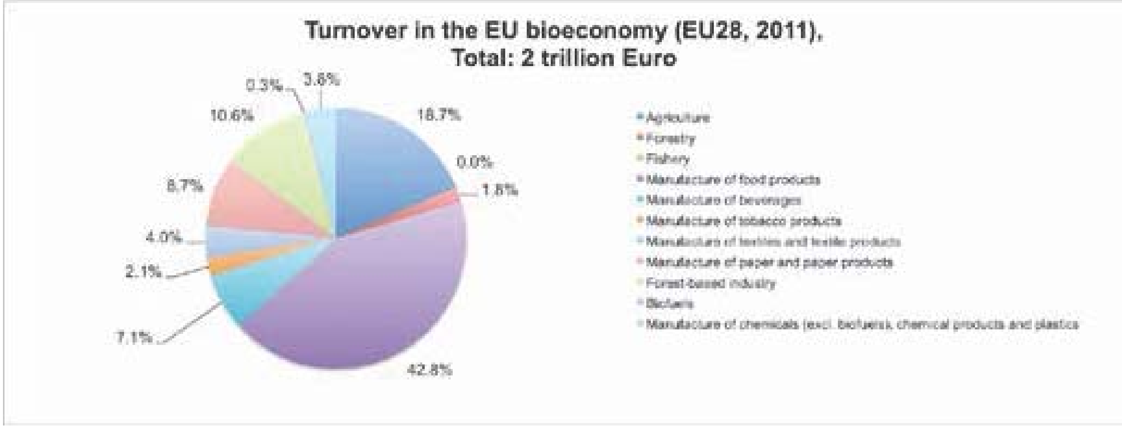
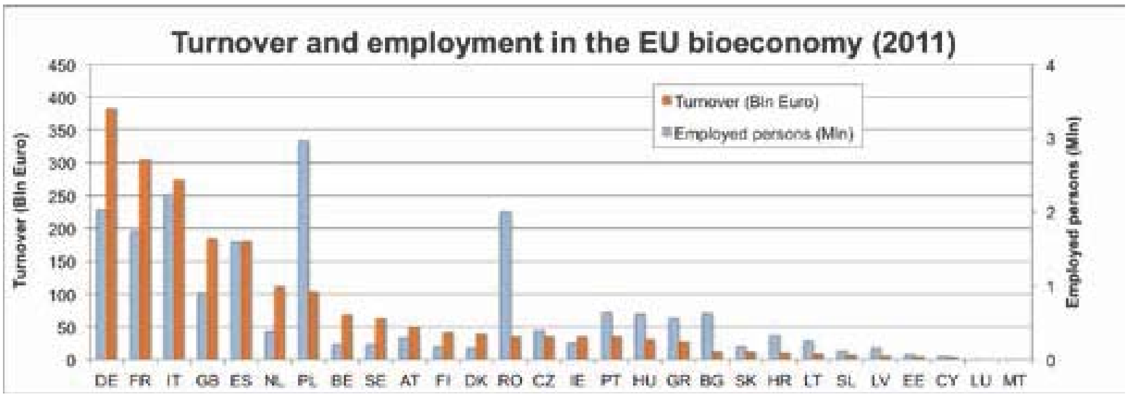


**Figure A2.2: Turnover in the EU bioeconomy in 2011 (Several Eurostat databases; Agriculture: economic accounts for agriculture; Forestry: economic accounts for forestry and logging; Fishery: data missing; Other sectors: annual detailed enterprise statistics for industry; own estimations)**




Turnover and employment in the bioeconomy in all EU-28 Member States can also be compared in one graph (Figure A2.3). Such a comparison highlights the differences between countries with very high turnover in relation to employment (e.g., Germany) and countries with the opposite relation (e.g., Poland, where the agricultural sector generates a lot of employment but comparatively little turnover). Please note, however, that the data for this figure has not been checked very carefully and that this figure therefore should only serve as an illustration.

**Figure A2.3: Turnover in the EU bioeconomy: Overall comparison in all EU-28 Member States (several Eurostat databases; Agriculture: economic accounts for agriculture; Forestry: economic accounts for forestry and logging; Fishery: data missing; Other sectors: annual detailed enterprise statistics for industry; own estimations)**




## A2.2. Comparison between material and energy uses

In this section, we compare the employment and turnover generated by biofuels and material use of biomass in the chemical industry based on the same biomass input. First, we explain in the following paragraphs in more detail how the data for both sectors have been calculated. Note that the bio-energy is not fully included and that there are different indirect effects, which are hard to cover and cause methodological problems.

*Employment in the manufacture of biodiesel*

In Eurostat, statistics on biodiesel can be found in the database PRODCOM under the code 20.59.59.97. The first four digits of this code signify that it belongs to the NACE Class 20.59 'Manufacture of other chemical products n.e.c. (not elsewhere classified)'. According to the Eurostat database Structural

Business Statistics (SBS), the total number of employed persons in NACE Class 20.59 amounts to 134,400 in the EU-28 in 2011. However, this database only presents statistics on Class level, not further broken down to product level. Data on employment in the manufacture of biodiesel can therefore not be directly found in Eurostat. To circumvent this problem, we make the following approximation:

According to PRODCOM, the production value of biodiesel is about EUR 7 billion, which is 14 % of the total production value of NACE Class 20.59 of about EUR 50 billion. Under the assumption that the relation between production value and employment is about the same in the chemical industry, we therefore assumed that also the employment in the manufacture of biodiesel is about 14 % of the total employment in the NACE sector 20.59. This results in an employment of about 19,000.

*Employment in the manufacture of bioethanol*

Ethanol for industrial uses can be found under the PRODCOM code 20.14.75.00 'Denatured ethyl alcohol and other denatured sprits' and code 20.14.74.00 'Undenatured ethyl alcohol'. According to Eurostat (SBS), the total number of employed persons in NACE Class 20.14 'Manufacture of other organic basic chemicals' amounts to 202,600. Like for biodiesel, we approximate the employment in the manufacture of bioethanol:

The sum of the production value of both PRODCOM codes in which ethanol can be found, amounts to about EUR 3 billion in the EU-28 in 2011. The production value of NACE Class 20.14 amounts to about EUR 136 billion. Ethanol therefore has a share of the production value of about 2 %. Again we assumed that also the employment in the manufacture of bioethanol is about 2 % of the total employment in the NACE Class 20.14. This results in an employment of about 4,000.

*Employment in the material use of biomass in the chemical industry*

According to SBS, employment in the manufacture of chemicals and chemical products (NACE Division 20) amounted to 1.2 million in the EU-28 in 2011. We have estimated that the bio-based feedstock used in the EU chemical industry amounts to about 8.56 million tonnes of dry matter (tdm) or about 5 % of its total raw material input in the chemical industry (CEFIC 2014, Piotrowski et al. al. 2015). Roughly, employment due to bio-based chemicals and chemical products could therefore also be considered to amount to 5 % of the total employment, i.e. 60,000.

*Comparison between energy and material use of biomass*

In total, employment for the manufacture of biodiesel and biofuels amounts to about 23,000 (19,000 for biodiesel and 4,000 for bioethanol). We calculated the feedstock demand for EU biofuels to be around 26.8 million tdm (16.5 million tonnes plant oil for biodiesel and 10.3 million tonnes sugar/starch for bioethanol; Piotrowski et al., 2015). The employment in the manufacture of biofuels therefore amounts to about 860 jobs per 1 million tonne of bio-based feedstock.

Given the feedstock input of 8.56 million tdm of biomass for material uses in the chemical industry, the estimated 60,000 jobs are equivalent to about 7,000 jobs per 1 million tonnes of feedstock. We therefore conclude that the material use of biomass in the chemical industry generates about 8 times more employment than the use of biomass for biofuels, based on the same biomass input.

*Employment generated in agriculture*

The assessment so far only considered employment generated in the industrial manufacture of biofuels and chemicals.

