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The role of biomass and bioenergy in a future bioeconomy: Policies and facts

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ABSTRACT

The European Commission has set a long-term goal to develop a competitive, resource efficient and low carbon economy by 2050. Bioeconomy is expected to play an important role in the low carbon economy. This paper provides a review of the policy framework for developing a bioeconomy in the European Union covering energy and climate, agriculture and forestry, industry and research. The Europe has a number of well-established traditional bio-based industries, ranging from agriculture, food, feed, fibre and forest-based industries. This paper proposes an analysis of the current status of bioeconomy in the European Union and worldwide until 2020 and beyond. We estimate the current bio economy market at about € 2.4 billion, including agriculture, food and beverage, agro-industrial products, fisheries and aquaculture, forestry, wood-based industry, biochemical, enzymes, biopharmaceutical, biofuels and bioenergy, using about 2 billion tonnes and employing 22 million persons. New sectors are emerging, such as biomaterials and green chemistry. The transition toward a bioeconomy will rely on the advancement in technology of a range of processes, on the achievement of a breakthrough in terms of technical performances and cost effectiveness and will depend on the availability of sustainable biomass.

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1. Introduction

The European Commission has set a long-term goal to develop a competitive, resource efficient and low carbon economy by 2050 (COM(2011)112 final) (EC, 2011a) and the green economy concept was incorporated into the general framework at different levels of EU policy. According to UNEP (2011), a green economy is defined as ´low-carbon, resource efficient, and socially inclusive', whose overall objective is ´improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities'. It aims at 'getting the economy right' by reducing polluting emissions, increasing resource efficiency, preventing the loss of biodiversity and valuing ecosystem services (UNEP, 2014).

The high-level horizontal strategies have enshrined the green economy concept, the main ones being the Europe 2020s flagship initiatives 'An industrial policy for the globalisation era' (EC, 2011c) and 'Resource efficient Europe' (EC, 2011d). As stated in the former mentioned flagship initiative focused on industrial policy, ´the Commission will work to promote the competitiveness of Europe's primary, manufacturing and service industries and help them seize the opportunities of globalisation and of the green economy´. The objective of the Resource efficient Europe flagship initiative is ´to support the shift towards a resource efficient and low-carbon economy that is efficient in the way it uses all resources. The aim is to decouple our economic growth from resource and energy use, reduce CO_2 emissions, enhance competitiveness and promote greater energy security´. In this sense, policies related to resource efficiency need to be seen as efforts for shifting towards a resource-efficient and low-carbon economy within the global context of green economy transition EC (2011c).

In the frame of the wider concept of green economy, *bioeconomy* vision is centred on the use of renewable raw materials and application of research, development and innovation and industrial biotechnology in sectors such as food, feed, paper and pulp, and biofuels production. In comparison to the environmental emphasis of green economy, the bioeconomy's focus is on new growth opportunities in both traditional and emerging bio-based sectors, while considering global challenges (e.g. raw material supply insecurity) and resource and environmental constraints (IEEP, 2014; EC, 2014). A bioeconomy entails the use of biotechnology on a large scale. The OECD defines *biotechnology* as 'the application of science and technology to living organisms, as well as parts, products and models thereof, to alter living or non-living materials for the production of knowledge, goods and services' (OECD, 2014). In the European Commission's approach, bioeconomy covers 'the production of renewable biological resources and the conversion of these resources and waste streams into value added products, such as food, feed, bio-based products and bioenergy', including both traditional and emerging sectors, i.e. 'agriculture, forestry, fisheries, food and pulp and paper production, as well as parts of chemical, biotechnological and energy industries' (EC, 2012). This multi-sector perspective of bioeconomy differs significantly from US bioeconomy strategy's exclusive focus on synthetic biology (US, 2012).

In order to set a framework for bioeconomy deployment, the European Commission has put forward the European strategy for building a sustainable bio-based economy as an opportunity to address several challenges, such as food security, natural resource scarcity, fossil resource dependence and climate change, with emphasis on the sustainable use of natural resources, competitiveness, socioeconomic and environmental issues. The policy model brings together several stand-alone policy areas (e.g. climate change, agricultural and industrial policy, R&D and innovation, environmental policy, etc.), as an attempt to provide an integrated response to several broad challenges—i.e. climate change; food and energy insecurity; resource constraints. A number of sectoral policies have been put in place at European level to support the development of a bio-based economy, including for instance the Biodiversity Strategy (EC, 2011b), which makes reference to the maintenance of natural capital as a critical economic asset (Mazza and ten Brink, 2012). In addition, the existing sector policy frameworks —such as agriculture, fisheries, forestry, manufacturing industry, (renewable) energy, transport, transport, water management, etc., already include sufficient elements capable of sustaining the development of green economy in the EU.

As part of a green economy, the bio-based economy plays a key role, being able to replace fossil fuels on a large scale, not only for energy applications, but also for chemicals and materials applications. The

bio-based economy integrates the full range of natural and renewable biological resources (land and sea resources, biodiversity and biological materials (plant, animal and microbial)—and biological processes. In this respect, a bio-based economy is nothing new in itself, as before the industrial revolution, economies were mainly bio-based. Biomass is already used as feedstock for example wood based materials, pulp and paper production, biomass-derived fibres, and as biofuel feedstock (from oilcrops, starch and sugar crops). Nevertheless, the transition toward a modern bio-based economy implies challenges such as the *sustainability* of biomass raw material, *efficiency* in biomass use and *economy of scales* in biomass mobilization.

2. Policy framework for the green economy/bioeconomy

In order to keep climate change below 2 °C, the European Council and Parliament have set the long-term objective of reducing Greenhouse Gas (GHG) emissions in the European Union (EU) by 80–95% by 2050, compared to 1990 levels (EC, 2011a). The *Roadmap for moving to a competitive low carbon economy in 2050* (COM(2011) 112 final) set out key elements for the EU's climate action helping the EU become a competitive low carbon economy by 2050. This is in line with the position endorsed by world leaders in the Copenhagen and the Cancun Agreements to deliver long-term low carbon development strategies (COM(2011) 112 final). The roadmap sets intermediate milestones for a cost-efficient pathway and GHG emission reductions, policy challenges, investment needs and opportunities in different sectors. The analysis of different scenarios indicates that a cost effective pathway requires a 40% domestic reduction of GHG emissions for 2030 compared to 1990 levels, and 80% for 2050. The energy sector should provide an important contribution to achieving these goals, with a share of low carbon technologies in the electricity mix to increase from around 45% today, to 60% in 2020, 75 to 80% in 2030, and almost 100% in 2050 (EC, 2011c).

The *Europe 2020 Strategy* (COM(2010) 2020) for growth and jobs aims to prepare the EU economy for the challenges of the next decade and to exit the financial crisis. Europe 2020 sets out a vision to achieve smart growth (research and in novation), sustainable growth (resource efficient and low-carbon economy) and inclusive growth (employment, productivity, social and territorial cohesion). The objectives of the strategy are supported by seven '*flagship initiatives*' to achieve its goals, which address each priority theme: (1) Smart growth (Digital agenda for Europe; Innovation Union; Youth on the move); (2) Sustainable growth (Resource efficient Europe, An industrial policy for the globalisation era); (3) Inclusive growth (An agenda for new skills and jobs; European platform against poverty). Five headline targets have been set for the EU for 2020 on: employment; research and development; climate and energy; education; social inclusion and poverty reduction. The climate and energy targets aim at reducing greenhouse gas emissions (GHG) by 20%, increasing the share of renewables in the EU's energy mix to 20%, and achieving the 20% energy efficiency target by 2020.

Resource Efficient Europe flagship initiative supports the shift towards a resource-efficient, low-carbon economy and to achieve sustainable growth. The aim is to 'decouple our economic growth from resource and energy use, reduce CO_2 emissions, enhance competitiveness and promote greater energy security'. *The Roadmap for a resource-efficient Europe* (COM(2011) 571) sets a framework for the actions to develop a resource efficient, sustainable economy by 2050 and proposes ways to increase resource efficiency and decouple economic growth from resource use. It sets out a vision for the structural and technological change needed to achieve by 2050, with milestones to be reached by 2020 (EC, 2011d).

The Europe 2020 Strategy calls for a bioeconomy within its Flagship Initiative '*Innovation Union*' as a key element for smart growth and green economy in Europe. *Innovation Union* aims to focus research, development and innovation policy addressing the challenges facing the EU, such as climate change, energy and resource efficiency, health and demographic change. A new approach to advance EU research and innovation was the establishment of *European Innovation Partnerships (EIPs)* to speed up the development of technologies to create the conditions for economic growth and social welfare. The agricultural European Innovation Partnership (EIP-AGRI) was also set to foster competitive and sustainable farming and forestry under the principle of 'achieving more and better from less' and to ensure a steady supply of food, feed and biomaterials (EC, 2014l).

2.1. Building a EU bioeconomy

Several EU policies and initiatives have an impact on the bio-based economy: agriculture, forestry, industry, energy, environment, climate change and research and innovation. The first steps toward a bioeconomy have been made in 2002 when the *Life Science and Biotechnology Strategy* (COM(2002) 27), was released to develop and apply life sciences and biotechnology, setting out several actions for the development of biotechnology (EC, 2002). The Strategy and Action Plan for "Innovating for Sustainable Growth: A Bioeconomy for Europe" (COM(2012) 60) aim "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" (EC, 2012). The strategy proposes a comprehensive approach to address five societal challenges through the introduction of a bioeconomy: (1) ensuring food security; (2) managing natural resources sustainably; (3) reducing dependence on non-renewable resources; (4) mitigating and adapting to climate change; (5) creating jobs and maintaining European competitiveness.

The Bioeconomy Strategy focuses on three areas: (1) investment in research, innovation and skills; (2) reinforcement of policy interaction; and (3) enhancement of markets and competitiveness in bioeconomy (EC, 2012b). In addition to the EU strategy, several EU Member States (MS) have designed national bioeconomy strategies, which are linked through the Standing Committee for Agricultural Research (SCAR) to the European Commission (M'Barek et al. 2014). A key component of the strategy is the production of food, feed, bio-based products and bioenergy and the sustainable use of renewable sources. This strategy aims to support better alignment of EU funding in research and innovation with the priorities of the bioeconomy. The Action Plan proposes the actions to be carried out for the development of bioeconomy markets along three directions: (1) promotion of research and innovation; (2) enhancing synergies and coherence between policies; (3) the development of bioeconomy markets and competitiveness. The Action Plan focuses in particular on cross-sectoral and multi-disciplinary approaches, developing *Joint Programming Initiatives (JPIs)* and *ERA-Net* activities and support bioclusters and *Knowledge and Innovation Communities (KICs)*.

A European *Bioeconomy Panel* has been set up to support synergies and coherence between different policy areas, to provide a discussion platform and framework to support the implementation of the strategy, to propose European joint actions and monitor and evaluate progress made (EC, 2012b). A *Bioeconomy Observatory* was established at the Joint Research Centre (JRC) to gather data and indicators to assess the progress of bioeconomy markets and socio-economic, scientific, technological, market and legislation impact. It shall produce foresights and forecasts on bio-economy, scenario analyses for aiming at supporting policies and derive research and innovation directions. The observatory has three main pillars which aim to gather data on: (1) investments in research, innovation and skills; (2) policy interaction and stakeholder engagement; and (3) markets and competitiveness (M'Barek et al. 2014).

2.2. Energy and climate change

The development of a EU energy policy started with the Green Paper 'A European Strategy for Sustainable, Competitive and Secure Energy" (COM(2006) 105) following the request of the European Council to develop a *long term and coherent energy policy* (EC, 2006). The European Council adopted in 2007 ambitious energy and climate change objectives for 2020: to reduce GHG emissions by 20%, to increase the share of renewable energy to 20%, and to make a 20% improvement in energy efficiency compared to the baseline projection. The European Council has also made a long term commitment to the decarbonisation of the economy, with a target to achieve 80% to 95% reduction in CO_2 emissions by 2050. The 2020 energy and climate goals have been incorporated into the "Europe 2020 Strategy for smart, sustainable and inclusive growth" and into its flagship initiative *Resource efficient Europe*. The integrated *Energy and Climate Change* package (2007) includes the energy and climate goals: *Energy policy for Europe* (COM(2007) 1 final) (EC, 2007a) and *Limiting Global Climate Change to 2 °C—The way ahead for 2020 and beyond* (COM(2007) 2 final) (EC, 2007b).

The *Energy 2020—A strategy for competitive, sustainable and secure energy* (COM(2010) 639) defines the energy priorities and sets the actions of an energy strategy until 2020 (EC, 2010b). The Energy 2020 strategy identifies five energy priorities: reduce energy consumption; build internal market and develop infrastructure; extend technological leadership; ensure secure, safe and affordable energy; and reinforce external dimension. The objectives of this strategy are part of the Europe 2020 strategy and the "Resource Efficient Europe" initiative, with one specific goal to support the development of innovative new low-carbon technologies, including through Strategic Energy Technology Plan (SET-Plan) (EC, 2014e).

The *Renewable Energy Directive* 2009/28/EC (RED) on the promotion of renewable energy sources translated into legally-binding frameworks the energy targets for 2020: the share of renewable energy of 20% in final energy consumption and 10% renewable energy in the transport sector (EU, 2009a). Fuel Quality Directive 2009/30/EC (FQD) set a target of a 6% GHG reduction for the fuels used in transport in 2020 (EU, 2009b). The RED and FQD include criteria for sustainable biofuel production and procedures for verifying that these criteria are met. The RED also includes a set of provisions to facilitate the development of renewable energy, such as a legal requirement for the MS to prepare National Renewable Energy Action Plans (NREAPs) with detailed roadmaps to reach the RES targets and measures taken to reach these targets and develop energy infrastructure. Bioenergy is expected to provide almost 60% of the renewable energy in 2020.

The Communication COM (2014) 15 final on *A policy framework for climate and energy in the period from 2020 to 2030* has put forward an integrated policy framework for the period beyond 2020 and up to 2030 to drive progress towards a low-carbon economy (EC, 2014f). It aims to build a competitive energy system that increases the security of energy supply, reduces energy dependence and creates new opportunities for growth and jobs. The targets proposed for 2030 include 40% reduction of GHG emissions compared to 1990 levels and a share of renewable energy of at least 27% in the final energy consumption. The European Council Conclusions on *2030 Climate and Energy Policy Framework* endorsed in October 2014 a binding EU target of 40% reduction in GHG emissions by 2030 compared to 1990, a binding target of at least 27% for the share of renewable energy in 2030 and a 27% energy efficiency indicative target (European Council, 2014).

The *Energy Roadmap 2050* (COM(2011) 885), investigated possible pathways for a transition towards a decarbonisation of the energy system, while ensuring energy security and competitiveness, and the impacts, challenges and opportunities for modernizing the energy system (EC, 2011e). A number of energy scenarios to achieve an 80% reduction in greenhouse gas emissions and about 85% reduction of energy-related CO_2 emissions have been examined. According to the decarbonisation scenarios of the Energy Roadmap 2050, it needs to achieve significant reductions in greenhouse gas emissions already in 2030 (57–65%) and to reach near-complete decarbonisation by 2050 (96–99%). RES are the key in any decarbonisation strategy. The share of renewable energy rises substantially in all scenarios to 28–31% in 2030 and 55–75% in the High RES scenario in 2050. The share of renewables in transport is expected to increase to 19–20% in 2030 and to 62–73% in 2050. Bioenergy is expected to have an important role within the long-term goal to become a competitive low carbon economy according (EC, 2011e).

2.3. Agriculture, fisheries and forestry

Launched in 1962, the Common Agricultural Policy (CAP) provides the overall EU framework for food production (EC, 2014b), with the aim to increase agricultural productivity; to ensure a fair standard of living for farmers; to secure the food supply; to stabilise markets; to provide affordable food. Agricultural support is provided by means of direct payments, through the European Agricultural Guarantee and Guidance Fund (EAGGF), set up in 1962. Farmers have to respect the *cross compliance rules* including food safety standards, environmental protection, animal welfare and the maintenance of land in good environmental and agricultural condition. The rural development was introduced as a second pillar of the CAP, to improve the competitiveness of farming and forestry, to protect the environment and the countryside, to diversify the rural economy and to support rural development. The CAP funding comes now under Heading 2 of the multi-annual framework

('Sustainable growth—natural resources'). The new CAP reform of 2013 seeks to strengthen the competitiveness of the agricultural sector, promote innovation, combat climate change and support the development of rural areas. The main objectives, as set in the Communication COM(2010) 672 final *The CAP towards 2020: Meeting the food, natural resources and territorial challenges of the future*, would be: (1) viable food production; (2) sustainable management of natural resources and climate action; and (3) balanced development of rural areas. Significant importance is given to fostering green growth through innovation, in the context of the emerging *bioeconomy*. In this framework, support could be directed to capacity building for the bio-based economy. Six priorities were formulated for rural development and the agriculture, forestry and rural areas: (1) fostering knowledge transfer and innovation; (2) enhancing competitiveness; (3) promoting food chain organisation (4) restoring, preserving and enhancing ecosystems; (5) promoting social inclusion and economic development. Of these, one priority directly relates to promoting resource efficiency and supporting the shift toward a low-carbon and climate-resilient economy (EC, 2010a).

The Common Fisheries Policy (CFP) is the EU instrument for the management of fishing and aquaculture. It sets limits for fishing activities and restrictions for the size of fishing fleet, to achieve a better balance between the fishing capacity and resources to ensure the sustainable exploitation of fisheries resources (EC, 2014c). The CFP aims to help producers get a fair price and ensure that certain health and safety conditions and fulfilled. Funding for the modernisation of the fishing fleet was made available through the Financial Instrument for Fisheries Guidance (FIFG) during 2000–2006 and the European Fisheries Fund (EFF) in the period 2007–2013 (Eurostat, 2013). The EU aquaculture and seafood processing industry has the potential to contribute to the 'marine pillar' of the bioeconomy, and to open up new markets for bio-based products and biofuels based on aquatic biomass (such as algae, etc.).

There is no common forestry policy for the EU; rather, the MS have their own national forestry policies. A new *EU Forest Strategy for forests and the forest-based sector* (COM(2013) 659 final) provides a framework for the forest sector and related policies, such as rural development, climate change, resource efficiency, bioenergy, biodiversity, bio-based economy, etc. (EC, 2013). The Strategy identifies the key principles for the forestry sector: sustainable forest management; resource efficiency, rural development and economic growth; sustainable production and consumption of forest products. A major objective is to improve competitiveness of forest-based products and value chains to contribute to the bio-based economy. One of the eight priority areas are related to *fostering the competitiveness and sustainability of the forest-based industries, bio-energy and the wider green economy* The role of bio-materials to mitigate climate, acting as carbon store or as carbon substitutes, replacing carbon-intensive materials and fuels is acknowledged. Another priority area addresses the development of n*ew and innovative forestry and added-value products*. The strategy underlines the role of an EU forest-based research area to stimulate innovation, to develop better forestry production systems and products and to enhance the sustainability and its contribution to the rural economy.

2.4. Industry

The European Commission developed the concept of the Knowledge-Based Bio-Economy (KBBE) in 2005 to develop a European bio-economy. It involves the replacement of fossil fuel feedstocks by renewable raw materials and the replacement of chemical processes by biological ones for the production of biological resources and their conversion into food, feed, bio-based products and bioenergy (Clever Consult, 2010; KBBE, 2014). Research in the area of KBBE has been promoted and financed via the 7th Framework Research Programme and complemented by MS resources via Joint Programming Initiatives. The Knowledge Based Bio-Economy Network (KBBE-NET) high-level expert group has been established in 2006 to detail a coordinated approach for the development of a research policy for a KBBE, together with the Standing Committee on Agricultural Research (SCAR) (EC, 2014d).

European Technology Platforms (ETPs) were created for strengthening of the European Research Area (ERA), as ndustry-led initiatives aiming to concentrate research efforts and address fragmentation across the EU, to boost research in order to improve European competitiveness.

ETPs have developed their Strategic Research and Innovation Agendas (SRIA) and roadmaps for leading technologies to achieve long-term development. In the area of bio-based economy, several ETP were established, including: 'European Aquaculture Technology and Innovation Platform' (EATIP); 'European Technology Platform for Global Animal Health' (ETPGAH); 'Food for Life' ETP; 'Plants for the Future' ETP; 'Forest based sector' Technology Platform; 'Farm Animal Breeding and Reproduction' (FABRE) TP; TP 'Organics' for organic food and farming research (Cordis, 2014).

The *Lead Market Initiative (LMI)* identified market sectors that are important and where an early adoption of technological innovation is likely to have a large impact. Lead markets are highly innovative, high-growth potential markets with a strong technological and industrial base in Europe. The LMI aims to support industry-led innovation and the up-take by creating adequate legal and regulatory frameworks, setting standards, improving access to risk capital and providing support for research, in order to bring new products into the market (EC, 2007c, 2009c). The Communication on the Lead Market Initiative (COM(2007) 860 final) indicated six sectors as lead markets: eHealth; protective textiles; sustainable construction; recycling; *bio-based products*; and renewable energies (EC, 2007d). The LMI includes non-food, bio-based products and materials, such as bio-plastics, bio-lubricants, surfactants, enzymes and pharmaceuticals, derived from biobased raw materials and processes based on biological systems. It excludes traditional paper and wood products, and biomass for bioenergy. An action plan is accompanying the LMI on bio-based products, deploying a set of policy instruments: legislation, public procurement, standardisation, labelling and certification, and complementary ones. The Action plan describes the actions for the implementation of the LMI on bio-based products, for providing access to finance for research and for biorefinery pilot and demonstration plants.

The EC Communication 'Preparing for our future: Developing a common strategy for key enabling technologies in the EU' (COM(2009)512) has identified the *Key Enabling Technologies* (KETs) that strengthen the EU's industrial and innovation capacity to address societal challenges (EC, 2009d). The Commission defines KETs as 'knowledge intensive and associated with high R&D intensity, rapid innovation cycles, high capital expenditure and highly skilled employment' (EC, 2009e). KETs are a priority within its *Europe 2020 strategy* and its flagship initiatives: *Innovation Union* (COM(2010) 546 final) (EC, 2010c), *An Industrial Policy for the globalisation era* (COM(2010) 614) (EC, 2010d) and *A Digital Agenda for Europe* (COM(2010) 245) (EC, 2010e). KETs are regarded as crucial for improving the competitiveness of European industries in the knowledge-based economy and the way toward a low carbon economy. Biotechnology has been identified as one of the KETs and priority areas and as the driving KET for the bioeconomy (EC, 2012). The activities envisaged include focusing innovation on KETs, promoting technology transfer, and joint strategic programming and demonstration projects. The "European strategy for Key Enabling Technologies—A bridge to growth and jobs" (COM(2012) 341 final) was set to boost the industrial production of KETs-based products (EC, 2012c). The strategy builds upon three pillars: technological research, product demonstration and competitive manufacturing activities. The main strategy goals are focusing on research and innovation on KETs, streamlining investment on financing innovation in KETs within the regional policy, and prioritise EIB lending activities on KETs deployment.

The *Eco-innovation* initiative was launched in 2008 as part of the Entrepreneurship and Innovation Programme (2007–2013) and was developed to implement the Environmental Technologies Action Plan (ETAP) (EC, 2014g). Thse Eco-innovation Action Plan (EcoAP) seeks to boost the development of environmental technologies and market uptake, which aims at reducing impact on the environment and making better use of resources, while strengthening economic growth and competitiveness (EC, 2014h). Eco-Innovation (COM(2011) 899 final) promotes innovation activities aiming to achieve sustainable development and a more efficient and responsible use of natural resources (EC, 2011f). Eco-innovation projects are not research projects. Eco-innovation represents a key opportunity to maintain the eco-technology leadership and making EU's economy even stronger and more competitive. A bio-based economy is also focused on these goals and overlaps with the eco-innovation initiative.

2.5. Research and innovation

Besides the policies in the areas of agriculture, forestry, energy, climate and industry, the policies on research and innovation were lately developed to stimulate the transition towards a bio-based economy. Research and Development (R&D) is one of the European Union's priorities, at the heart of the Lisbon Strategy to boost employment and growth and to become the "most dynamic, competitive knowledge-based economy in the world". The Communication *Towards a European Research Area* (COM(2000) 6 final) proposed the creation of a European Research Area (ERA) to avoid fragmentation and duplication of research in the EU through better coordination and cooperation (EC, 2000). The research in the KBBE area is strengthened through the *European Research Area Networks (ERA-NETs)*, which provide a framework for networking, coordination and cooperation of national programmes for the development and implementation of joint programmes or activities. ERA-NET has promoted the exchange of best practice, combining ideas and resources and the developing transnational research activities. More than 40 ERA-NET projects under 6th and 7th Framework Research Programmes with relevance to the bioeconomy have been funded and three *Joint Programming Initiatives (JPI)*: (JPI-FACCE 'Agriculture, Food security and Climate Change', JPI HDHL 'Healthy Diet for a Healthy Life', JPI Oceans 'Healthy and Productive Seas and Oceans') (Platform, 2014). ERA-Nets cover the cooperation in food, fisheries, animal health and welfare, plant genomics, systems biology, and biotechnology.

The Framework Programmes for Research are EU funding programmes created to support and foster research in the European Research Area (ERA). The 7th EU Framework Programme for Research (FP7) covered all EU research activities during the period 2007–2013 (EC, 2014i). It was complemented by the *Competitiveness and Innovation Framework Programme (CIP)* which supported innovation activities (including eco-innovation) during 2007–2013 (EC, 2014j). The broad objectives of FP7 have been grouped into four categories: Cooperation, Ideas, People and Capacities and specific programmes corresponding to the main areas of EU research policy. One of the research theme was 'Food, Agriculture and Fisheries, and Biotechnology', with the primary aim to build a *KBBE*, which is focused on three major activities addressing the developments in the bio-based economy: (1) sustainable production and management of biological resources; (2) fork to farm: food, health and well-being; (3) life sciences, biotechnology and biochemistry.

The EU financing in research and innovation will come during the period 2014–2020 from the new *Horizon 2020* Framework Programme (EC, 2014k). Horizon 2020 is a key pillar of the flagship initiative Innovation Union of the Europe 2020 Strategy, contributing toward enhancing Europe's competitiveness. Horizon 2020 consists of three main research areas: 'Excellent science', 'Industrial Leadership'; and 'Societal challenges'. Horizon 2020 will also aim at developing closer synergies with other EU programmes (e.g. in education, competitiveness and SMEs) and funds, such as the structural and Cohesion Policy funds. The Framework Research Programme will be complemented by additional measures to develop the European Research Area.

2.6. Funding opportunities

2.6.1. Public funding options

Various funding sources on R&D, agriculture and forestry, industry and rural development could be utilised to foster the development of a bio-based economy. These funds do however not always specifically refer to the biobased economy, but they address areas which are directly related to it.

The EU Regional Policy offers support for rural areas and to the farm sector through the Structural Funds (SF) (made up of the European Regional Development Fund (ERDF) and the European Social Fund (ESF)) and the Cohesion Fund (CF). Structural funds could support investments in rural green infrastructure and research, such as regional and trans-regional clusters, poles of excellence, technology transfer and industry support to adapt to economic changes. The Structural Funds can also support measures on innovation and R&D, the competitiveness of SMEs for the deployment of technologies, processes and products and the shift towards a low carbon economy. The Key Enabling Technologies (KETs) are one of the investment priorities for the *European Regional Development Fund (ERDF)* and are integrated into the regional policy. ERDF could support 'technological and applied

research, pilot lines early product validation actions, advanced manufacturing capabilities' (EC, 2014l). Together with the Common Agricultural Policy (CAP), the Structural Funds and the Cohesion Fund represent the majority of the EU budget. It was estimated that spending on forest-related measures during the 2007–2013 period through the European Agricultural Fund for Rural Development amounted between € 9 billion and € 10 billion.

The Common Agricultural Policy (CAP) in the EU is financed by two funds: the European Agricultural Guarantee Fund (EAGF), which provides direct payments to farmers and finances measures to regulate agricultural markets, and the European Agricultural Fund for Rural Development (EAFRD), which provides funds for rural development (EC, 2014m). The CAP does not support investments in bio-based facilities; however, CAP could support the supply chain for improving feedstock economics and increasing biomass availability, by providing subsidies to farmers for biomass production and developing the infrastructure. However subsidies to change to energy crops are not available. With a budget of € 303 billion for the period 2014–2020, direct payments represent a significant part of the EU's agricultural and rural development budget. The European Fisheries Fund (EFF) was the financial instrument of Common Fisheries Policy (CFP), with a budget of around € 4.3 billion for 2007–2013. The EFF has been replaced by the European Maritime and Fisheries Fund (EMFF), which has a budget of around € 6.5 billion for the period 2014–2020. The EMFF will support the rebuilding of the fish stocks and reducing the impact of fisheries on the marine environment. The EMFF will also support growth in coastal communities and emerging maritime sectors (EC, 2014n).

The Eco-innovation Action Plan (EcoAP) targets specific eco-innovation barriers and opportunities under the Innovation Union flagship initiative of the 2020 Strategy. Support for the EcoAP activities is delivered through Horizon 2020 for R&D projects. Horizon 2020 has for example a budget of €3.2 billion for climate action and resource efficiency initiatives, which include eco-innovation. Specific support for the development and implementation of environmental policy and for environmental, nature conservation and climate action projects is provided through the EU Life funding instrument (EC, 2014k). The Competitiveness and Innovation Framework Programme - Entrepreneurship and Innovation Programme (CIP-EIP) supports projects in eco-innovation through three initiatives: financial instruments, networking, and pilot and market replication projects. (EC, 2014o). A wider use of environmental technologies and investments in eco-innovation can also be supported by the structural and cohesion funds.