According to FADN 2013, the total labour input in Europe needed for the operation of a farm amounts to between 30 h/ha for the cultivation of wheat and 60 h/ha for the cultivation of maize. Converted into full-time equivalents (FTE; 1 FTE = about 2,000 h), this results in 0.015 FTE/ha for wheat and 0.03 FTE/ha for maize. Furthermore, we assume an average feedstock yield of about 2 t/ha and that only about 50 % of feedstock needed for the production of biofuels (26.8 million tonnes) are actually produced in the EU (13.4 million tonnes). This very rough approximation leads to an employment of about 100,000 to 200,000 in the EU for the production of the feedstock needed for European biofuels.

Adding this estimate to the employment in the manufacture of biofuels leads to the conclusion that total employment for biofuels may amount to 123,000 to 223,000. For comparison, Charles et al. 2013 state that the number of EU jobs at biofuels facilities alone amounted to 3,630 in total in 2011 (2,502 for biodiesel and 1,128 for bioethanol) but around 120,000 in total along the whole value chain (50,000 for biodiesel and 70,000 for bioethanol). Given the high uncertainty of both our estimation as well as the one presented by Charles et al. 2013, both results lie in the same range.

Regarding feedstock for material uses in the chemical industry, employment in agriculture would be the same per tonne of feedstock as for biofuels. This results in an employment in agriculture of about 30,000 to 60,000.

## A2.3. Conclusions

Table A2.1 shows the overall comparison of employment for biofuels and chemicals. Where we presented ranges in the above paragraphs, we assume average values here. The last two columns show that employment based on the same amount of biomass input is about 8 times higher for bio-based chemicals compared to biofuels if only the manufacturing stage is taken into account. If additionally the agricultural production is considered, this factor decreases because employment in agriculture per tonne of biomass is the same for both sectors. Still, employment per 1 million tonnes of biomass is about twice as high for chemicals as for biofuels.

**Table A2.1: Overall comparison of employment in EU-28, year 2011**

| | Employment in agriculture | Employment in manufacture | Total employment (agriculture and manufacture) | Bio-based feedstock demand in million tonnes | Employment in manufacture per 1 mln t of bio-based feedstock | Total Employment (agricultural and manufacture) in per 1 mln t of bio-based feedstock |
|---|---|---|---|---|---|---|
| Biofuels | 150,000 | 23,000 | 173,000 | 26.8 | **900** | **6,500** |
| Bio-based chemicals | 45,000 | 60,000 | 105,000 | 8.6 | **7,000** | **12,300** |

Figure A2.5 and A2.5 compare graphically the employment in both sectors. Figure A2.4 highlights that employment in agriculture has a much higher share in biofuels than in bio-based chemicals.

**Figure A2.4: Total employment (agricultural and manufacture) in biofuels and bio-based chemicals in EU-28, year 2011 (Piotrowski et al., 2015)**

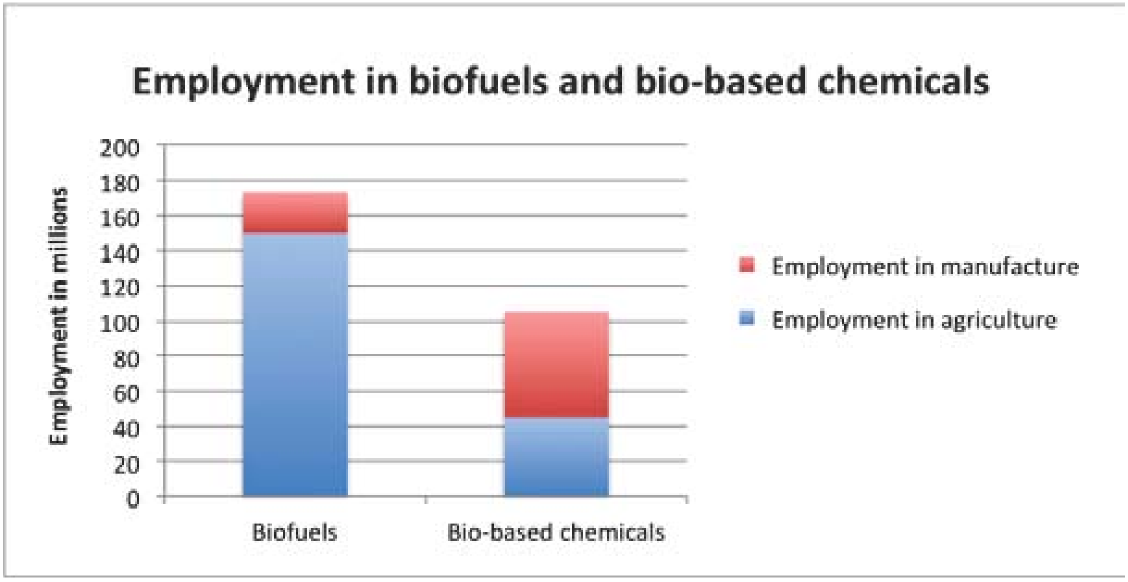
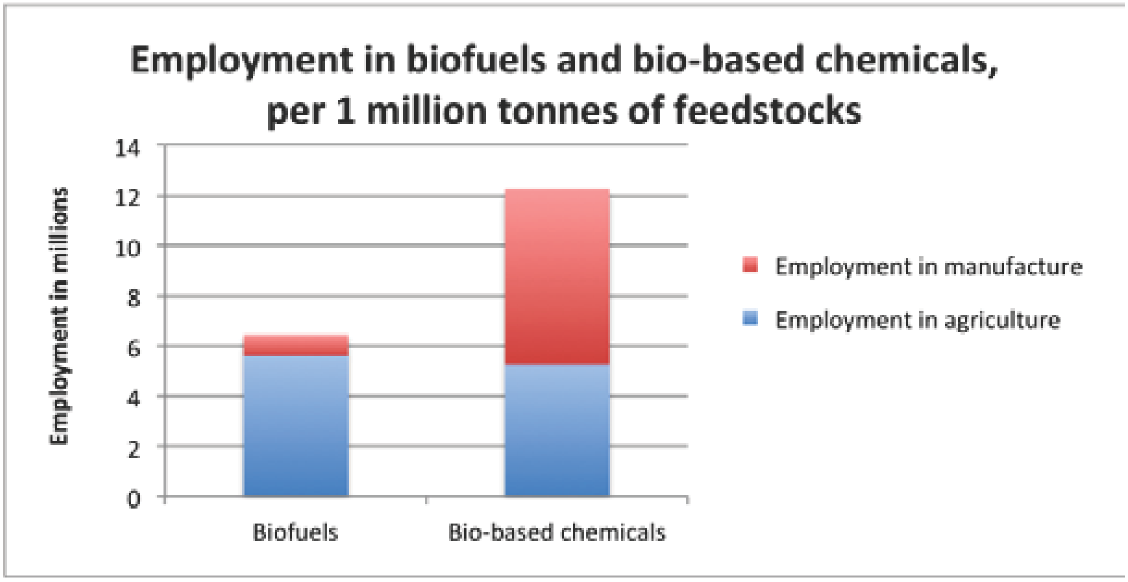


Figure A2.5: Total employment (agricultural and manufacture) in biofuels and bio-based chemicals in EU-28, year 2011 per 1 million tonnes of bio-based feedstock (Piotrowski et al. 2015)



# Annex 3: Raw material and biomass supply and demand of the world — Today and in 2050

The following scenarios are explorative, plausible (based on solid data and assumptions) and consistent. They were mainly developed in Piotrowski et al. (2015) and adapted and expanded for the SCAR exercise. Especially the alternative food and feed scenario and the scenario 'High growth — low pressure' scenario were added to the original scenarios LOW, BAU, Bioeconomy and Strong Bioeconomy.

Except for the alternative food and feed scenario all scenarios share the following assumptions:

- For the food and feed demand we took the same data for all scenarios, see all details about our assumptions in Annex 4.
- For the bio-based economy it seems for us more interesting how material use, bioenergy and biofuel demand will develop. Even in the last scenario with high shares of solar and wind etc. the impacts are mainly on energy, fuels and chemicals and not on food and feed.
- The compound annual growth rate (CAGR) on demand is also the same in all demand scenarios. The main difference is the bio-based share in the chemical and plastic industry.