Horizon 2020 provides financial support for R&D activities, implementing the Europe 2020 flagship initiative *Innovation Union*. It is the biggest EU research programme ever with a budget of almost €80 billion over 7 years (2014 to 2020). Research and innovation activities on bioeconomy are funded under 'Societal Challenges' (with a budget of €29.7 billion), in particular 'Food security, sustainable agriculture, marine and maritime research, and the bioeconomy' (€ 3.9 billion). Other challenges – such as 'Climate action, resource efficiency and raw materials', 'Secure, clean and efficient energy', 'Health, demographic changes and well-being', 'Inclusive and reflective societies' and 'Smart, green and integrated transport' – can also provide the knowledge for the transition towards a bio-based economy (EC, 2014k). Horizon 2020 funds projects under the pillar '*Industrial Leadership*' (€ 17.0 billion) to speed up the development of the technology and innovation that will support 'Leadership in enabling and industrial technologies', including projects relevant to bioeconomy, as well as by providing access to risk finance and supporting innovation in SMEs. A major component of this pillar are the *KETs*, with a budget of €6.7 billion, supporting pilot lines and demonstrator projects, for achieving technology and product validation and more integration between the KETs. The research and innovation under 'Excellent science' pillar (€ 24.4 billion), aiming to increase the excellence of the science base, could also contribute to advance toward bioeconomy, through support to frontier research, emerging technologies, career development, research training, and development of research infrastructures (EC, 2014k).

2.6.2. Funding instruments

The *Strategy Energy Technology Plan (SET Plan)* (COM(2007) 723 final) is the technology pillar of the EU's energy and climate policy, being established for accelerating the development of low-carbon energy technologies, to achieve the 2020 energy and climate change goals and to contribute to the transition to a

low carbon economy (EC, 2007e). The *Bioenergy Technology Roadmap of the SET Plan* (SEC (2009) 1295) was set up as part of the seven Roadmaps on low carbon energy technologies including concrete actions aimed at the advancement in the technologies and achieving commercial deployment (EC, 2009f). The estimated budget for implementation is EUR 9 billion over 10 years. Within the SET-Plan, several European Industrial Initiatives were set to strengthen energy research and innovation and foster the development of key energy technologies. The *European Industrial Bioenergy Initiative (EIBI)* is one of the industrial initiatives launched in 2010, to address the techno-economic barriers to the development and commercial deployment of advanced bioenergy technologies (EIBI, 2014a). The EIBI aims at building and operating demonstration and/or flagship plants for innovative bioenergy value chains (Technology Map 2013). At least 70% of the output of the biorefineries must be bioenergy and the remaining 30% can be biochemicals, biomaterials and other. The EIBI Implementation Plan for 2013–2017 describes the core activities aimed at building and operating demonstration and/or flagship projects, including the evaluation and selection criteria of the projects and Key Performance Indicators (KPIs) for monitoring the progress (EIBI, 2014b).

Public/private partnerships, involving industry, research community and public authorities, have been set up (COM(2013) 494) to pursue ambitious research objectives under *Joint Technology Initiatives (JTIs),* supporting large-scale multi-national research activities. JTIs are the Joint Undertakings (JUs), independent legal entities that manage research projects in strategic areas for research and innovation (EC, 2013b). JUs organise calls for proposals, oversee selection procedures and conclude contractual arrangements for projects set up to implement the Strategic Research Agendas (SRAs) of European Technology Platforms (ETPs). Seven JTIs have been set up, including 'Innovative Medicines Initiative (IMI)', 'Fuel Cells and Hydrogen' (FCH), and 'Bio-Based Industries' (BBI) Joint Undertaking. The Bio-based Industries JTI has been identified as a new initiative on bioeconomy. The *BBI* is a new Public-Private Partnership between the EU and the Bio-based Industries Consortium established to increase the investment in the bio-based industry in Europe. The BBI Joint Undertaking aims to mitigate the market barriers for investment into research, demonstration and deployment activities for bio-based industries and helps to achieve critical mass in terms of scale of activity, excellence, and potential for innovation. It foresee €3.8 billion investments in bio-based innovation from 2014–2020 (Horizon 2020), of which €1 billion of EU funds (Horizon 2020) and €2.8 billion of private investments (BBI, 2014).

NER300 is an EU funding programme for innovative low-carbon energy demonstration projects, in particular for carbon capture and storage (CCS) and innovative Renewable Energy Sources (RES) technologies (EC, 2014p). The programme covers CCS technologies (pre-combustion, post-combustion, oxyfuel, and industrial applications) and RES technologies (bioenergy, concentrated solar power, photovoltaics, geothermal, wind, ocean, hydropower, and smart grids). NER300 is funded from the sale of 300 emission allowances from the New Entrants' Reserve (NER) set up for the third phase of the EU emissions trading system (EU, 2009c). Through the first call, about € 1.2 billion were provided in 2012 (additional €2 billion expected from private sources) to 20 projects on bioenergy, concentrated solar power and geothermal, wind, ocean power and smart grids. Under the second award decision in July 2014 a total of €1 billion were provided (additional €860 million from private sources) to 18 renewable energy projects. According to the European Council *Conclusions on 2030 Climate and Energy Policy Framework* (October 2014), the NER300 facility will be renewed (NER400), with the scope extended to 'low carbon innovation in industrial sectors' and the initial budget increased to 400 million allowances (European Council, 2014).

2.6.2.1. Loans and loan guarantees. The European Investment Bank (EIB), the EU's financing institution, supports the implementation of EU's policy objectives by financing viable capital projects. EIB support projects along six priorities, as defined: Small and Medium Enterprises (SMEs); regional development; environmental sustainability (climate action and urban and natural environment); innovation; trans-European networks; and energy. EIB loans can be combined with EU grants for individual project, in line with the overall EU policies. The EIB provides loans and guarantees for projects which are closer to the market, such as pilot lines, demonstration plants and investments in innovative assets related to production facilities.

The *Risk Sharing Finance Facility (RSFF)*, managed by the EIB, offered funding for higher-risk research and innovation (including infrastructure) projects in the area of KETs, which have a strong European dimension. The *Risk-Sharing Instrument (RSI)* was a pilot guarantee scheme, as part of the RSFF, managed by the European Investment Fund (EIF) under the FP7, aiming at improving access to debt finance for research projects. The Risk-Sharing Finance Facility provided €11.3 billion funding for research projects and provided over €1.4 billion as loan guarantees. The 'InnovFin—EU Finance for Innovators' was launched by the European Commission and the EIB Group in the framework of Horizon 2020 to provide guarantees or direct loans (€24 billion available) to research and innovation projects. InnovFin aims to improve access to risk finance for research and innovation projects, research infrastructures; public-private partnerships and special-purpose projects promoting first-of-a-kind, industrial demonstration projects (EIB, 2014).

3. Bioeconomy in the EU: State of play and potential

Europe has a number of well-established traditional bio-based industries, ranging from agriculture, food, feed, fibre, forest-based industries, including pulp and paper and wood products, to the biotechnology, chemical, biofuels and bioenergy industries. Bioeconomy is already one of the biggest and most important components of the EU economy and it was previously estimated at over € 2 trillion, providing 20 million jobs in 2009 (EC, 2012). Based on recent data, we estimate the bio-based economy turnover at about € 2.4 billion, including agriculture, food and beverage, agro-industrial products, fisheries and aquaculture, forestry, wood-based industry, biochemical, enzymes, biopharmaceutical, biofuels and bioenergy, with almost 22 million persons employed (Table 1).

Table 2 shows our estimate, based on Faostat data (Faostat, 2014), of the total biomass used worldwide, in Europe and in the European Union, including fodder, food crops, industrial crops, crop residues, wood, animal products and aquatic biomass. The data, however, does not include various waste generated, such as waste from food industry, food waste or other biogenic waste. The data shows that almost 15 billion tonnes of biomass were used worldwide in 2011, of which 4.2 billion tonnes for food, 3.7 billion tonnes for feed, 3.4 billion tonnes for processing (sugar, starch, vegetable oils and others in food industry and for materials) and 2.1 billion tonnes being used for energy.

For the European Union, we estimate that almost 2 billion tonnes biomass were used in total, including agricultural and forestry biomass, animal products and aquatic biomass. Of the total biomass of almost 2 billion tonnes of all biomass in the EU in 2011, 21% was used for food, 44% for feed,

Table 1
Estimated contribution of the bio-based economy in the European Union in 2012.
Source: Eurostat (2014).

Sector	Annual turnover (€ billion)	Value added (€ billion)	Employment (1000 s)
Agriculture	404	157	10200
Food and beverage	1040	207	468
Agro-industrial products	231	62	2092
Fisheries and aquaculture	36.6	9.7	199
Forestry logging	42	22	636
Wood-based industry	473	136	3452
Bio-chemicals	50		120
Bioplastics	0.4	1.4	
Biolubricants	0.4	0.6	
Biosolvents	0.4	0.4	
Biosurfactants	0.7	0.9	
Enzymes	1.2		
Biopharmaceuticals	30	50	142
Biofuels	16		132
Bioenergy	34		350
Total	2357		21790

Table 2
Biomass supply worldwide, in Europe and in the European Union in 2011.
Source: Eurostat (2014).

	World [million tonnes]	Europe [million tonnes]	European Union [million tonnes]
Cereals	2318	413	279
Starchy Roots	796	129	60
Sugar Crops	2093	197	126
Pulses	68	7	4
Treenuts	15	3	2
Oilcrops	541	84	61
Vegetables	1,082	105	68
Fruits	632	100	80
Stimulants and spices	28	6	4
Food crops	**7573**	**1043**	**684**
Fibre crops	35	0	0
Fodder crops	1078	573	564
Crops	**8686**	**1616**	**1248**
Crop residues	2359	323	212
Agricultural biomass	**11044**	**1940**	**1460**
Wood	2389	446	290
Agriculture and forest biomass	**13434**	**2386**	**1750**
Meat and animal products	1153	279	200
Aquatic biomass	181	21	14
Total biomass	**14768**	**2686**	**1965**

19% for processing and 12% for energy production (Fig. 1 top right panel). If the whole biomass from agriculture and forestry in the EU is considered (thus including agricultural crops, wood products, agricultural and forest residues), we estimate that from about 1.8 billion tonnes used in 2011, less than 13% was used for food, 49% for feed, 22% for processing and almost 14% for energy (biofuels, heat and electricity) production (Fig. 1 top left panel).

Of the 1.2 billion tonnes of biomass coming from various crops (fodder, food and industrial crops) in the EU in 2011, about 220 million tonnes (18%) were used for food purposes, 747 million tonnes were used for feed (60%) and 179 million tonnes (vegetable oil, starch, sugar, etc.) were used for processing (14%) and 38 million tonnes for energy (mainly biofuels) production 3% (Fig. 1 bottom left panel). The total use of agricultural crops for energy (biofuels production, represented just above 2% in the EU.

The waste from agricultural crops accounts for 23 million tonnes (not considering crop residues such as straw, leaves from sugar beet and residues from food processing), or just below 2% of total consumption of agricultural crops (Faostat, 2014). In addition, about 110 million tonnes vegetal and animal waste are generated from food processing, households and other sectors (Eurostat, 2014). For the total biomass coming from agriculture (thus including various crop residues) we estimate that about 1.5 billion tonnes were used in 2011, of which 15% for food, 58% for feed, 18% for processing and almost 5% for energy (biofuels, heat and electricity) production (Fig. 1 bottom right panel).

3.1. Agriculture and food industry

Agriculture currently covers 174.1 million hectares of land or 40% of the total land area of the EU. Of this, about 103.9 million ha are arable land, 59.1 million ha are permanent grassland and meadow and 10.7 million ha permanent crops. The output value of the EU's agricultural industry at producer prices, comprising the output values of crops and animals, agricultural services and the goods and services produced from non-agricultural secondary activities was estimated to € 404 billion in 2012 (Eurostat, 2014) (Table 3). Gross value added at producer prices of the EU-28's agricultural industry in 2012 was an estimated EUR 156.5 billion. There were 12.2 million farms across the EU in 2010. The agricultural labour input in the EU-27 in 2012 was estimated at 10.2 million annual working units (equivalent to one person working fulltime for a whole year) (Eurostat, 2013).

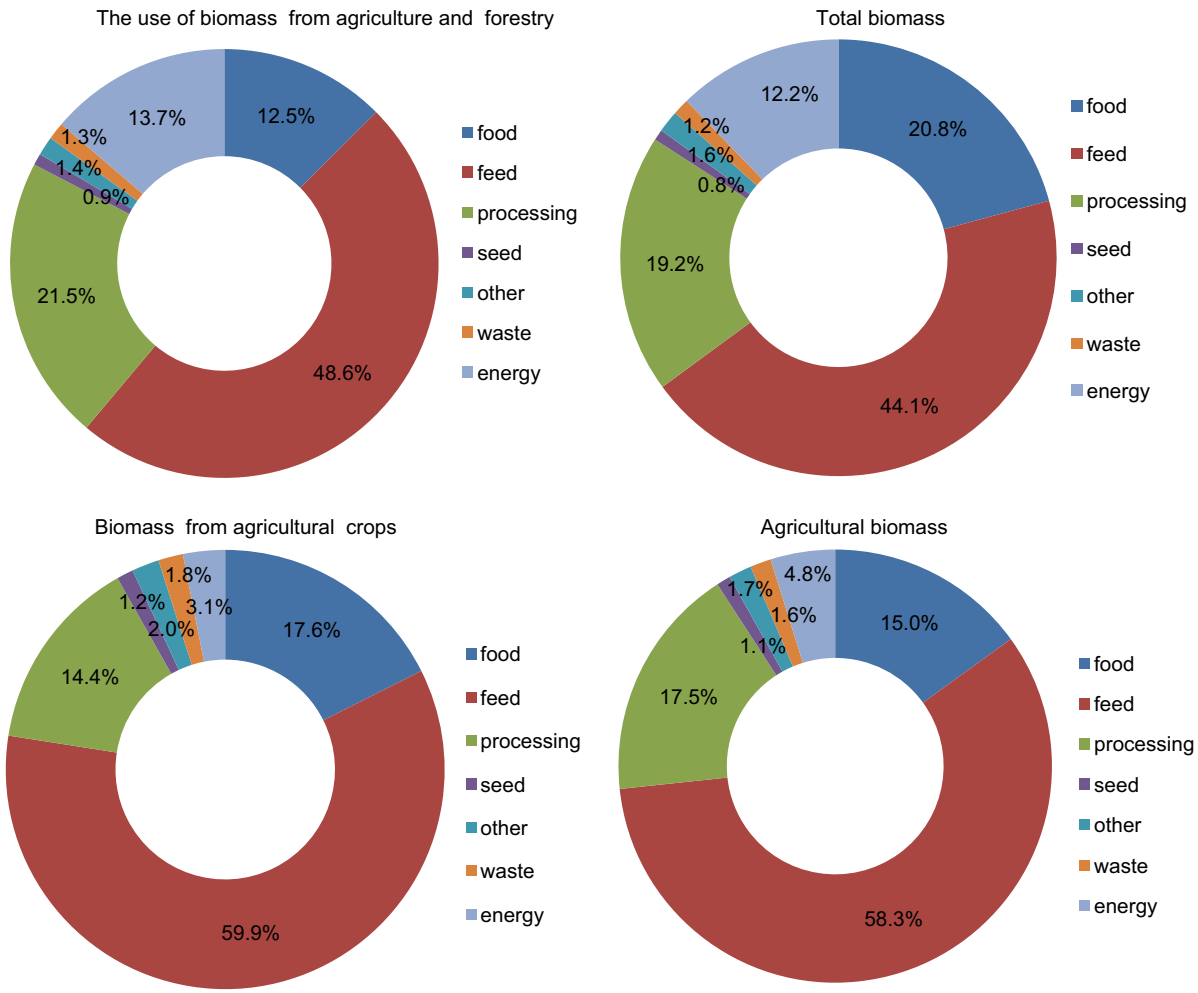

Fig. 1. The use of biomass in the EU in 2011 (*Source*: Faostat, 2014). See text and Table 2 for definitions.

Table 3
Main indicators for agricultural industries in the European Union, 2012.
Source: Eurostat (2014).

	Turnover (€ billion)	Value added at factor cost (€ billion)	Number of enterprises (1000 s)	Number of persons employed (1000 s)
Agriculture	**404**	**157**	**12200**	**10200**
Food products	890	169	262	4,091
Vegetable and animal oils and fats	51	4	8	59
Starch and starch products	10	2	0	16
Sugar	13	4	0	21
Beverages	150	38	24	377
Food and beverage	**1040**	**207**	**286**	**4468**
Tobacco products	30	7	0	33
Textiles	80	22	60	621
Wearing apparel	73	21	126	1015
Leather and related products	47	12	36	422
Industrial products	**231**	**62**	**223**	**2092**
Agricultural industry	**1675**	**426**	**12709**	**16759**

With a turnover of € 1040 billion, a value added of € 207 billion and 4.5 million people employed in almost 286,000 companies, the food and beverage industry is one of the largest and the most important manufacturing sectors in the EU (Eurostat, 2014). There is a wide range of food and beverage products that are made available for human consumption and animal feed, as well as a range of inputs for non-food processes. The industrial products derived from agriculture worth additional € 231 billion and a number of 2.1 million persons employed in the EU.

From a total amount of 684 million tonnes of food crops used in the EU in 2011 (including cereals, starchy roots, sugar crops, pulses, treenuts, oilcrops, vegetables, stimulants and spices), about 220 million tonnes (32%) were used for food purposes, 183 million tonnes were used for feed and 191 million tonnes were used for processing. About 27 million tonnes were used for energy (biofuels production, representing less than 4% of total food crop use in the EU (Fig. 2).

The production of cereals (including rice) in the EU was estimated to be 285 million tonnes in 2012. This represented about 12% of global cereals production (Faostat, 2014), making the EU one of the world's biggest producers of cereals. The largest share of cereals is used for feed (more than 60%) and food (23%). A share of cereals is also used for processing (3.5%) and another for biofuels (ethanol) production (3%).

Vegetable oil is produced from different raw material crops and oilseed crops experienced a significant growth between 2000 and 2012 with rape and turnip rape (20 million tonnes in 2012), and sunflower (7 million tonnes in 2012) being the main types of oilseeds that are produced in the EU. However, significant amounts of oilseeds are imported, domestic production representing only about 70% of the total consumption in the EU and with the import of vegetable oil (palm oil, etc.) playing an important role. The largest proportion of oilseeds (including domestic and imported) is used for processing and the production of vegetable oils (59%) and about 29% is used for biofuels (biodiesel) production (Fig. 3).

The EU produced 125 million tonnes of sugar crops in 2012, of which 116 million tonnes of sugar beet (Eurostat, 2013). Sugar beet production in the EU is managed by a system of production quotas, minimum price guarantees and trade measures designed for sugar. Almost 85% of sugar crops were used for processing in the food industry while we estimate that in 2012, (based on Eurostat, 2014; Faostat, 2014; USDA, 2013) about 9.6% of sugar crops (12 million tonnes) were used in the biofuel sector in 2012 (Fig. 3).

The EU starch industry, with an annual turnover of about € 7.7 billion, has been producing for decades bio-based products that are used in food, non-food, and feed applications (Eurostat, 2013), including hundreds of products used in the chemical, cosmetics, textile, paper, plastics and detergent industries. In 2012, the EU starch industry produced about 10 million tonnes of starch from 23 million tonnes of agricultural raw materials, of which 7.7 million tonnes of maize, 7.8 million tonnes of wheat, and 7.5 million tonnes of potatoes. The EU uses 8.9 million tonnes of starch, of which 62% in food, 1% in feed and 37% in non-food applications, mainly paper making and 5 million tonnes of starch by-products

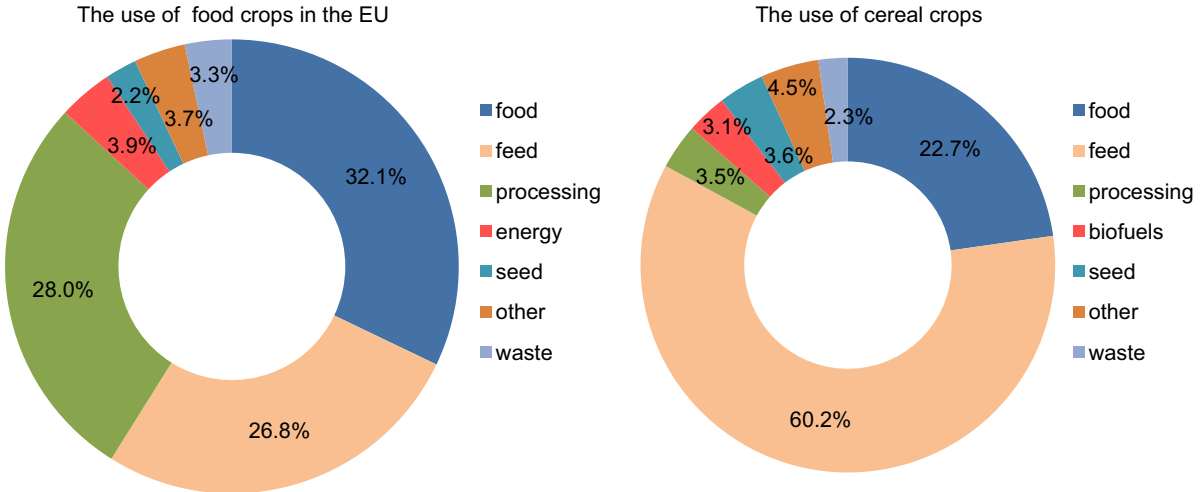

Fig. 2. The use of food crops and cereal crops in the European Union (*Source*: Faostat, 2014).

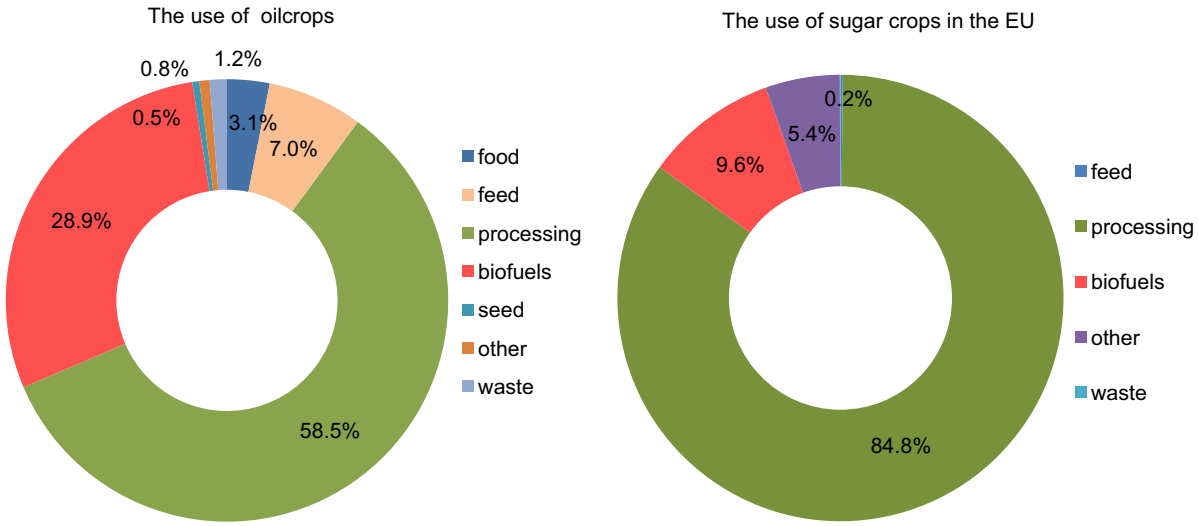

Fig. 3. The use of oil crops and sugar crops in the European Union (*Source*: Faostat, 2014).

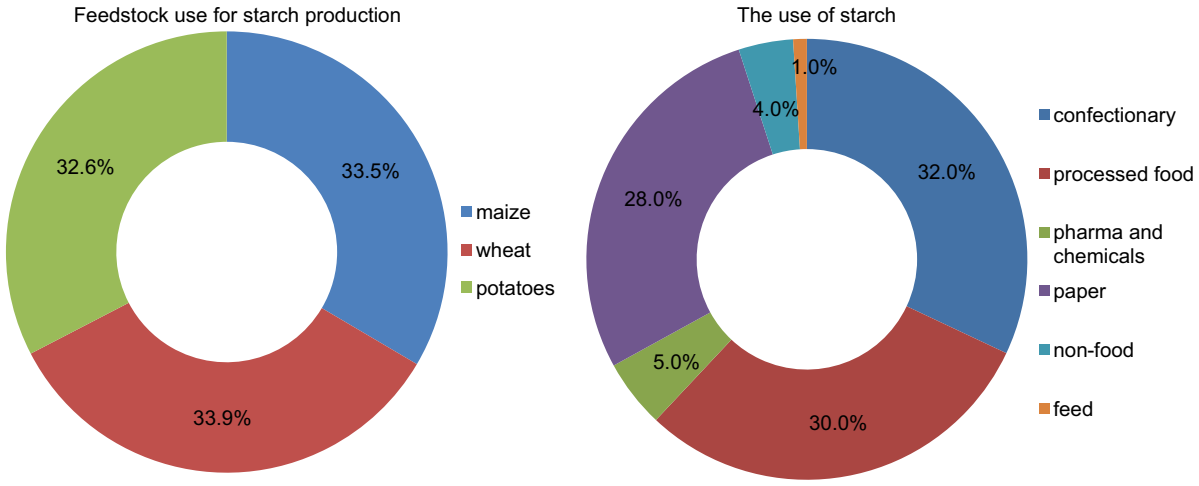

Fig. 4. The production and use of starch in the European Union (*Source*: Faostat, 2014).

(Starch Europe, 2014; Faostat, 2014). The starch by-products include oil, fibres and proteins, which are used for both animal and human nutrition (Fig. 4).

3.2. *Fisheries and aquaculture*

The EU is one of the biggest fishery producers in the world, accounting for about 3.5% of global fisheries and aquaculture production. The total production of fishery products (catches and aquaculture) in the EU was estimated at 6.4 million tonnes of live weight equivalent in 2011 (Eurostat, 2013). The European Union accounts for just above 5% of total fisheries production worldwide, which is a decrease compared to previous years. About one fifth of the EU's total fishery production comes from aquaculture with a production of 1.3 million tonnes of live weight in 2011. The EU fishing fleet had steadily decreased in the last years from a number of 104,000 vessels in 1995 to about 82,000 vessels in 2012 with a combined gross tonnage of 1.7 million tonnes. According to DCF data, the EU fishing fleet generated an income of €7.2 billion in 2011, with a gross value added generated by the EU fishing fleet in 2011 of €3.4 billion and 98,560 number of persons employed in 2011 (in full time equivalents) (Table 4).

Aquaculture (marine and freshwater) is an important activity in the EU in economic terms with a turnover of roughly € 4.0 billion and about 28,000 employees. Its share of total world aquaculture production is 1.5% in terms of volume and almost 4% in terms of value. The total number of companies

Table 4
Main indicators of fisheries and aquaculture in the European Union in 2012.
Source: Eurostat (2014), STECF (2013).

	Turnover (€ billion)	Value added at factor cost (€ billion)	Number of enterprises (1000 s)	Number of persons employed (1000 s)
Fisheries	7.2	3.4	82*	99
Aquaculture	4.0	1.5	14.5	28
Processing	29.4	6.3	3.5	100**
Fishery industry	36.6	9.7	85.5	199

* Number of vessels.
** Full time equivalents.

with aquaculture in the EU was estimated between 14,000 and 15,000. The Gross Value Added for the EU aquaculture sector was estimated to be more than 1.5 billion Euros in 2011 (STECF, 2013) while the fish processing sector in the EU accounted for about €29.4 billion of income and a Gross Added Value of more than €6.3 billion, employing around 100,000 people in 3500 enterprises.

3.3. *Forestry*

The EU's wood-based industries cover a range of forestry downstream activities, including woodworking industries, furniture industry, pulp and paper manufacturing and the printing industry. The wood-based industries are a very important EU economic sector, with a production value of € 456 billion, and an added value of around € 136 billion and about 3.5 million jobs (Eurostat, 2014). Additional 0.6 million people are employed in forestry and logging operations (Table 5). The EU has a total forest area of about 179.5 million ha (around 42% of the EU area and approximately 5% of the world's forests), of which 135.0 million ha are available for wood supply; the forested area of the EU is slowly increasing. The growing stock of forest and other wooded land in the EU-28 totalled some 24.4 billion cubic metres (over bark) in 2010 and the net annual increment in forests available for wood supply to about 776 million cubic metres (Eurostat, 2013).

From a theoretical biomass potential from European forests of 1277 million m^3 per year in 2010, (stemwood, stumps, logging residues and biomass from thinnings), the biomass potential from forests was estimated at 747 million m^3 per year in 2010 (under the medium mobilisation scenario). For 2030, the biomass potential from forest was estimated at 733 million m^3 in the medium mobilisation scenario, but it range between 625 million m^3 and 898 million m^3 per year in different scenarios (EUWood, 2010) (Table 6).

According to Eurostat, 2014, about 423 million m^3 per year was removed from forests in the EU in 2012. The domestic use of woody biomass was estimated at 577 million m^3 in 2010, including 544 million m^3 from forests (roundwood and forest residues) and 33 million m^3 from landscape wood (Mantau, 2012). Of this amount, the pulp and paper sector uses 108 million m^3 woody biomass, the wood processing industry) uses 261 million m^3 and 209 million m^3 is used directly for energy production.