CAGR 2011-2050: Food: 0.8 %
Feed: 0.6 %
Energy (all kinds of): < 1 % (Europe: 0 %)
Chemicals and polymers: 3-4 % (Europe: 1.5-2 %)

For the first time, Piotrowski et al. (2015) show detailed analyses for the material sector. The starting point is 2011 with a demand of 1.26 bn t dry matter for biomass in the material sector with the following shares in 2011 and trends towards 2050:

- Construction and furniture: 42 % (increasing)
- Animal bedding: 34 % (increasing with meat and milk production)
- Pulp and paper: 16 % (constant)
- Chemical and polymer industry: 5 % (strongly increasing)
- Textiles: 3 % (strongly increasing)

**Table A3.1: Biomass supply and demand of the world 2011 and 2050 in different scenarios (Piotrowski et al., 2015), Billion t dry matter**

| Sector | Status 2011 | Scenario 2050: LOW biomass supply | Scenario 2050: BAU | Scenario 2050: Bioeconomy | Scenario 2050: Strong bioeconomy | Scenario 2050: High growth — low pressure |
|---|---|---|---|---|---|---|
| **Food** | 1.75 (14 %) | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 |
| **Feed** | 7.06 (58 %) | 8.3 | 8.3 | 8.3 | 8.3 | 8.3 |
| **Bio-based chemicals and materials** | 1.24 (10 %) | 1.0 | 2.4 | 4.0 | 5.7 | 3.7 + 2.0 solar chemicals |
| **Bioenergy** | 2.98 (16 %) | 1.5 | 4.3 | 4.2 | 4.2 | 2.0 (+ other renewables) |
| **Biofuels** | 0.15 (1 %) | 0 | 1.0 | 2.0 | 3.5 (to meet 2 °C climate target with biofuels in transport) | 1.0 + 3.0 solar fuels (+ other renewables for electric cars) |
| **Total demand for biomass** | **12.18 (99 %)** | **13** | **18.2** | **20.7** | **23.9** incl. additional biomass sources | **17.2 + 5.0 solar fuels and solar chemicals** |

**Scenario 2050: LOW biomass supply**

Assumptions: Due to soil degradation, the area for arable and permanent crops as well as permanent meadows and pastures decreases by a total of 100 million ha. Based on several studies, we concluded that in the past the loss of agricultural area due to all forms of degradation amounted to about 10 million ha per year, so from 2011 to 2050, the total loss could amount to almost 400 million ha. However, in the LOW scenario we assume a lower loss of only 100 million ha due to less pressure on agricultural land.

Regarding crop yields, Alexandratos and Bruinsma (2012) presented assumptions for yield increases of 13 main crops or crop groups until 2050. For the Low-scenario, we assume 50 % lower yield increases than projected by Alexandratos and Bruinsma (2012).

Finally, we assume that the average annual increase of the Multi Cropping Index (MCI) is reduced between 2011 and 2050 from about 0.003 to 0.001. The MCI then reaches a value of 0.91 in 2050.

Summary: Decrease of total arable land (degradation and no expansion of arable land), no expansion of planted forest, moderate increase of yields and MCI. High biodiversity is guaranteed — but biomass production is nearly on the same level as 2011 and it will mainly cover the demand for food and feed. Less than 20 % are left for material use and bioenergy — this is less than for 2011. That means that the demand for materials and energy has to be covered mainly by other sources (fossils or renewables).

**Scenario 2050: BAU**

Assumptions: In the BAU-scenario we assume that loss of agricultural land due to degradation will amount to 400 million ha until 2050. However, these losses are offset by cultivation of new agricultural areas of 435 million ha. These are areas suitable for rain-fed cultivation that are not currently used for crop production and not protected. We assume that 50 % of these areas were previously used as meadows and pastures, so that concomitantly the area of meadows and pastures decreases by about 218 million ha. Additionally, 100 million ha of forests are converted into agricultural land (as already internationally agreed until 2030).

Regarding crop yields, we assume the yields as projected by Alexandratos and Bruinsma (2012). For the MCI, we assume that the average annual increase of about 0.003 continues until 2050. The MCI then reaches a value of 0.96 in 2050.

Due to the higher demand for biomass in the BAU-scenario compared to the LOW-scenario, we assume an increase of the utilisation of primary harvest residues from 25 % to 40 %.

Regarding forest biomass, we assume that the effective utilisation of the naturally regenerated forests (excl. primary forests) increases from 15 % to 40 % and the wood yield from planted forests increases from 8.5 cbm/ha*a to 14 cbm/a*a. Furthermore, the area of the planted forests increases by 195 million ha.

Summary: Moderate net increase of arable land and planted forest, decreasing permanent pastures and meadows, increase of yields and MCI. The share of biomass to cover the demand of the chemical and plastic industry will increase from 10 % today to 20 %. The demand for bioenergy is based on the IEA-scenario *ETP 2012 2°C* (ETP 2DS) as described in IEA 2012. This scenario 'sets out cost-effective strategies for reducing greenhouse gas emissions in the energy sector by 50 % in 2050 compared to 2005 levels' and keeping the +2 °C climate target. Biomass demand from food and feed, materials and bioenergy can be covered by supply scenario BAU. The left over biomass leads to the biomass for biofuels. This is 4 times the volume compared to 2011.

**Scenario 2050: bioeconomy**

Assumptions: In the bioeconomy-scenario we assume that loss of agricultural land due to degradation will amount to 500 million ha until 2050. However, these losses are offset by cultivation of new agricultural areas of 760 million ha. These are areas suitable for rain-fed cultivation that are not currently used for crop production and not protected. We assume that 50 % of these areas were previously used as meadows and pastures, so that concomitantly the area of meadows and pastures decreases by about 380 million ha. Additionally, 100 million ha of forests are converted into agricultural land (as already internationally agreed until 2030).

Regarding crop yields, we assume 25 % higher yields than projected by Alexandratos and Bruinsma (2012). For the MCI, we assume that the average annual increase of about 0.003 increases to about 0.004 until 2050. The MCI then reaches a value of 1.01 in 2050.

Due to the higher demand for biomass in the bioeconomy scenario compared to the other scenarios, we assume an increase of the utilisation of primary harvest residues from 25 % to 50 %.

Regarding forest biomass, we assume that the effective utilisation of the naturally regenerated forests (excl. primary forests) increases from 15 % to 40 % and the wood yield from planted forests increases from 8.5 cbm/ha*a to 20 cbm/a*a. Furthermore, the area of the planted forests increases by 390 million ha.

Summary: High net increase of arable land and planted forest, decreasing permanent pastures and meadows, stronger increase of yields and MCI. The share of biomass to cover the demand of the chemical and plastic industry will increase from 10 % today to 40 %. The demand for bioenergy is based on scenarios of the IEA 2012 (see above, but more lignin is used in the chemical industry instead of incineration). Biomass demand from food and feed, materials and bioenergy can nearly be covered by supply scenario BAU. The demand for biofuels is doubled compared to BAU. The higher total biomass demand can be covered by the high supply scenario — which can realised still in a sustainable way, but this requires modern and advanced agriculture such as precision farming. Because of the additional arable land and planted forest required, an additional loss of biodiversity can hardly be avoided.

**Scenario 2050: Strong bioeconomy**

Assumptions: The main differences to 'bioeconomy' are: The share of biomass to cover the demand of the chemical and plastic industry will increase from 10 % today to 95 %. And the demand for biofuels is based on IEA 2012 as a share of biofuels in transport to keep the +2 °C climate target. According to IEA 2012, this demand for biomass for biofuels would amount to about 3-4 million tonnes dry matter (equivalent to 60 EJ).

The additional biomass demand cannot be covered by additional arable land and planted forest, higher yields and higher MCI. The sustainable potential of traditional agriculture and forestry reaches a limit and cannot stay in a safe operating space.

The additional biomass demand can only be covered by high supply scenarios, including a strong increase of microalgae on non-arable land, especially macroalgae ocean farming and transforming deserts in arable land with cheap solar energy for producing sweet water.

**Scenario 2050: High growth — low pressure**

The demand is the same as in the 'Strong bioeconomy' scenario, but the demand is less covered by biomass but more by other renewables especially solar energy. That means that the left over biomass demand can be covered by BAU supply scenario.

The non-fossil demand for materials and energy is mainly covered by other renewable energies such as solar, wind and water energy and storage systems. In detail:

- The total material demand for the chemicals and plastics is covered by solar chemicals and to a lesser extent by complex biomolecules

- The energy demand is mostly covered by renewables and less by bioenergy (same level as BAU scenario).

- The fuel demand is covered mainly by solar fuels and by a low share by biofuels (same level as BAU scenario). Together with electric cars driven by renewable energies, the left over demand for fossil fuels is lower than in all other scenarios.

In total about 5 billion tonnes dry matter has to be covered by solar chemicals and solar fuels in 2050. Will this be possible? From a technology point of view, it is possible already today to produce from $CO_2$ and water with renewable electricity gaseous and liquid molecules such as methane, methanol, kerosene and more, which can be used as fuels or raw material for the chemical industry. The efficiency for this transformation is today about 60 % and can probably be increased by 2050 to about 80 %.

Different technologies can be used for this transformation, for example via electrolysis and methanisation, but in the future also different kinds of artificial photosynthesis. Those technologies are also called power-to-gas, power-to-liquid or power-to-chemicals (Dena 2015, personal communication). Today worldwide more than 30 pilot plants are running and the first commercial plants will soon start operation. The costs are higher than for fossils but on the same level as for biofuels.

Which area is needed to produce for example 5 billion tonnes methane from power-to-gas? With existing technologies it is possible to produce about 80 tonnes methane per ha and year in the desert (with 80,000 GJ solar radiation per ha and year). To produce 5 billion tonnes methane would therefore need 63 Million ha in the desert. The total desert area is about 2.75 Billion ha (Piotrowski at al. 2015). That means that about 2.3 % of the global deserts would be enough to cover more than 95 % of the total demand of the (organic) chemical and plastic industry and also a relevant demand for fuels.

Conclusion: Even the demand from high growth scenarios can be covered with less fossil resources and a sustainable growth in biomass supply, if there would be a strong investment in solar and other renewables, delivering not only heat and electricity, but almost all raw material for the chemical industry and a high share of synthetic fuels (solar fuels).

In such a scenario, high growth can be combined with low pressure on nature resources and low pressure on climate. But it needs a strong commitment, investment and implementation of solar, wind and other renewables and in Carbon Capture and Utilization (CCU) technologies to produce also raw materials and fuels from solar.

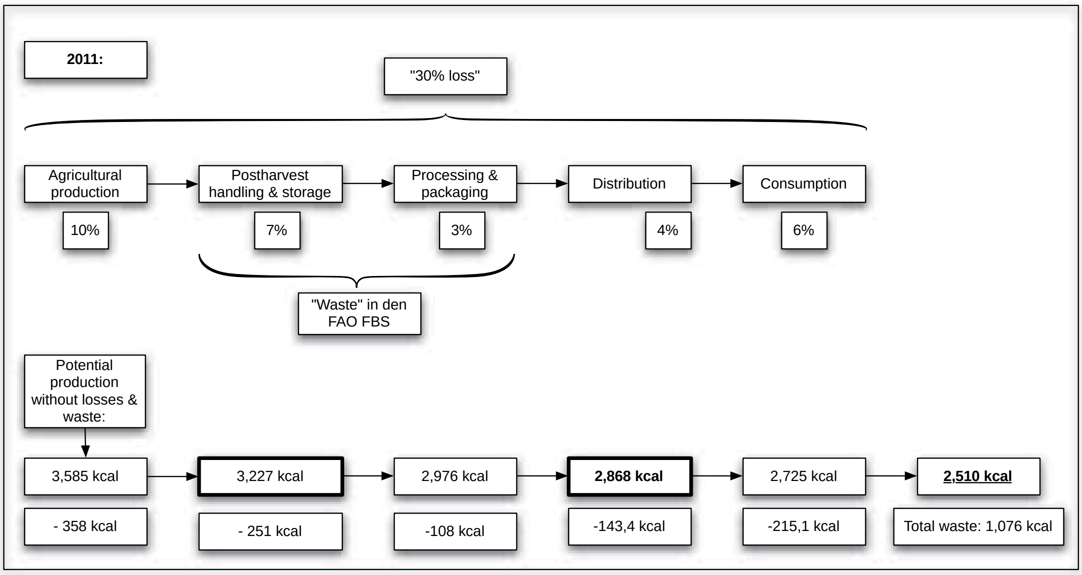
# Annex 4: Food demand in 2011 and 2050

In 2011, **1.7 billion tons (dry matter)** from agricultural production were used to produce plant-based food and **262 million tons (dry matter)** of animal-based food were produced.

The food assumptions for 2011 do consider food waste and losses along the food value chain based on the assumptions of Gustavsson et al. (2011). On average, 30 % of food is assumed to be lost in 2011 (10 % in agricultural production, 7 % in distribution and storage, 3 % in processing and packaging, 4 % in retail/trade, 6 % by the consumer). The per capita consumption considering food losses and waste up to the retail/trade was 2,868 kcal per day in 2011 (FAO *Food Balance Sheet*).

The following Figure shows these results graphically. The figure shows that when assuming the per capita consumption after accounting for losses and waste up to the retail stage to be 2,868 kcal and when further assuming the total food waste and losses to be distributed along the food chain according to Gustavsson et al. (2011), the amount of food calories after accounting only for the losses at the stage of agricultural production amounts to 3,227 kcal/capita*day. We assume this amount of food calories to be the share of the recorded agricultural production by FAOSTAT that enters the food chain.

### Figure A4.1: Global food losses and waste along the value chain in 2011 (Piotrowski et al. 2015)




According to the FAO F*ood Balance Sheets* (FBS), supply of food calories in 2011 was split into 63 % carbohydrates, 26 % fat and 11 % protein. Furthermore, according to the FBS, this supply was split between plant and animal sources as shown in Table A4.1.

### Table A4.1: Global average shares of nutrient supply for human consumption in 2011 (FAO Food Balance Sheets)

| | Plant based | Animal based |
|---|---|---|
| Protein | 61 % | 39 % |
| Fat | 55 % | 45 % |
| Carbohydrates | 97 % | 3 % |

Finally, we convert the 3,227 kcal/capita*day into mass of plant and animal based nutrients according to these shares and add a 10 % surcharge to both plant and animal based foods to account for other substances (minerals, dietary fibres).

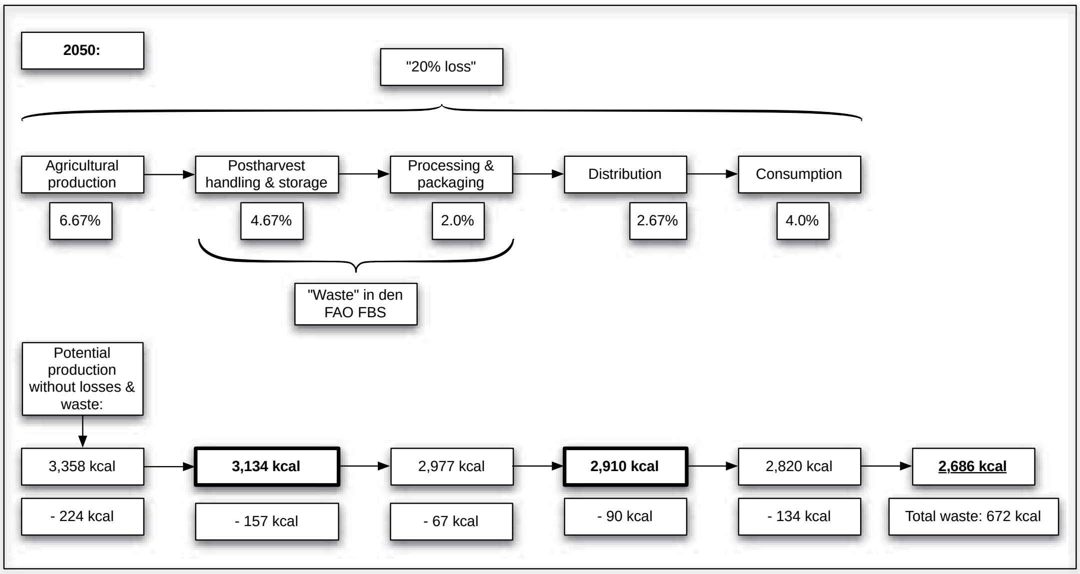
The resulting masses of dry matter of plant- and animal-based food are finally entered on the demand side of biomass for human consumption (see the following Table A3.2).