Forest industry is a good example of the cascade use of wood; wood is used/reused several times in different processes and important amounts of wood and paper are recovered and recycled. Thus, the total supply of woody biomass in the EU in 2010 was calculated at 994 million m^3, considering multiple uses of wood, industrial residues and recycled material from wood products. Of this amount, 457 million m^3 wood were used to produce materials in the EU in 2010, of which 142 million m^3 for pulp production and 315 million m^3 for wood products. Significant amounts of wood residues are generated and recycled across during wood processing (176 million m^3), which are reused to produce various products (wood based materials, pulp and paper) and generate energy (Mantau, 2012). At the end of the production cycle, about 60% of wood used in wood processing is used for energy generation (Fig. 5).

Table 5
Main indicators for wood-based industries in the EU in 2012.
Source: Eurostat (2014).

	Turnover (€ billion)	Value added at factor cost (€ billion)	Number of enterprises (1000 s)	Number of persons employed (1000 s)
Forestry and logging	42	22		636
Wood and wood products	121	32	185	1015
Pulp, paper and paper products	175	42	20	650
Printing and printing related activities	84	33	120	767
Furniture	93	29	126	1020
Wood based industry	473	136	451	3452
Forest-based industry	515	158	451	4088

Table 6
Wood biomass potential and the use of wood in the EU [m^3].
Source: EUWood (2010), Mantau (2012).

Wood biomass potential	2010	2020	2030
Supply			
Forest	686	678	681
Wood	308	370	429
Total	994	1048	1110
Use			
Material	458	529	620
Energy	346	573	752
Total	804	1102	1372

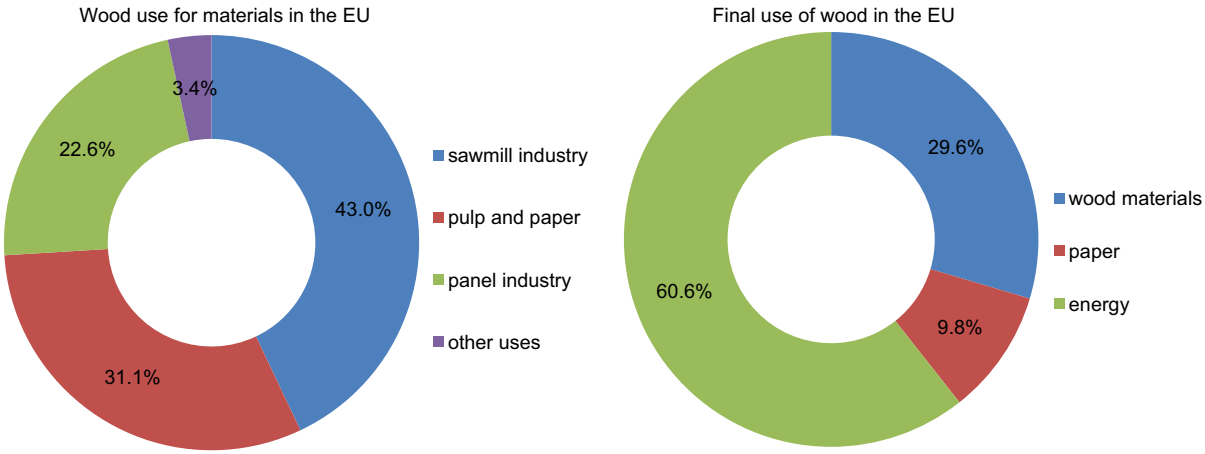

Fig. 5. The use of wood in the European Union (*Source*: Mantau, 2012).

3.4. Bioenergy production

3.4.1. Biofuels

The mandatory targets for the use of renewable energy in transport has boosted the use of biofuels in the EU reaching 564 PJ in 2012. The NREAPs forecasted a use of biofuels of about 1216 PJ Mtoe in 2020, representing more than 90% of the renewable energy expected to be used in transport (Ecofys, 2012; Banja et al., 2013). The global market for biofuels has increased significantly from € 13 billion in 2005 to almost € 60 billion in 2011. In the EU, we estimate biofuel market at about € 15.7 billion in

2012. Considering the expected use of biofuels in 2020 in the transport sector, we estimate, based on the projections for price developments (Charles et al., 2013), that the biofuel market could increase to about € 30 billion in 2020 in the EU. The NREAPs estimate that about 105 PJ lignocellulosic biofuels could be used in transport in 2020, but this depends on their commercial availability and prices. We estimate that the number of persons employed in the biofuels sector would increase from about 125,000 persons in 2012 to about 375,000 persons in 2020 (EurObservER, 2013; Charles et al., 2013).

Today, biofuels are produced largely from food-crops (sugar and starch crops for bioethanol and oil crops for biodiesel). A recent European Council decision limited the use of conventional biofuels to 7% of the energy use in transport for 2020 (European Council, 2014); the rest should come from 2nd generation lignocellulosic biofuels. In the EU, bioethanol is produced from wheat (3.9 million tonnes), maize (4.1 million tonnes), sugar beet (12.1 million tonnes), barley (0.4 million tonnes) and rye (0.4 million tonnes). The bioethanol production capacity increased to about 8.5 billion litres per year in 2012, with an actual annual production of about 4.8 billion litres (2.4 Mtoe) or 57% of the total capacity. Biodiesel is the main biofuel used in the EU in transport, being produced from rapeseed (15.3 million tonnes), soybean (3.5 million tonnes), imported palm oil, recycled vegetable oil and animal fat (Fig. 6). The biodiesel production capacity increased to about 26.3 billion litres, with an annual production of about 10.5 billion litres (8.3 Mtoe) or 40% of the total capacity (EC, 2014q; USDA, 2013). A significant share of the feedstock for domestically produced biodiesel (rapeseed, soybean) came from import together with vegetable oil (mainly palm oil) is also used. Due to the cap on food crop-based biofuels, a further expansion of first generation biofuels is not expected while lignocellulosic biofuels have not yet achieved commercial maturity.

In total, we estimate that about 40 million tonnes of biomass feedstock were used in 2012 to produce biofuels. Significant amounts of by-products of bioethanol and biodiesel were generated; about 3.5 million tonnes of Distillers Dried Grains (DDGs), and about 12 million tonnes of oil meals (which are both generally used for feed). For 2020, about 63 million tonnes of biomass feedstock alone could be used for food crop-based biofuels productions, based on the projections of the NREAPs. In addition about 15 million tonnes of lignocellulosic biomass (wood, straw, etc.) would be needed to produce lignocellulosic biofuels. The production of by-products from bioethanol and biodiesel in 2020 is expected to reach 20 million tonnes of Distillers Dried Grains (DDGs), and about 45 million tonnes of oil meals (some of which produced outside of the EU), respectively.

3.4.2. *Bio-heat and bio-electricity*

The contribution of biomass to energy generation in the EU is important and will further increase, as result of the renewable energy targets for 2020. Bioenergy production is expected to account for about 57% of the renewable energy use in 2020, of which 45% will consist in heat and electricity production from biomass and 12% will be provided by biofuels (Ecofys, 2012; Banja et al., 2013). In 2012, about 141 TW h electricity, about 3.0 EJ heat and about 565 PJ of biofuels came from biomass. A significant amount of biomass was used in households (1679 PJ) in 2012, mainly as traditional wood

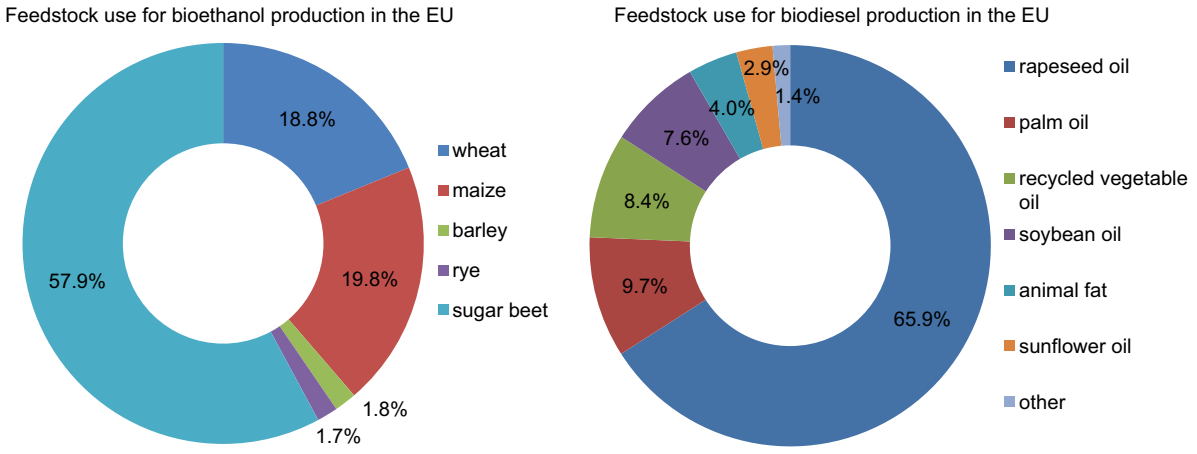

Fig. 6. Feedstock use for biofuel production in the EU in 2012.

fuel in the form of logs, round and split, for heat and hot water production increasing amount is also used an wood pellets. Based on the data from the progress reports (EC, 2014q) we estimate that about 280 million tonnes biomass was used for bioenergy, of which 240 million tonnes biomass was used for heating and electricity production. Of this, about 178 million tonnes came from forestry, 32 million tonnes from agriculture and about 30 million tonnes from waste. About 100 million tonnes of biomass was sources as direct supply of wood biomass from forests and other wooded land (forest fellings etc.) and about 78 million tonnes of biomass came as indirect supply of wood biomass (residues and co-products from wood industry etc.). From agricultural sector, about 40 million tonnes were originating from energy crops and 32 million tonnes from agricultural by-products, processed residues and fishery by-products (our calculation from Progress reports).

Significant amount of electricity is expected to be generated from biomass (233 TW h) in 2020, while the heat derived from biomass should reach 3792 PJ (Ecofys, 2012; Banja et al., 2013). For 2030, the biomass electricity production is projected (Energy Roadmap 2050) to further increase to 360 TW h in 2050 in the reference scenario and up to 460–494 TW h in 2050 in different decarbonisation scenarios (EC, 2011e). Based on the projections made for 2020 on the use of biomass for energy generation, we estimate about 420 million tonnes biomass to be used for heating and electricity production. Of this, about 224 million tonnes came from forestry, 136 million tonnes from agriculture and about 60 million tonnes from waste. About 144 million tonnes of biomass is expected to come as direct supply of wood biomass from forests and other woodland (domestic and import) (forest fellings etc.) and about 80 million tonnes of biomass will be provided by indirect supply of wood biomass (residues and co-products from wood industry etc.). From agricultural sector, about 84 million tonnes could come from energy crops and 52 million tonnes from agricultural by-products, processed residues and fishery by-products. The economic value of the bioenergy production (heat and electricity) in the EU in 2012 was estimated at € 34 billion (EurObservER, 2013) and we estimate that this could grow to € 44 billion in 2020, based on the NREAPs projections for bioenergy production. The bioenergy sector employed almost 350,000 people in the EU in 2012, we estimate to grow to about 450,000 people in 2020. Table 7 shows the current use of biomass for bioenergy production (electricity, heating and biofuels) and the expected demand for 2020, we estimated on the basis of the MS progress reports and NREAPs projections.

3.5. *Bio-based industries*

The contribution of biotechnology to EU economic performance is currently modest, but growing rapidly. Biotechnology makes use of biological systems and processes to manufacture various products covering a range of sectors: industry (white biotechnology), medicine (red biotechnology), agriculture (green biotechnology), aquaculture (blue biotechnology). Biotechnology has multiple industrial applications including the manufacture of chemicals, fine chemicals and biopharmaceuticals, bio-polymers and bio-plastics, food, feed, detergents and biofuels.

Table 7
Biomass use for bioenergy in the European Union (million tonnes).
Source: our calculation

	2012	2020
Forestry biomass	**178**	**224**
Wood biomass (wood fellings etc.)	100	144
Wood residues and co-products	78	80
Agricultural biomass	**72**	**136**
Energy crops	40	84
Agricultural by-products/residues	32	52
Waste	**30**	**60**
Total	**280**	**420**

3.5.1. Biochemicals

The global chemistry market was estimated at the € 3127 billion in 2012 and to $4012 billion by 2020. The European chemical industry holds a strong position, with a market of €673 billion, of which € 558 billion in the European Union, but with a market share declining due to the increase of global market (Cefic, 2014a). Chemical industry produces a wide range of products, such as base chemicals (petrochemicals and basic inorganics), polymers (plastics, synthetic rubber, fibres), specialty chemicals (auxiliaries for industry, paints and inks, crop protection, dyes and pigments) and consumer chemicals (and detergents as well as perfumes and cosmetics). From the market point of view, industrial biotechnology has a larger long-term business potential than red biotechnology. It is estimated that more than 20% of all chemicals coming from the traditional chemistry sector could be produced by biotechnological means in 2020 (Meyer and Werbitzky, 2011).

There are already several bio-based products on the market and in the EU, the chemical industry has used about 8.6 million tonnes of renewable raw materials in 2011 in comparison with 90 million tonnes of feedstock used to produce various chemical substances (Cefic, 2014b). The renewable raw materials include vegetal oils and animal fats, carbohydrates, sugar and starch, natural rubber, etc. (EC, 2012b) (Fig. 7).

The sales of chemicals based on industrial biotechnology were estimated at around € 48 billion in 2007 (3.5% of total chemical sales) and increased in 2010 to around € 100 billion (6% of chemicals) and was expected to increase to 135–150 billion Euro in 2012 (9% of chemical market) and to € 515 billion until 2020 (Riese, 2009; Festel Capital, 2010). The percentage of products derived from biotechnological processes will increase in all market segments: base chemicals will increase from € 16 billion in 2010 to € 71 billion in 2020, polymers and fibers will increase from € 19 billion to €167 billion, specialty chemicals will reach €89 billion from € 22 billion, consumer chemicals will grow from € 18 billion to € 104 billion and active pharma ingredients from € 16 billion to € 83 billion. The share of biochemicals was estimated to be 3.5% in the case of biobased products, 9% in the case of specialty chemicals, 12% for consumer chemicals and 34% for active pharma ingredients. Overall, the share of biochemicals could reach between 20% and 22%, depending on the development of technologies, feedstock prices and policy framework (EC, 2013c), of which about 20% of base chemicals (including polymers and fibres), 15% of specialty chemicals, about 25% consumer chemicals and more than 50% of active pharma ingredients (Fig. 8) (Festel Capital, 2012). For the EU, it was estimated that up to 30% of oil-based chemicals and materials would be replaced with bio-based ones by 2030 (BBI, 2014).