### Table A4.2: Plant and animal based food in 2011 (Piotrowski et al., 2015)

| | Plant based food (billion t) | Animal based food (billion t) |
|---|---|---|
| Protein | 0.14 | 0.09 |
| Fat | 0.13 | 0.11 |
| Carbohydrates | 1.26 | 0.04 |
| Others | 0.17 | 0.03 |
| **Total** | **1.70** | **0.26** |

For 2050, the scenario considers a **population of 9.55 billion.** Alexandratos und Bruinsma (2012) expect the per capita food consumption after food losses and waste up to the retail/trade stage to increase to 3,070 kcal/capita/day, which amounts to an **annual growth rate of per capita consumption** of **+0.17** %. However, this result was based on the assumption of a continuation of 30 % food waste and losses until 2050. After also taking into account the 6 % food losses and waste at the consumer level, this would result in a net food consumption of 2,686 kcal/capita/day. If food waste and losses along the whole chain are going to be reduced from 30 % to 20 % until 2050, 320 kcal/capita/day less would be needed at the stage of recorded agricultural production in order to allow for the same level of net consumption. The annual growth rate of per capita consumption, measured at the retail/trade stage would then only be 0.04 % p.a. instead of 0.17 % p.a. As above, the following figure shows these results graphically.

### Figure A4.2: Global food losses and waste along the value chain in 2050 (Piotrowski et al. 2015)




Additionally, between 2011 and 2050, the **annual demand for food** and the consumption of food (kcal/capita/day) are not only expected to increase, but to **shift towards more animal-based calories**. The share of animal-based calories is projected to increase from 18 % to 20 %.

**Model assumptions for food demand in 2050 – All scenarios:**

Population growth, shift of dietary needs towards more animal-based calories and the reduction of food losses and waste are projected to increase the demand for agricultural biomass used for food production (i.e. plant-based) from **1.7 bn t** (dry matter) in 2011 to **2.2 bn t** (dry matter) in 2050. The production of animal-based food is projected to increase from **262 m t** to **390 million t** (dry matter).

*Feed demand in 2011 and 2050*

The demand for feed in 2011 was **7.1 billion t (dry matter)**. The calculation is based on the global number of livestock, livestock species and the region specific demand for feed (FAOSTAT and Krausmann et al., 2008). Moreover, 10 % of food waste and losses will be used for feeding purposes.

In the following, we describe in a bit more detail how this calculation was done. The following table shows the assumptions for the species-specific daily feed intake by world regions as presented by Krausmann et al. (2008).

### Table A3.3: Species-specific daily feed intake, regional breakdown (Krausmann et al. 2008)

**Table S2. Species-specific daily feed intake [kg DM / head / day], regional breakdown.**

| | S. & C. Asia | E. Europe | N. Africa & W. Asia | N. America & Oceania | W. Europe | Sub-Saharan Africa | Latin America & Caribbean | E. Asia |
|---|---|---|---|---|---|---|---|---|
| Cattle and buffaloes | 6.4 | 9.2 | 6.8 | 14.3 | 13.9 | 6.7 | 9.5 | 7.9 |
| Sheep and goats | 1.0 | 1.5 | 1.0 | 1.5 | 1.5 | 1.1 | 1.0 | 1.0 |
| Pigs | 0.9 | 1.3 | 1.6 | 1.5 | 1.6 | 0.8 | 1.4 | 1.3 |
| Poultry | 0.05 | 0.08 | 0.06 | 0.09 | 0.10 | 0.05 | 0.07 | 0.07 |

Source: own calculations, see text.

These figures were based on 2000. However, it is plausible that between 2000 and 2011, a certain increase of feed efficiency has taken place due to several factors (e.g. breeding progress, change of production systems, feed quality improvement). To take this into account, we have searched for sources of estimates of feed efficiency gains over time. Such estimates can be found in Bouwman et al. (2005) and Wirsenius et al. (2010). As both Figures A4.3 and A4.4 show, both studies partly come to similar conclusions, i.e. low overall low efficiency of beef and mutton, high efficiency of dairy cattle and poultry as well as high efficiency gains of pig production.

### Figure A4.3: Global average feed efficiencies by species (Wirsenius et al., 2010; Piotrowski et al. 2015), note: the percentage values below the white arrows, added by the nova institute (Piotrowski et al. 2015), indicate the average annual increase in feed efficiency between 1992/94 and the reference scenario 2030.

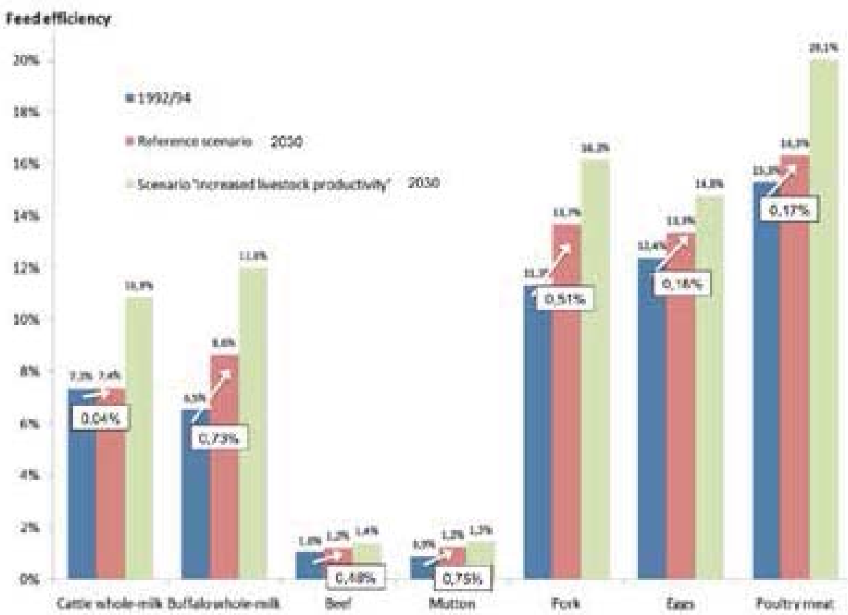
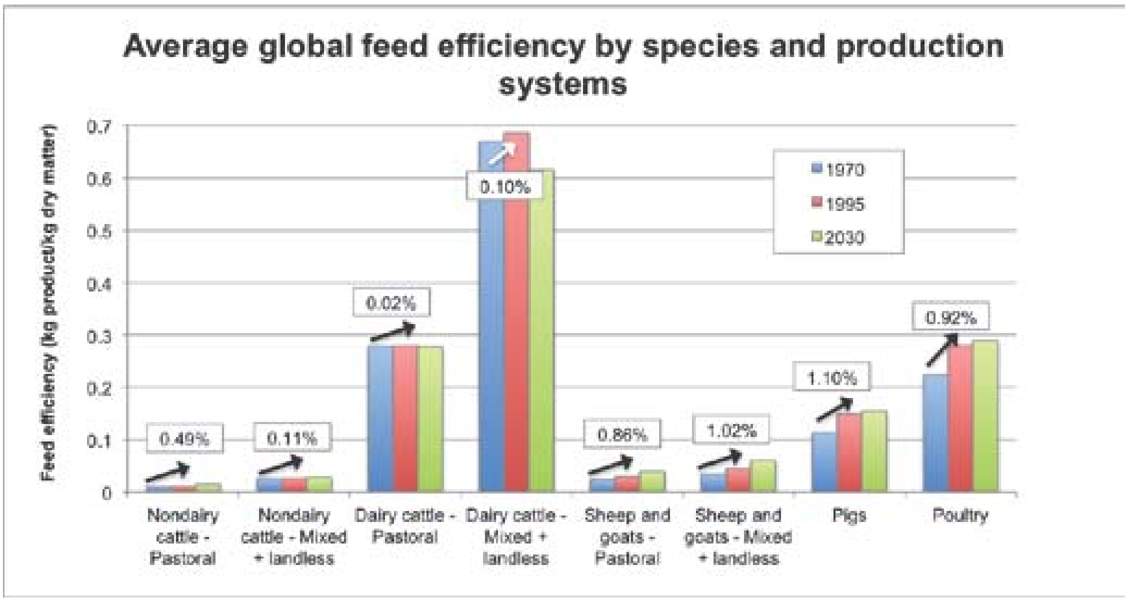



Fig. 3. Global averages of feed-to-food efficiency for major livestock systems in 1992/1994 and in scenarios for 2030. Feed efficiency is calculated as gross energy content of product output, divided by gross energy content of feed eaten. Data for 1992/1994 from Wirsenius (2000, 2003a,b).

### Figure A4.4: Global average feed efficiencies by species and production systems (Bouwman et al., 2005; nova, 2015), note: the percentage values indicate the average annual increases in feed efficiency between 1970 and 1995




However, how exactly the feed efficiency has increased between 2000 and 2011 is not possible to conclude from these two studies. Since the study by Wirsenius et al. (2010) is newer, we assume that the species-specific efficiency gains shown for the period 1992/4 to 2030 are also valid for the period 2000 to 2011.

When we calculate the global feed demand in 2011 by multiplying the world livestock population in 2011 (differentiated by major world regions) taken from FAOSTAT with the species-specific daily intake as presented originally by Krausmann et al. (2008), this results in at total of 7.4 billion t dry matter. However, when we apply the annual feed efficiency gains as shown by Wirsenius et al. (2010), this feed demand is reduced to 7.1 billion t dry matter, equivalent to a decrease of about 0.4 % p.a. (see Table A4.4 below). Finally, we assumed that 10 % of the plant-based food waste and losses (in total about 883 kcal/person*day or 520 million t dry matter per year) would be used for feeding purposes. This effectively reduces the feed demand by about 50 million t dry matter.

### Table A4.4 World livestock in 2011 and world feed demand (Piotrowski et al 2015, no final data)

| | World livestock in 2011 (in millions) | World feed demand (in million t dry matter) |
|---|---|---|
| Cattle and Buffaloes | 1,621.8 | 4,838.3 |
| Sheep and Goats | 2,017.7 | 737.8 |
| Pigs | 967.2 | 449.4 |
| Poultry Birds | 22,913.3 | 577.8 |
| Horses | 58.5 | 213.4 |
| Asses | 43.2 | 94.7 |
| Mules | 10.5 | 22.9 |
| Camels | 26.6 | 97.2 |
| Rabbits and hares | 895.0 | 32.7 |
| Other Rodents | 18.4 | 0.7 |
| Other Camelids | 8.4 | 30.6 |

| | | |
|---|---|---|
| Animals Live Nes | 6.1 | 11.2 |
| **Total** | **28,586.6** | **7,106.8** |

In 2050, population growth and the increasing demand for more and especially animal-based calories are expected to increase the demand for feed.

However, the improvement of feed conversion efficiency due to breeding progress, change of production systems, feed quality improvement and alternative protein sources (i.e. insects and artificial meat) is expected to play a major role in reducing the global demand for biomass in feed production. For the BAU-scenario, we have not made explicit assumptions for the impacts that each of these factors for increasing feed efficiency could *ceteris paribus* have in the future. Rather, we have assumed that due to the sum of these factors, average global feed efficiency could be increased from 0.4 % p.a. in the past to 0.6 % p.a. from 2011 to 2050.

Moreover, 15 % of food waste and losses are expected to be used for feeding purposes (i.e. reduction of losses), which causes a reduction in biomass demand required for feed production additionally.

**Model assumptions for feed demand in 2050 – All scenarios:**

The demand for biomass required for feed production is expected to increase from 7.1 billion t (dry matter) in 2011 to 8.3 billion t (dry matter) in 2050.

# 3. Infographic

To facilitate the debate, an infographic about the possible scenarios inspired by the report was produced in all EU languages. The aim is to steer the discussion not only in EU institutions but also at Member State level. The recommendations from the Foresight Exercise should steer national discussion on the future of the primary production sectors and about the challenges ahead of us.

The infographic in a poster format is annexed to this book. For reprinting and dissemination purposes it is available for download on the SCAR webpage:

www.goo.gl/oRL96H

# 4. SCAR Reflection on the 4th Foresight *"Sustainable Agriculture, Forestry and Fisheries in the Bioeconomy – A Challenge for Europe"*

## 4.1. Introduction

As stated in the European Commission's communication, "Innovating for sustainable growth: A Bioeconomy for Europe" ([9]), the **Bioeconomy** "*encompasses the production of renewable resources and their conversion into food, feed, bio-based products and bio-energy. It includes agriculture, forestry, fisheries* ([10]), *food and pulp and paper production, as well as parts of chemical, biotechnological and energy industries*".

The public, policymakers and others will have to play a main role in the governance of the Bioeconomy. The fourth SCAR Foresight states that it will not be sufficient if only technology and market developments govern the economy. Its recommendation is to rethink the role of governance and it encourages policymakers to develop new policy models, in addition to orienting investments towards developing new value chains and business models. Policy decisions concerning sustainable production and consumption patterns should build on a food-feed, a material-chemical and a fuel-energy systems-based approach and the inter-linkages between those systems and primary production. Consequently, policies related to the three primary sectors - agriculture, forestry and fisheries/aquaculture - have to change in order to meet the challenges in a sustainable way.

Better use of biomass coming from the primary production sectors can create economic opportunities, social benefits, and environmental improvements and avoid waste, but the implementation of the EU Bioeconomy strategy requires governance and political decisions at regional, national, European and global levels to ensure a sustainable approach with fewer trade-off situations and better exploitation of synergies. In this context, investment in research and innovation plays a key role.

The fourth SCAR Foresight is the first to cover all aspects of the Bioeconomy including agriculture, fisheries/aquaculture and forestry and exploring the complexity of systems and their interconnections. A 2050 time-frame was used to reflect the need for a long-term view in the development of effective strategies for the Bioeconomy and the primary sector. The exercise opens multiple windows on possible future scenarios, provides food for thought in policy development and offers a coherent framework for planning and organising research and innovation systems.

This exercise builds on a number of sectoral foresight documents, including the previous SCAR foresight exercises on agriculture, that of the ERA-Net COFASP for the fisheries and aquaculture sector, the ERA-Net SUMFOREST for the forestry sector, the SCAR Strategic Working Group AKIS for knowledge and innovation systems, and the Joint Research Centre's exercise on global food security. The SCAR is ideally placed to synthesise and integrate the evidence from these diverse sources and make recommendations on well-balanced policy actions.

Based on the outcomes of this exercise, SCAR has new ground on which to fulfil its advisory role for the European Commission, the Member States and others. This reflection paper is not based solely on the 4th SCAR Foresight experts' report, but contains also on potential future actions inspired by the Foresight exercise. It is not a matter only of research and innovation themes, but also of coherent policies across countries and sectors. Other important aspects include: a better alignment of national programmes, reinforcing scientific research networks, better use of existing knowledge,

([9]) COM (2012)60,

([10]) In the scope of this document, fisheries include both capturing and farming aquatic organisms...

more efficient sharing of data and information, driving more sustainable behaviours, developing new sustainable business and policy models, and emphasising the role of research and innovation in creating jobs, growth and investment-.

## 4.2. Primary Production and the Bioeconomy

The Bioeconomy is a broad concept that includes a wide range of opportunities under the concept of sustainable development. A Bioeconomy approach helps to overcome compartmentalisation of the different industries that are based on bioresources and in developing a systemic and operational vision of the relationship between society, ecosystems and primary production.

However, its scope, the high number of sectors involved and the challenges and potential societal implications call for a thorough examination of the relevant components, actors and relationships to enable sustainable exploitation of the available opportunities, while avoiding any undesired consequences.

Despite the broad scope of the Bioeconomy, sectoral views are still dominant, creating a potential for conflicts that might potentially undermine the anticipated benefits. The fourth Foresight exercise therefore embedded agriculture into a broader bio-based economy context together with the other primary production sectors of fisheries/aquaculture and forestry.