3.5.2. Bio-plastics

In the past, plastics have been fully derived from oil products, but there is a significant expansion of the biobased plastics. Bio-plastics (both as biodegradable and non-biodegradable polymers) are used in multiple applications, such as packaging, consumer goods and household appliances, agriculture/horticulture, consumer electronics, and automotive (Biochem, 2010; European bioplastics, 2012). Most bio-plastics are currently produced from food crops feedstock, such as maize. On a longer term, bio-

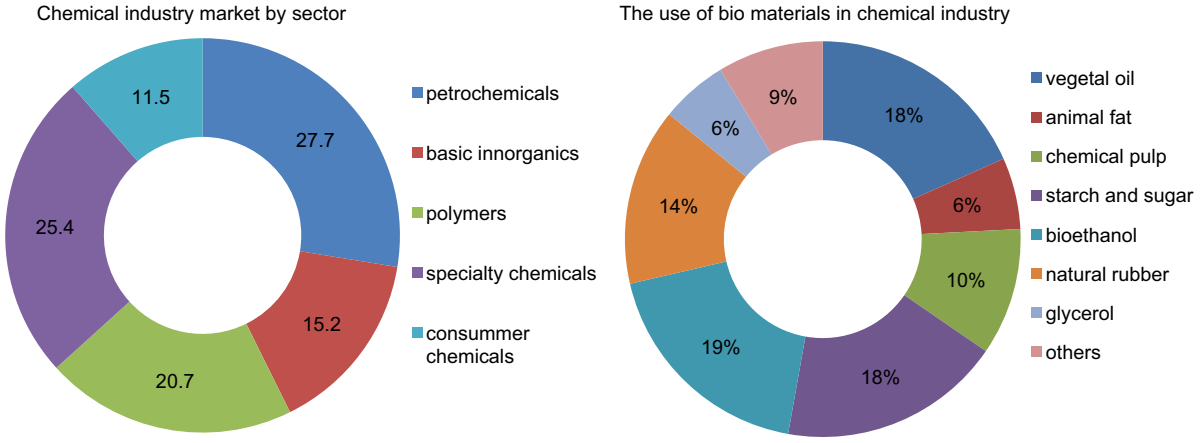

Fig. 7. Chemical industry market and the use of bio-materials in the EU in 2011 (*Source*: Cefic, 2014b)

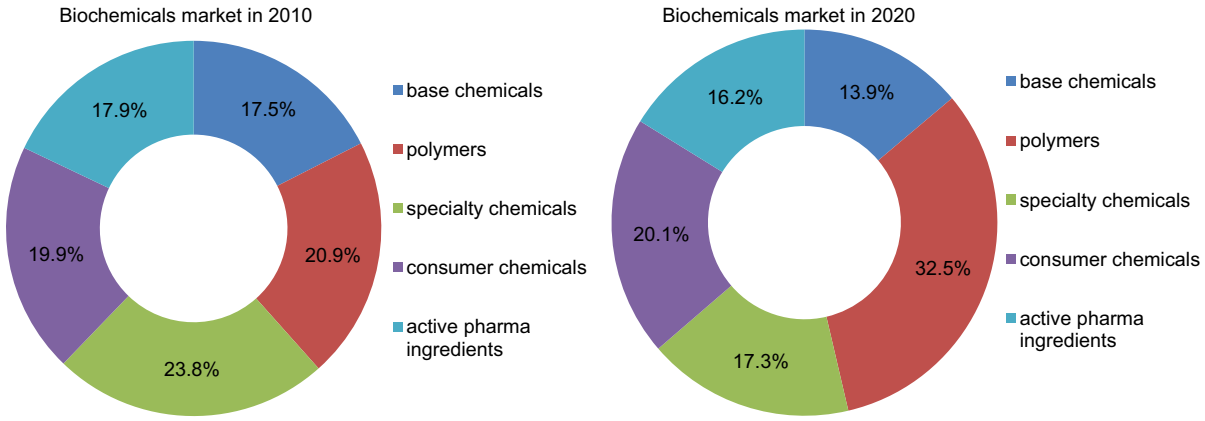

Fig. 8. Bio-chemicals market in 2010 and 2020 (*Source*: Festel Capital, 2012; Cefic, 2014b).

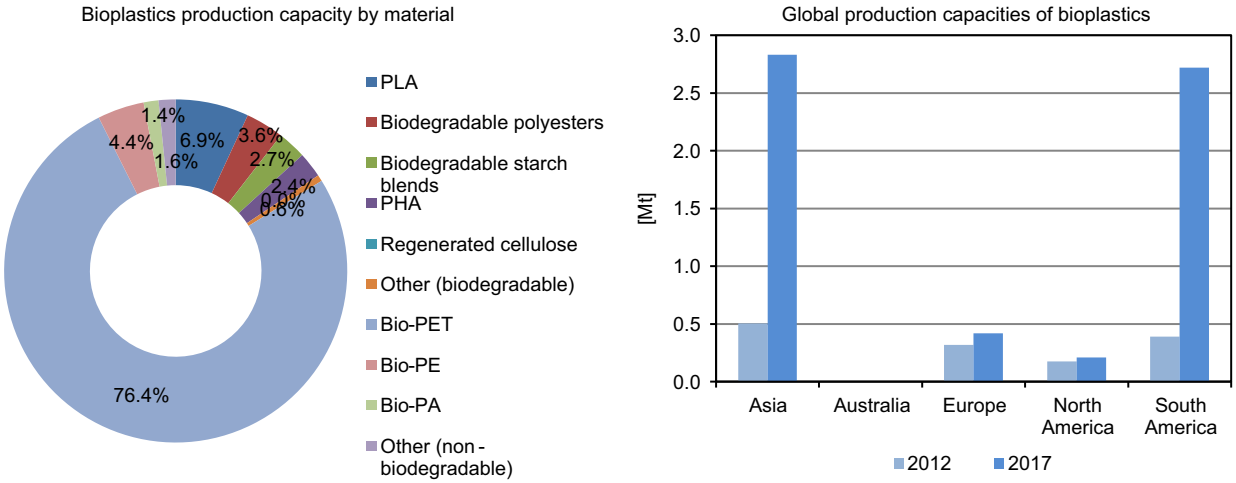

Fig. 9. Production of bioplastics (*Source*: IFBB, 2012).

refineries might be able to produce several products using lignocellulosic feedstock using waste, grass and wood.

The global consumption of bioplastics amounted to about 0.9 million tonnes in 2012, representing about 0.3% of 288 million tonnes of plastics consumed (Statista, 2014), Bio-plastics consumption grow up to 3 million tonnes by 2020 and its global production capacity is projected to increase from 1.4 million tonnes/year in 2012 to 6 million tonnes/year in 2020 (European bioplastics, 2012). In Europe, about 0.3 million tonnes bioplastics are produced annually, or about 0.5% of the plastics production of 57 million tonnes and could increase up to 0.9 Mt in 2020 (Rouhiainen, 2012) (Fig. 9). The global market potential of bioplastics was estimated at € 4.5 billion in 2012, which could increase to € 14.9 billion in 2017 (IFBB, 2012). For Europe, the bioplastics market was estimated at € 420 million in 2012 and € 485 million in 2013, with a potential increase to € 900 million in 2017 and to € 1.4 billion in 2020 (European Bioplastics, 2012; BIO-TIC, 2014). Currently, 5–10% of the plastics available on the market could be bio-based plastics and in the long-term, this share could increase up to 70–85%. If considering that biobased plastics could potentially substitute around 85% of polymers, the potential for bioplastics in Europe could reach, by 2050, up to 50 million tonnes. The market for bioplastics is expected to reach about € 5.2 billion in 2030 in the reference scenario and between € 4.3 billion and € 6.7 billion, with growth rates between 10% and 15% (BIO-TIC, 2014; European Bioplastics, 2012).

3.5.3. Bio-lubricants

Lubricants are used largely in automotive applications and various industrial applications. Global lubricant demand was 35 million tonnes in 2012 (without marine oils) (Gosalia, 2014) and it is expected to reach 44 million tonnes by 2020. Bio-lubricants, including plant-oil based products and synthetic plant-based lubricants, are increasingly being preferred due to improved properties of biodegradability, viscosity and emissions.

The global bio-lubricant production amounted to about 0.6 million tonnes in 2013 and is expected to reach 0.9 million tonnes by 2020 with the global market expected to increase from $2 billion in 2013 to $3 billion by 2020. The European production of lubricants was 4.5 million tonnes in 2008 and it is estimated that biolubricants represented about 0.14 million tonnes or about 3% of this production. Bio-lubricant consumption could grow up to 0.3–0.4 million tonnes by 2020. In economic terms, it was estimated that the biolubricants market valued € 410 million in 2010 and will reach € 640 million by 2020 (Rouhiainen, 2012; Grand View Research, 2014a–c; Research and Markets, 2014; NNFCC, 2014).

3.5.4. Bio-solvents

Solvents are organic substances that have the ability to dissolve other organic substances. Solvents are used in paints and varnishes, printing inks and adhesives and in pharmaceuticals, cosmetics, and cleaners. The global market for solvents is expected to increase from 18 million tonnes in 2012 to reach about 23 million tons by 2020 (Transparency Market Research, 2014a,b). In economic terms, the solvents market was valued at $ 24 billion in 2012 and is expected to reach about $ 35 billion by 2020. Pushed by lower environmental impact, biodegradability, low toxicity and no volatile organic compounds emissions, bio-solvents are gradually replacing the conventional ones and their market is expected to experience rapid growth. The global market for bio-solvents was $4.0 billion in 2012 and is estimated to reach $ 6.5 billion by 2018 and $ 7.7 billion by 2020. The EU solvent market totalled 5.0 million tonnes in 2008 of which 0.6 million tonnes (12%) of bio-based solvents and their consumption is expected to further increase to about 1.1 million tons by 2020. The market for bio-solvents in the EU was evaluated at € 356 million in 2010 and to grow to about € 400 million in 2020 (Biochem, 2010; Rouhiainen, 2012; Transparency Market Research, 2014a).

3.5.5. Biosurfactants

Surfactants are used to produce household detergents, cleaners, personal care products, agricultural chemicals, textiles, coatings, etc. The global surfactants market is projected to reach 23 million tonnes and a value of $40 billion by 2020. Globally, bio-based surfactants represent a small share of the surfactant market with about 0.3 million tonnes produced in 2012, expected to reach 0.5 million tonnes by 2020. The global market for bio-surfactants was assessed at $ 1.7 billion in 2012 and could reach $ 2.3 billion by 2020 (Grand View Research, 2014b; Transparency Market Research, 2014b). The EU is the largest market and the leading producer for bio-based surfactants, although their production is still very small compared to conventional surfactant production. The consumption of bio-based surfactants reached 0.18 million tonnes in 2013 and a market value of € 680 million, representing about half of the global market; EU market value is expected to increase to almost € 900 million in 2020 (Rouhiainen, 2012; BIO-TIC, 2014). On longer term, until 2030, bio-based surfactants are expected to be produced from a variety of feedstocks including traditional plant oils, fats and sugar biomass but also algae and waste streams. The market for bio-based surfactants in the EU was estimated to increase to about € 1.3 billion in 2030, with estimates varying from € 0.9 billion to € 1.8 billion, respectively (BIO-TIC, 2014).

3.5.6. Enzymes

The industrial enzyme market has been expanding lately with the advancements in biotechnology, especially in the area of genetics and protein engineering, which opened up new enzyme application areas, new products and process improvement. There are more than 3000 known enzymes, of which only about 150 are used commercially. Enzymes are biologically produced proteins that catalyse chemical processes and speed up chemical reactions (up to millions of times faster), with many

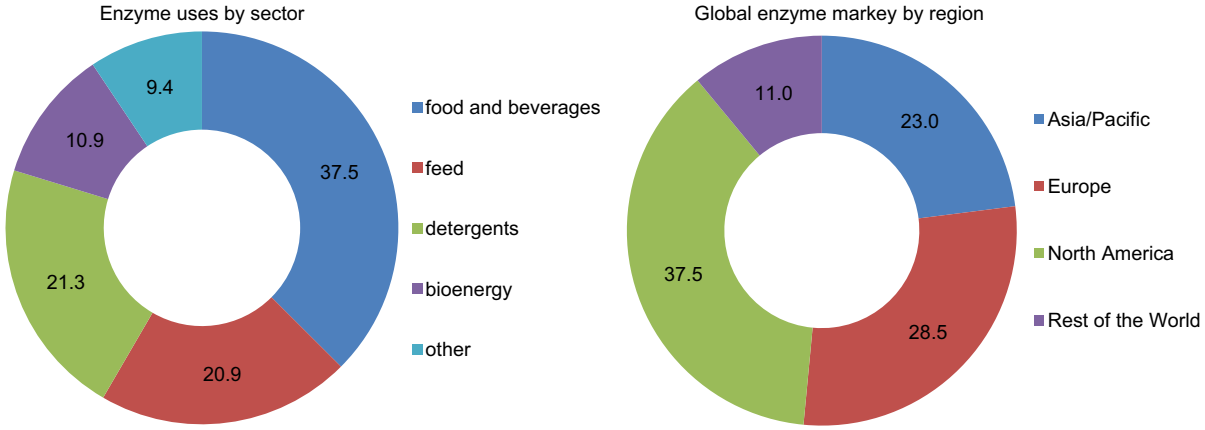

Fig. 10. Enzymes uses and markets in 2012 (*Source*: Grand View Research, 2014c).

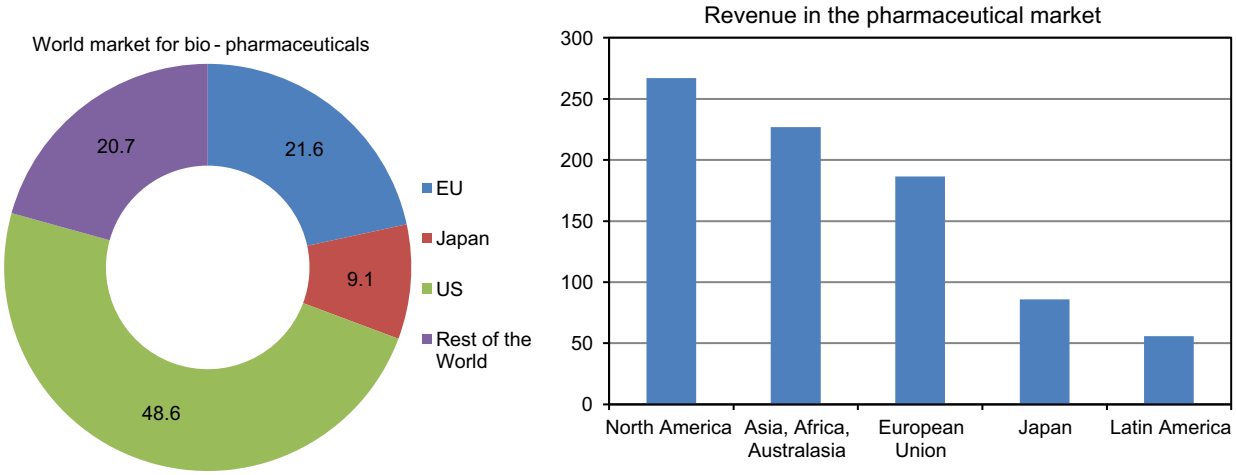

Fig. 11. The market for pharmaceuticals and biopharmaceuticals in 2012.

applications in food and beverages, detergents, animal feed, pulp and paper, fine chemicals, pharmaceutical, biofuels, etc. (Fig. 10) (Binod, 2013; Golden and Handfield, 2014).

Improved industrial biotech processes that facilitate the conversion of lignocellulosic biomass into biofuel are being developed and the market for enzymes for biofuels production is expected to expand. The global market for enzymes was estimated at about $4.5 billion in 2012 and it is expected to grow at almost $8 billion in 2020. Europe is the world leader in key industrial biotechnologies such as enzyme technologies, with Novozymes from Denmark holding a market share of 47% worldwide. The European market for enzymes was estimated at $ 1.2 billion in 2012 (Ambjerg, 2012; Grand View Research, 2014c; BCC Research, 2014).

3.5.7. *Biopharmaceuticals*

The global market for medicines was $ 956 billion in 2011 which is expected to reach $ 1200 billion in 2016, with the EU having a market of about $ 168 billion. The pharmaceutical market is the most important driver for innovation in industrial (red) biotechnology. The pharmaceutical industry is the technology sector with the highest added-value per person employed, well above the average value for high-tech industries.

Over the past 30 years, pharmaceuticals based on biotechnology or biologics have been growing at twice the rate of the whole pharmaceuticals market. The global sales of bio-pharmaceuticals were estimated at $ 170 billion in 2012, accounting for 18% of the overall global market for pharmaceuticals. The EU biopharmaceuticals account for about €30 billion representing approximately 22% of the pharmaceuticals market; up to 50% of new medicines are now biopharmaceuticals (Fig. 11).

Biopharmaceuticals employs about 142,000 people in the EU (Efpia 2013). IMS Health forecasts that the global biologics market will reach $ 250 billion by 2020 (IMS Health, 2014). Biopharmaceuticals are expected to experience a significant increase in the world with growing rates of 8–10% per year to reach a share of 25% revenue from biotechnology in 2020 (HM Government, 2013). The EU market for pharmaceuticals based on biotechnology could reach € 52 to € 60 billion by 2020.

3.6. Biomass demand, supply and potential

Biomass availability and the competition between the alternative use of biomass (food, feed, fibre, bio-based materials and bioenergy) are major concerns for the development of a bioeconomy. Biomass is a renewable, but limited resource, as biomass production requires land and additional resources (water, nutrients). It is therefore important to analyse the demand for biomass in relation to the existing potential.

Several studies have provided estimates of the potentially available amount of biomass in the EU and worldwide, showing large variations. The estimates of the world supply of biomass in 2050 show large ranges, between 100 and 300 EJ with most studies providing a range of potentially available sustainable biomass of 150 to 400 EJ by 2050 (Chum et al. 2011).

In the EU, several studies provide estimates of the biomass potential for energy utilization in the EU, covering forest, agriculture and waste to a different extent. The European Environment Agency assessed the environmentally compatible biomass potential for the European Union (covering 25 Member States) for energy use at 9839 PJ: 1641 PJ from forestry, 4007 PJ from agriculture and 4181 PJ from waste (EEA, 2006). Another study, carried out by the Biomass Futures project, shows that the biomass sustainable potential might be even larger in the EU27 in 2020, reaching 15,675 PJ, of which 7000 PJ from forestry, 6600 PJ from agriculture and 2075 PJ from waste (Elbersen et al., 2012). This review of the estimates of bioenergy potential shows that there are a wide variations and high uncertainties about the real potential (Table 8).

The assessment of the future biomass availability is difficult to define and dependent on the assumptions made regarding the future demand for various uses, including food and feed (translated into land requirements) as well as the industrial products (fibre, pulp and paper, wood products, etc.) and energy. The estimates for the potential of energy crop depend on the land area assumed to be available, which depends on the assumptions about population growth, diet, and crop yield improvements.

The biomass demand for reaching the 2020 targets for bioenergy in the European Union will increase significantly by 2020 (see also Sections 3.4.1 and 3.4.2). Based on the NREAPs projections we quantified the biomass required for reaching the proposed 2020 targets for bioenergy (electricity, heating and transport) for the whole EU and each Member State (Scarlat et al., 2013). The results show that in the EU, total biomass demand would increase from 3110 PJ in 2005 to 7437 PJ in 2020. Our calculations also show that the amount of biomass actually used in 2010 reached about 4764 PJ and about 5010 PJ in 2012, in line with the aggregated data from the MS progress reports on biomass supply. The major part is expected be delivered by solid biomass, with 4.996 PJ, followed by biofuels with 1216 PJ, biogas with 887 PJ and bioliquids with 338 PJ EC, 2007e. Comparing the potential and demand, the biomass potential of the European Union is large enough to ensure the biomass demand of 7424 PJ needed to reach the bioenergy targets.

Table 8
Biomass potential for energy use in the European Union.
Source: EEA (2006), Elbersen et al. (2012)

	Current potential [PJ]	2020 Potential [PJ]	2030 Potential [PJ]
Forestry	1779–4490	1717–4605	2303–4647
Agriculture	1968–2135	3684–4019	2931–5945
Waste	4145–6029	4145–7411	4019–7201
Total	7892–13105	9546–16035	9253–17794

According to the aggregated data from the NREAPs provided by the Member States, we estimated that biomass domestic supply is expected to increase from around 3542 PJ in 2006 to around 5454 PJ in 2020. The MS data show that domestic biomass supply should mainly come from forestry with 3124 PJ, from agriculture and fisheries with 1628 PJ and from waste 703 PJ (Banja et al., 2013). Some biomass is also expected to be imported for bioenergy production, although the domestic potential is not fully exploited, in the form of biofuels as well as solid biomass (wood residues, wood pellets, etc.). At the moment significant amount of biomass is imported in the EU (mainly as wood pellets, feedstock for biofuels, etc.).

Bio-based materials and biobased chemicals do not account yet for a very big share of biomass use. There are large uncertainties about the real available potential of biomass for different uses due to the competing uses (e.g., increased use of wood products, pulp and paper, the use of agricultural residues for fodder, as well as new biomaterials) and the application of various sustainability criteria. However, the switch toward a bioeconomy will entail high demand for biomass not only for bioenergy, but also for bio-materials such as plastics that are presently derived from fossil sources. The conversion of a fossil fuel-based economy into a bio-based economy will probably be constrained by the overall limited availability of sustainable biomass in the EU. The EU will depend on the biomass import to provide biomass feedstock for the bio-based economy in the future. Imports will mainly consist of crops, vegetable oils, wood and wood products, wood pellets or biofuels. An increase in the bio-based economy is expected to be a worldwide development. Therefore, only a part of the globally available biomass potential is available for the EU.

The biomass supply for bioenergy production (electricity and heating) is expected to further increase, to reach about 6045 PJ in 2030 and 6234 PJ in 2050 in the reference scenario, ranging between 5765 PJ and 6798 PJ in 2030 and between 7247 PJ and 9603 PJ in different decarbonisation scenarios of the Energy Roadmap 2050. On long term, biofuels consumption in transport sector was projected to increase to 1476 PJ in the Reference scenario in 2030 and 1547 PJ in 2050 ranging between 1048–1100 PJ in 2030 and 2863–3033 PJ in 2050, in different scenarios (EC, 2011e). Thus, we estimate that the use of biomass for bioenergy should increase significantly to reach about 420 million tonnes biomass in 2030 and 432 million tonnes in 2050 in the reference scenario, ranging between 378 million tonnes and 439 million tonnes in 2030 and between 562 million tonnes and 702 million tonnes in different decarbonisation scenarios in 2050. This biomass demand is possible to be available in the EU, but the biomass mobilisation from all sources is the key, depending on the cost of biomass.

4. Discussion on the road to bioeconomy

4.1. Perspectives for bioeconomy

The development of bioeconomy has great perspectives, and biotechnology is likely to be widely applied by 2030, in primary production to develop new plant varieties, microorganisms or algae etc., in health to produce new biopharmaceuticals and in industry to produce biochemicals, biopolymers, enzymes and biofuels.

The OECD estimated the maximum contribution of biotechnology to Gross Value Added (GVA) in the European Union and the United States to be 5.6% and 5.8%, respectively. The biotechnology could contribute by 2030 to 50% of primary production, 80% of pharmaceutical production and 35% of industrial production in sectors where biotechnology has potential applications. Biotechnological processes are expected to account for up to 50% for fine chemical production and for speciality chemicals. The biotech share of commodity chemicals will be smaller, between 5% and 10%, while the share of bio-based polymer could reach a share between 10% and 20% of total polymer production worldwide, until 2025 (OECD, 2009).

Biotechnology has a key role to play in the bio-based economy, but in order to benefit from the advantages of a biobased economy, innovative technologies have to be developed. An increase in the demand for high value bio-based products is an incentive for technological development along the whole supply chain, from production to conversion, to develop newer, integrated technologies, based on prioritisation and cascading use of biomass, better use of co-products, etc. However, creating new

markets for bio-based materials depends on achieving a breakthrough in terms of technical performances and cost effectiveness comparable to present fossil based products available on the market.

A key factor in the transition to a bio-based economy will be the development of biorefinery systems. Biorefining is however not a new concept, being used for example in the pulp and paper production. Biorefineries are a promising integrated approach for the co-production of both value-added products (bio-materials, bio-chemicals, bio-plastics, food, feed) and bioenergy (biofuels, biogas, heat and/or electricity). Biorefineries are largely at the conceptual stage, with potentially interesting new products and routes still being identified. The deployment of the new biorefinery concepts will rely on the advancement in technology of a range of processes, in biotechnology and in synthetic biology (Cherubini et al., 2009; Biochem, 2010; Rødsrud et al., 2012; JRC, 2013). Biotechnology could play an important role in the production of a range of bio-based products either integrated in biorefineries or not. A major issue for biorefinery development is related to the huge demand for biomass associated to large capacity needed to become cost effective, which severely impact on the logistics, collection area and cost of feedstock.

4.2. Opportunities for bio-based economy

The bioeconomy brings the opportunity to develop new biobased industries, open new markets for bio-based products and using resources more efficient and environmentally friendly. A bio-based economy could play a significant role in effectively addressing the pressing global challenges, such as climate change, increasing population, limited natural resources, and increasing demand for food and materials. A European bio-based economy and the sustainable production of chemicals, materials and fuels from biomass can contribute to limit the negative impacts on the environment, mitigate climate change and reduce dependency on decreasing fossil resources (GEF, 2012; EC, 2012b).

The bioeconomy would allow sustainable production and exploitation of biological resources and improve the economic and environmental sustainability of the industry. A bio-economy has the potential to contribute significantly to the development of a green, low carbon economy due to the lower carbon footprint of bio-based products. The bio-based economy introduces a closed carbon cycle and prevents releasing more CO_2 in the atmosphere through to the extraction of carbon (oil, gas or coal) from the earth, as our current fossil-based system. However, this does not automatically mean that the bio-based economy is carbon neutral (GEF, 2012).

The EU has a great potential to become a knowledge and technology leader in bio-economy, thanks to its good science basis, good R&D capacities and technological leadership in some key enabling technology areas. Investments in research and innovation in biotechnology will contribute to fostering EU leadership, if translating research results into products and services. A bio-based economy is mainly focused on the production of high added value bio-based products (such as biochemicals and biopharmaceuticals) besides food, feed and fibre. Biorefineries entail a mix of cutting-edge technologies with high potential for innovation and high added value.

The transition to a bio-based economy has enormous potential for development in the EU. Shifting towards a bio-economy creates new business and innovation opportunities in all European regions, in areas such as agriculture, forestry and industry. The bio-economy offers great potential for job creation and green growth, in agriculture, forestry and manufacturing sectors. In this sense, a bio-based economy can contribute to Europe2020 Strategy goals for smart, sustainable and inclusive growth.

The limited availability of sustainable biomass for bio-based materials requires biomass prioritisation and it is an incentive for cascading use of biomass, which can bring significant improvements in resource efficiency with optimal value creation. Cascading use of biomass would contribute to minimising resource use and reducing the competition between different uses: food and feed, chemicals, materials, fuel and energy (GEF, 2012; PBL 2012).

The bioeconomy can significantly contribute to the development of rural areas and industrial areas, which suffered from declining economic activities. The bioeconomy would help shifting agricultural activities towards more sustainable and environmentally friendly activities, creating new supply

chains for biomass feedstock for bio-based industries and developing aquaculture infrastructures. The creation of new non-food markets for crops and biomass feedstock (including residues and waste), could provide alternative income sources for farmers (EC, 2012b).

4.3. Concerns and challenges for bio-based economy

The transition from fossil-based industry towards low carbon, resource efficient and sustainable one is a major challenge. The switch entails the transformation of conventional industrial processes and products into bio-based processes, the development of industrial biotechnologies, integrated bio-refineries and the opening of new markets for bio-based products. The growth potential for bio-based products depends on their capacity to substitute fossil-based products at competitive cost, with smaller ecological footprint and lower GHG emissions.

Achieving resource efficiency and a low carbon economy are key challenges for the future of EU's economy. The concerns on bio-based economy focus on the real GHG balance of bio-products, the hierarchy of biomass use, the food supply and food security, land use changes, overuse of natural resources and water and nutrients scarcity. The reduction of GHG emissions has been the main driver in favour of a transition toward a bio-based economy, but there are several concerns in relation with the real GHG savings from feedstock production, land use changes and bioenergy conversion steps (GEF, 2012).

Moving toward a bio-economy would make increasing use of natural resources from land and sea and lead to an enormous increase in the demand for biomass, which would question the sustainability of a bio-based economy. The availability of sustainable biomass for different uses is critical. Biomass production is dependent upon several factors, such as land, water, nutrients, etc. If more land is needed for increased biomass production, this land could become available through the conversion of forest land and grasslands to arable land, releasing important amounts of CO_2 into the atmosphere. Important issues are both direct and indirect land use changes and the carbon debt for the use of forest biomass for example. The amount of land required for biomass production strongly depends on the type of crop and the allocation of land use for co-products (e.g. for materials, feed, etc.) (PBL 2012; Scarlat et al., 2013).

The increased use of forest and agricultural waste streams for bio-based materials could however have negative effects on the level of organic matter in soil and soil biodiversity with additional negative impacts on soil fertility and soil productivity (GEF, 2012). The need to increase crop productivity could lead to increased use of fertilisers and pesticides with additional problems related to water and soil pollution. The bio-based economy can aggravate water scarcity in many areas of the world, because it puts additional pressure on water demand. Additional demand for land for food and non-food crops could result in more monocultures, negative environmental impact and more pressure on natural habitats and biodiversity.

A major risk in fostering a bio-economy lies in the increased competition between food supply and non-food biomass production. The world population is expected to reach 9 billion people by 2050. An increase in food consumption due to the population increase, changes in diet and improvement in well-being will result in extra demand for food and feed crops, putting more pressure on land use (OECD, 2009). Increased demand for biomass for bio-based products undermine food security and have significant impact in terms of price levels and price volatility. Although non-food crops provide an additional income for farmers, the main issue for food security is the access to food rather than food availability, since poor people, who need to buy food, might be affected the most by the increase in food prices.