The complex nature of the Bioeconomy calls for a comprehensive and coordinated approach that would allow policies to be developed that can achieve a balanced governance at the regional, national, European and global levels and transform potential conflicts and trade-offs into win-win situations. In this context, investment in research and innovation is needed to ensure the biomass needs of the different sectors can be met in a sustainable way.

## 4.3. The main messages and challenges

The fourth Foresight experts' report identified basic data on the currently available levels of biomass and made projections for the potential availability for the next 30-40 years. These indicate that today's resource availability is not sufficient in any worst- and best-case-scenarios until 2050 even if the population, climate and geopolitical tendencies are unchanged. However, the underexploited biomass production cycles could increase efficiency through less-waste and better-use strategies. In this case, the scenarios show that the minimum required for a sustainable food system would still require investments into increasing total biomass production and availability by 2050. The two other systems from materials and energy are also demanding enormous quantities of biomass, which obviously raise governance and research questions, where the role of the governing structures will be crucial for the sustainable use and management of the biosphere.

The experts agree that the main question is the need to develop sustainability criteria, which depend on the objective of research and innovation. In this respect, research and policy are connected, but the economic, environmental and societal interests are conflicting. Therefore, there is a need to motivate stakeholders to use multi actor approaches and commonly agreed principles for inter- and cross-sectoral approaches and methods based on an integrated knowledge and innovation system.

### Diversity

A requirement to underpin a sustainable Bioeconomy, as highlighted by the Foresight exercise, is **diversity** at the biological level (biodiversity), the field/water and body level (intercropping, mosaics and agro-forestry, multi-trophic aquaculture), the landscape/seascape level and the social and economic levels. Diversity fosters resilience, makes use of local assets and ensures a reservoir of opportunities in the face of future challenges.

It is necessary to distinguish and take into account diversity at two levels: (1) the mobilisation and development of biodiversity in production systems and food systems at the macroeconomic level (national, European or world); and (2) local or regional differences and the need to create local solutions, taking into account local and regional specificities.

### Complexity

Complexity is a prominent feature of the Bioeconomy, with many interconnecting factors and feedback loops, including: (**a)** Primary sectors: agriculture, fisheries/aquaculture, forestry; (**b)** Uses of biomass: food, feed and fibre, materials and chemicals, energy and biofuels;(**c)** Global societal challenges: increasing demand (mainly driven by population growth, other demographic changes and increasing wealth), decreasing resources (land, water, soil, biodiversity, oil and unsustainable use of current resources like minerals), and climate change; and **(d)** developments in science, technology, and market in other areas.

These interactions are so important that any sectoral policy failing to take into account the influence of, or its impact on, the other components will be less effective, or more likely be faced with many undesirable side effects. A **holistic and integrated approach** is always needed with all its interdependencies and feedback loops. A comprehensive Bioeconomy strategy should provide a framework for comparing and reconciling the needs and expectations of the different sectors, across the spectrum from primary production through to the end users and consumers.

## A priority on food availability

Food and nutrition security stays a priority concern today and in the future. We need to ensure that sufficient, healthy and nutritious food is available for all and, in the face of a global population of over 9 billion, (which would mean an increase in food and feed production of up to 70%, on the opinion of FAO), the challenge is significant.

However, not food production *per se* deserves the highest priority. Food security means the more complex issue of access to affordable, acceptable, safe, healthy and nutritious food, which includes primarily social and economic aspects.

## Vulnerability of the Biosphere

The Bioeconomy is more than a relationship between and within sectors. The Bioeconomy should be based on a healthy **long-term relationship between society and the biosphere**. Having its roots in the sustainability principle, the Bioeconomy implies living off but not eroding the natural capital, while possibly repairing past damage and improving the environment and production capacities for future generations. This means increasing production without harming the environment, sparing finite natural resources and using renewable resources.

## Sustainability, Cascading and Circularity

**Sustainability** needs to be the guiding principle and a constant reference in its three dimensions - social, economic and environmental. However, claims of sustainability need to be substantiated and not an image-enhancing marketing label attached to any initiative or policy. Indicators, data collection systems and analytical tools should be developed as a base for evaluations on sound evidence, taking into account the variety of social, economic and environmental conditions across regions.

The diversity of local conditions, the different scale of human activities, the lag times between causes and consequences in both natural and socioeconomic contexts need to be considered.

**Cascading** is an important guiding principle for the optimal resource-efficient use of biomass, giving priority to the highest-value products before cascading down to uses of lesser value. Considerable latitude exists in the concept of value (biomass market value, environmental footprint, downstream values, energy efficiency, employment) as well as who should make the decisions in cases of conflicting values. As with sustainability, the cascading principle also needs to take into account regional, social and economic differences.

Another basic principle of the Bioeconomy is **Circularity**, based on prolonging the life of products. This can be achieved through repair, reuse of parts, recycling of materials, and parts that are subject to wear. This is, in the case of biomaterials, interwoven with the cascading principle, as overall efficiency in the use of resources is fundamental. This principle has profound implications for business models and the roles of and interactions between producers, processers and consumers. In addition waste management and consumer behaviour will play an important role in future.

## 4.4. Challenges and priorities for Research & Innovation

There is a need to increase the productivity of agriculture, forestry and aquatic primary production in a sustainable way. The concept of “sustainable intensification” (despite its somewhat controversial interpretations) should be a guiding principle, implying obtaining more value for society out of existing resources without additional environmental burdens. This can be done through an **ecosystem-based** approach to meet the higher demands in a sustainable way.

The sustainable use of ecosystem services should be maximised to replace, where possible, external inputs. This includes, for example, the maintenance of soil fertility, the control of pests and diseases through integrated pest management or more effective waste management in farming. It requires research and innovation to understand and address the complex multiple interactions occurring in agroecosystems, forest ecosystems- and, marine ecosystems and to exploit the knowledge to devise production systems requiring minimal external input.

Plant, animal, human and environmental health could be tackled through the unifying concept of **sustainable diets**, joining up the sustainability of production systems with diets and lifestyles that promote individual health and lower social costs, as well as reducing the environmental burden. Thus, modifying diets represents a powerful hub level to reduce environmental footprints and social costs. Changing consumer behaviour observed in the world requires dedicated research combining nutritional and cultural components and the taking into account of social drivers of consumption patterns, including working conditions, aging and urbanisation.

Research and innovation should support **transitions that provide multiple benefits**, such as higher levels of soil organic matter (carbon sink, increased fertility, less synthetic fertilisers), balanced diets and lifestyles (less overall need for animal feed, reduced impact of metabolic and cardiovascular diseases), the extraction of nitrogen and phosphorus from urban sewage (less pollution, replacement of fertilisers that are either scarce or produced with high consumption of fossil energy sources) or, for example multipurpose offshore platforms (developing aquaculture and freeing coastal space for other currently competing activities, less pollution in enclosed coastal areas, combination with wind farms for energy sufficiency).

A **participatory** approach should be applied in those areas of research that benefit from more regional and traditional knowledge and require motivated participants to adopt the outputs. In the case of plant and animal breeding, this could facilitate the selection of traditional and new varieties better suited to the different territories and the use of regional connections with high quality food chains. More generally, stakeholders along the whole value chain should be involved to share their knowledge. Consumers should have access to full knowledge of production systems in order to make informed choices on sustainable behaviours and lifestyles.

Research should also focus on the **interactions** between subsectors and should take into account trade-off situations: food/feed with energy/biofuels, and with materials/chemicals, in order to understand the nature and degree of possible conflicts of interest and to support the development and implementation of reconciling policies. The social and economic consequences of the development of the Bioeconomy within regions and for the relationships between regions should be explored, as well as the consequences for producers regarding the change of land use and ownership.

The contribution of new technologies is central in the Bioeconomy. "Green" and "white" biotechnologies have already clearly demonstrated their innovation potential. There are high expectations for cellulose and lignin as sources of valuable building blocks for chemical compounds, and for plant protein for both feed and direct human consumption. For example, microbial consortia in the soil, in their interactions with plants and in their role in the human and animal gut, are also an important subject area.

### The sociocultural dimensions of the Bioeconomy: Fostering social innovation and adapting regulation

A sustainable Bioeconomy requires that knowledge about the potential impacts of technologies and mechanisms of social change should progress as fast as the technology. Primary producers and stakeholders along the whole value added chain should be fully involved in the governance of the Bioeconomy and the expectations and values of the younger generations should be one primary concern.

The acceptance by the consumer will be conditioned by improved service and durability due to bio-based products and by job creation. It should also ensure the convergence and stabilisation of different public policies (e.g. agriculture, fisheries, environment, economic, social) over long periods to allow investment and the commitment of private actors. In addition existing production systems, for example dairy production and their competitiveness to production of bio-based products should be taken into account.

## 4.5. Consequences for the organisation of research and innovation within the European Research Area (ERA)

Both public and private research and innovation have a role to play in the ERA of the Bioeconomy and should combine their activities to strengthen research capacity in the relevant fields (e.g. through public-private partnerships). Moreover, public organisations and research should rethink their public role, focusing on the functioning of the knowledge and innovation systems and guaranteeing that public goods are properly addressed. An emphasis should be laid on impartial inquiry and evidence – based decision making and policy advice, whereas the society is their "constituency".

A stronger engagement with society may mean supporting grassroots initiatives such as citizens' science or participatory research and innovation initiatives to provide scientifically sound methods for designing experiments and surveys and analysing data.

The needs of society should also be reflected in the creation of new, or the reinforcement of existing, value chains in the framework of the Bioeconomy, making use of advanced technologies, ICT *in primis*, for better integration of regional production systems and businesses into the global economy.

The **complexity** of Bioeconomy and the relevance of the interactions between different sectors call for more **inter- or transdisciplinarity** of approaches. Transformative innovation may best occur at the intersection of disciplines and depends on the effective cross-fertilisation of disciplines that are perceived as distant.

However, inter- or transdisciplinarity, clearly advocated by EU and national research programmes, is still far from being properly implemented. The European Innovation Partnerships and the Horizon 2020 Societal Challenge 2 "Multi-Actor Approach", introduced in the 2014-2020 programming period, represent a significant step in the right direction. However, this effort should be matched by parallel radical changes in the **academic education system** and in the evaluations on which scientists' careers are based.

Education should aim to prepare professionals (not only scientists) with the skills, culture, and openness to deal with complex issues where transdisciplinary interactions are more relevant than the effect of individual components. Public education, in a broader context, should aim at creating a new generation of consumers, better equipped to make informed, evidence- based decisions on complex issues, such as those involving sustainability.

The career development of scientists should move away from a privileged, discipline-based approach and the career path, award and incentive systems need to be reviewed. Mobility across different disciplines and professional fields and the application of the work of researchers in policy and in industry, as well as public outreach activities, should be valued.

Research programmes should favour **intersections** among disciplines, the collaboration of actors and the combination of technologies. Information and communication technologies, big data management and analysis, materials sciences, behavioural and cognitive sciences, and social sciences should interact with the more traditional fields of research on primary production systems, as the only reasonable approach to the complex issues of sustainability, ecosystem management, circularity, the cascading approach and lifestyle changes.

**Knowledge and innovation systems** are fundamental to filling the gap between the advancements of science and their application in creating value for society. It is not only a matter of redesigning advisory services but a rethink of the way **knowledge is generated and shared**. Unlocking entrepreneurial competences through a multi-actor approach will be essential in tackling the great challenges and in encouraging the application of promising results. The European Commission and Member States should prioritise the open, unrestricted availability of research results and data produced with the support of public resources. The initiative on open access publications undertaken by the Commission is a notable step in the right direction; it should be pushed further, with a similar effort to publish all research data in **Linked Open Data** form. Ways to encourage scientists and stakeholders to publish and share their annotated datasets, as well as to translate research results into easy accessible end-user material for farmers and consumers, should be developed. New rewarding and assessment systems for applied research are needed to incentivise multi-actor approach and an interconnected knowledge and innovation system.

An effort should be made by the European Commission and the Member States to increase efficiency **in the use of research resources**, particularly in the face of an almost general decline in national funds for research and innovation. Efforts for unlocking existing knowledge, for example through thematic networks compiling ready-to-use knowledge across the EU, need to be supported. The **alignment of national research programmes** already initiated with the EU's ERA-Net mechanism and existing Joint Programming Initiatives, could be developed further, removing administrative and legal national barriers to increased integration, and with simplification of management.

A balance between **basic and challenge-driven research** should be preserved. In a 2050 perspective, basic research is fundamental both for laying the foundations for applied research and in preparing for the unexpected. Knowledge exchange should bridge the gap between results and application in the real world, whereas challenge-driven research builds on that basic research and promotes innovation by effectively applying its results and transforming them into practice.

## 4.6. Impact on policies

The fourth Foresight report outlines a strong technology and know-how requirement for further innovative approaches. Research and Innovation should offer the evidence base to develop adequate policies. The investments need to target **new value-chains, business and policy models** in both the public and the private sectors. The public sector needs to be prepared for a change in the governance structure to be able to cope with the complex policy interlinkages, with a holistic and integrated view to support the public goods. The sustainable Bioeconomy cannot be governed by markets and technology alone. It requires reflexive governance. The rebuilding of structures requires commonly agreed principles and constant monitoring. The fourth Foresight highlighted the five main guiding principles that could be enormously challenged by the current national economic interest. However, the discussions on developing the common grounds should start as soon as possible.

In the context of the fourth Foresight exercise, the state of play of the Bioeconomy was described by presenting three main processing sectors: the food-feed, the materials-chemicals and the fuel-energy systems that use bioresources from the primary sectors. It became evident that for sustainable production and consumption patterns, policy decisions in coherent sectors should be based on a system-based approach and the interlinkages between those systems and the primary sector. **The food and feed, materials and energy systems need to be tackled in their complexity**. Consequently the policies related to the three primary sectors - agriculture, forestry and fisheries/aquaculture - will change in the future influenced by the Bioeconomy. In this context the **food and nutrition system requires a new approach** in a sustainable way with strong support from EU and national policies.

There is a need to take the impact of policy development in the above mentioned sectors on the food/feed sector into account. A **"food-impact-assessment"** in line with the "environmental-impact-assessment" should be considered for the *ex-ante* analysis of policies in the Bioeconomy context.

The complexity of relationships within the Bioeconomy and of the impacts of its development requires balanced strategies and effective **governance**.

Leaving this to the market alone is not adequate for the long-term preservation of public goods. Policies encouraging the desired developments and ensuring constant reference to the overarching principle of sustainability should be devised.

**Subsidies and regulations** can create a favourable economic environment in helping new business models take off or they can eventually curb the development of alternatives to the status quo. An ungoverned Bioeconomy would potentially lead to accidentally developed production and processing systems, as appropriated at the cost of smaller businesses, family farming/fishing, and locally rooted and traditional production systems. The way in which the Bioeconomy should develop, however, should be based also on the value society attaches to these different implementations (i.e. small vs. large; family run vs. company/shareholder owned; diverse vs. uniform). Business competition might be different from region to region and might also change over time.

At European Commission level coherent **policy development** is required, with coordinated action by several directorates-general.

The "silo approach" of a strict, sector-based policy approach should change to a holistic, integrated approach. The implementation of the EU-Bioeconomy strategy is an opportunity for the European Union to play a more **active role** and take a global responsibility for primary production and the stakeholder involved in the process.

**SCAR will take the opportunity for its advisory role for Member States, European Commission and other decision makers using the results of the 4th SCAR Foresight.**

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The 4th SCAR Foresight Exercise launched by the Standing Committee on Agricultural Research in spring 2014 explored the interactions between the primary sectors and the broader bioeconomy. With an emphasis on the future, the exercise explored not only what will happen, but also what might happen by developing the paradigm of the bioeconomy, with the fundamental constraint of sustainability. Internal contradictions within primary production sectors and possible conflicts among sectors were a major point of interest. The report should help to set the research and innovation agenda, establish priorities, and provide ground for policies. The exercise was organised in a participative way involving the stakeholders from the beginning of the process facilitated by the European Commission (DG RTD Bioeconomy Directorate).

*Studies and reports*

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