Several options are available to address this competition for food and non-food biomass production, such as the use of marginal and degraded land, increasing productivity, cascading use and enlarging biomass base (residues and waste, etc.). However, there are uncertainties about the degree to which the increase of agricultural production (e.g. yield improvement) can address this large increase in biomass demand and to what extent the competition can be avoided. The introduction of new technologies, through for example, the use of micro-algae could significantly

contribute at reducing competition with food, because of thy have high productivity and do not compete for agricultural land.

4.4. Sustainability concerns, standardisation and certification

Ensuring sustainability is a major issue for a bio-based economy. At global level, there are several certification schemes varying considerably in scope, as were developed for a range of products and several sectors (agriculture, forestry, etc.), as a result of various concerns or specific purposes (fair-trade, environmentally sound cultivation, organic agriculture, etc.). Several certification systems apply to the agricultural sector (such as IFOAM, GlobalGAP, SAN and FAIR TRADE) being developed to ensure environmentally friendly or sustainable agricultural production, healthy and safe products or to develop organic agriculture with the sustainability criteria addressing mainly environmental aspects. Several ongoing initiatives for forest certification (such as FSC and PEFC) were set mainly to ensure sustainable management of forests (Van Dam et al., 2010; BTG, 2008).

As result of sustainability concerns related to the biofuels production, several certification schemes were developed worldwide for biofuels. The EU has also proposed MS to use the same criteria for the use of solid and gaseous biomass for energy production. However, sustainability requirements do not apply for biomass used for the production of bio-based products and bio-chemicals. A number of initiatives were launched to develop voluntary sustainability standards for the production and conversion of biomass to bioenergy. These certification schemes include limited environmental, economic and social aspects, while some specific issues are not addressed. For example, the issues of indirect effects, food availability, food security are only addressed in certain certification schemes, developed for biofuels sustainability. The environmental viability of biofuels has been questioned based on the concerns over indirect land use changes that need to be addressed in a certification scheme for biobased materials as well.

Sustainability requirements should cover all types of biomass, with the same criteria for different uses of (food, feed, chemicals, materials, biofuels and bioenergy). Sustainability criteria for bio-based products, bioenergy and biofuels should be comparable to avoid leakage, must address sustainable biomass production and GHG emissions and cover conversion steps and include various aspects such as resource efficiency (EC, 2012b). The *Roundtable on Sustainable Biomaterials (RSB)*, built on the previous Roundtable of Sustainable Biofuels, expanded its scope in 2013 to cover biomaterials—bioenergy (liquid biofuels as well as biomass and biogas for energy generation) and bio-based products (biochemicals, such as bioplastics and bio-lubricants) (RSB, 2014).

Besides certification addressing sustainability concerns and contributing to increase public acceptance for bio-based products and processes, standardisation is essential to support the creation of new markets and to create trade opportunities for the bio-based economy. The application of standards can help removing trade barriers, increase market transparency and increase public acceptance. To address the lack of standards for bio-based products, the Commission has issued several standardisation mandates to CEN. CEN develops European standards covering horizontal aspects of bio-based products as well standards for specific bio-based products such as bio-surfactants (CEN/TC 276), bio-solvents (CEN/TC 411), bio-plastics (CEN/TC 249) and bio- lubricants (CEN/TC 19) (Bio-based Economy, 2014).

Labelling can play an important role for bio-based products, providing consumers with clear information on the characteristics and environmental performance of the products (e.g. bio-based content, biodegradability, sustainability. Product labels should give clear and reliable information about the environmental performance of bio-based products. A harmonised and standardised approach across the EU is needed to avoid proliferation of various labelling schemes. A good example is the EU Ecolabel (EC, 2014r), a voluntary scheme that applies in the EU, based on a harmonised and standardised approach across the EU, identifying products and services with a reduced environmental impact.

5. Conclusions

Biomass is expected to contribute to about half of the EU Renewable Energy target in 2020. Bioenergy at EU level is expected to remain the main RES contributor. Within this framework, it is necessary to ensure that these expected increases in biomass use take place within a sustainable framework and biomass sustainability is thus a key issue.

An important issue to monitor is the competition of uses between traditional uses of biomass (e.g. food, feed and fiber), bioenergy, traditional forest industries (e.g. panel, pulp and paper) and growing sectors such as biomaterials and green chemistry. This might open perspectives for an integrated use of biomass through a cascading approach or by setting up biorefineries.

A significant increase in the demand for biomass for bio-based materials, together with the predictable increase in biomass demand for bioenergy will increase the competition for natural resources, in particular for land and water resources with potential negative impact on the land use patterns, biodiversity and environment. The expected developments in livestock breeding and yields increase in crop production will contribute to increasing biomass production.

References

Ambjerg H.C., 2012. Bio-based Solutions for the Food and Beverage Industry DSM Food Specialties, DSM Bio-based Business Seminar.

Banja M., Scarlat N., Monforti-Ferrario F., Dallemand J.F., "Renewable Energy Progress in EU 27 (2005–2020)," Joint Research Centre, 2013, Ispra, Italy, 2013.

BBI, 2014. Bio-based Industries, ⟨http://www.bbi-europe.eu/⟩, 2014.

BCC Research , 2014. Global Markets for Enzymes in Industrial Applications, BIO030H.

BIO-TIC, 2014. Overcoming Hurdles for Innovation in Industrial Biotechnology in Europe, Market Roadmap: Draft 2 .

Binod, P., Palkhiwala, P, Gaikaiwari, R., Nampthiri, K.M., Duggal, A., Dey, K, Pandey, A., 2013. Industrial enzymes—present status and future perspectives for India. J. Sci. Ind. Res. 72, 271–286.

Bio-based Economy, 2014, ⟨http://www.biobasedeconomy.eu/standardisation/⟩.

Biochem, 2010. Report on the "Assessment of the Bio-based Products Market Potential for Innovation", Final Report, Grant agreement no . SI2.549080-256268, 2010.

BTG, 2008. Sustainability Criteria and Certification Systems for Biomass Production. Project no.1386, Prepared for DGTREN—European Commission.

Cefic, 2014a. Landscape of the European Chemical Industry, The European Chemical Industry Council, 2014 .

Cefic, 2014b. Measuring Bio-Based Raw Materials use in the Chemical Industry. The European Chemical Industry Council, 2014 .

Cherubini, F., Jungmeier, G., Mandl, M., Wellisch, M., Philips, C., Joergensen, H., Biorefineries, Adding Value to the Sustainable Utilisation of Biomass, IEA Bioenergy Publication T42:2009:01, IEA Bioenergy Task 42 on Biorefineries, 2009.

Charles C., Gerasimchuk I., Bridle R., Moerenhout T., Asmelash E., Laan T., 2013, Biofuels—At What Cost? A review of costs and benefits of EU Biofuel Policies, IISD-GSI.

Chum, H., Faaij, A., Moreira, J., Berndes, G., Dhamija, P., Dong, H., Gabrielle, B., Goss Eng, A., Lucht, W., Mapako, M., Masera Cerutti, O., McIntyre, T., Minowa, T., Pingoud, K., 2011. Bioenergy. In: Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Seyboth, K., Matschoss, P., Kadner, S., Zwickel, T., Eickemeier, P., Hansen, G., Schlφmer, S., von Stechow, C. (Eds.), IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Clever Consult, 2010. The Knowledge Based Bio-Economy (KBBE) in Europe: Achievements and Challenges, 2010 .

Cordis, 2014. Community Research and Development Information Service, ⟨http://cordis.europa.eu/technology-platforms/home_en.html⟩.

EC, 2000. Towards a European Research Area, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, COM(2000) 6 Final.

EC, 2002. Life Sciences and Biotechnology—A Strategy for Europe, COM(2002) 27 .

EC, 2006. Green Paper. A European Strategy for Sustainable, Competitive and Secure Energy, COM(2006) 105 Final.

EC, 2007a. An Energy Policy for Europe, COM(2007) 1 .

EC, 2007b. Limiting Global Climate Change to 2 °C—The way ahead for 2020 and beyond (COM(2007) 2 Final).

EC, 2007c. Accelerating the Development of the Market for Bio-based Products in Europe. Report of the Taskforce on Bio-based Products Composed in Preparation of the Communication "A Lead Market Initiative for Europe" (COM(2007) 860 Final).

EC, 2007d. A Lead Market Initiative for Europe, COM(2007) 860 Final.

EC, 2007e. A European Strategy Energy Technology Plan (SET-PLAN), 'Towards a Low Carbon Future', Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, COM(2007) 723 Final .

EC, 2009c. Commission Staff Working Document Lead Market Initiative for Europe Mid-term Progress Report, SEC(2009) 1198 Final .

EC, 2009d. Preparing for Our Future: Developing a Common Strategy for Key Enabling Technologies in the EU, (COM(2009) 512).

EC, 2009e. Commission Staff Working Document 'Preparing for Our Future: Developing a Common Strategy for Key Enabling Technologies in the EU Current Situation of Key Enabling Technologies in Europe' Accompanying the Communication from

the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, SEC(2009) 1257.
EC, 2009f.Investing in the Development of Low Carbon Technologies (SET-Plan). A Technology Roadmap, Commission Staff Working Document Accompanying Document to the Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, SEC(2009) 1295.
EC, 2010a. The CAP Towards 2020: Meeting the Food, Natural Resources and Territorial Challenges of the Future, COM(2010) 672 Final.
EC, 2010b. Energy 2020. A Strategy for Competitive, Sustainable and Secure Energy. COM(2010) 639 Final.
EC, 2010c. Europe 2020 Flagship Initiative Innovation Union Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, COM(2010) 546 Final .
EC, 2010d. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, An Integrated Industrial Policy for the Globalisation Era Putting Competitiveness and Sustainability at Centre Stage, COM(2010) 614 Final .
EC, 2010e. A Digital Agenda for Europe, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions COM(2010) 245 Final.
EC, 2011a. A Roadmap for Moving to a Competitive Low Carbon Economy in 2050, COM(2011)112 final, Brussels, 2011, .
EC, 2011b. Our life Insurance, Our Natural Capital: An EU Biodiversity Strategy to 2020. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, COM(2011) 244 Final .
EC, 2011c. European Commission, A Resource-efficient Europe—Flagship Initiative Under the Europe 2020 Strategy COM(2011) 21 Brussels, 2011 , .
EC, 2011d. Roadmap to a Resource Efficient Europe, COM(2011) 571 Brussels, 2011 .
EC, 2011e. Energy Roadmap 2050 (COM(2011) 885) .
EC, 2011f. Innovation for a sustainable Future—The Eco-innovation Action Plan (Eco-AP), Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, COM(2011) 899 Final .
EC, 2012. Bioeconomy Strategy, "Innovating for Sustainable Growth: A Bioeconomy for Europe", COM(2012) 60 Final, Brussels, 2012(.
EC, 2012b. Commission Staff Working Document Accompanying the Document Communication on Innovating for Sustainable Growth: A Bioeconomy for Europe, SWD(2012) 11 Final .
EC, 2012c. A European strategy for Key Enabling Technologies—A bridge to growth and jobs, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions COM(2012) 341 Final .
EC, 2013. A New EU Forest Strategy: For Forests and the Forest-based Sector, COM(2013) 659 Final .
EC, 2013b, Public–private Partnerships in Horizon 2020: A Powerful Tool to Deliver on Innovation and Growth in Europe, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, COM(2013) 494 Final.
EC 2013c. Industrial Policy Indicators and Analysis. Special Feature: Bio-based Sector Achievements and Further Challenges, with Focus on the Bio-based Products Task Force, 2013 .
EC, 2014. Green Economy, ⟨http://ec.europa.eu/environment/basics/green-economy/index_en.htm⟩.
EC, 2014b. Agriculture and Rural Development, ⟨http://ec.europa.eu/agriculture/index_en.htm⟩, 2014 .
EC, 2014c. Fisheries, ⟨http://ec.europa.eu/fisheries/cfp/index_en.htm⟩, 2014 .
EC, 2014d. Standing Committee for Agricultural Research (SCAR), ⟨http://ec.europa.eu/research/agriculture/scar/index_en.html⟩.
EC, 2014e. The European Strategic Energy Technology Plan, ⟨http://ec.europa.eu/energy/technology/set_plan/set_plan_en.htm⟩.
EC, 2014f. A Policy Framework For Climate and Energy in the Period from 2020 to 2030, COM(2014) 15.
EC, 2014g, Environmental Technologies Action Plan (ETAP), ⟨http://ec.europa.eu/environment/ecoap/about-action-plan/etap-previous-action-plan/index_en.htm⟩, 2014 .
EC, 2014h⟨http://ec.europa.eu/environment/ecoap/index_en.htm⟩, 2014 .
EC, 2014i. Research and Innovation FP7, ⟨http://ec.europa.eu/research/fp7/index_en.cfm⟩, 2014.
EC, 2014j. Competitiveness and Innovation Framework Programme (CIP), ⟨http://ec.europa.eu/cip/⟩, 2014.
EC, 2014k. Research and Innovation, ⟨http://ec.europa.eu/research/index.cfm⟩, 2014 .
EC, 2014l. EIP-Agri, ⟨http://ec.europa.eu/eip/agriculture/en⟩, 2014.
EC, 2014m. Agriculture and Rural Development, ⟨http://ec.europa.eu/agriculture/cap-funding/index_en.htm⟩, 2014 .
EC, 2014n. Fisheries, ⟨http://ec.europa.eu/fisheries/index_en.htm⟩, 2014.
EC, 2014º. Environment, ⟨http://ec.europa.eu/environment/life/funding/lifeplus.htm⟩.
EC, 2014p, Climate Action, NER 300 Programme, ⟨http://ec.europa.eu/clima/policies/lowcarbon/ner300/index_en.htm⟩, 2014.
EC, 2014q. Progress Reports, ⟨http://ec.europa.eu/energy/renewables/reports/reports_en.htm⟩, 2014 .
EC, 2014r. Ecolabel, ⟨http://ec.europa.eu/environment/ecolabel/⟩.
Ecofys, 2012, Renewable energy progress and biofuels sustainability, Report for the European Commission, ENER/C1/463-2011-Lot2, 2012.
EEA, 2006, European Environment Agency, "How much bioenergy can Europe produce without harming the environment?," Report No 7/2006 ISBN 92-9167-+849-X2006,2006, .
Efpia, 2013, The Pharmaceutical Industry in Figures. European Federation of Pharmaceutical Industries and Associations.
EIB, 2014. European Investment Bank, ⟨http://www.eib.org/⟩, 2014.
EIBI, 2014a. European Industrial Bioenergy Initiative, ⟨http://www.biofuelstp.eu/eibi.html⟩, 2014.
EIBI, 2014b. European Industrial Bioenergy Initiative (EIBI) Boosting the Contribution of Bioenergy to the EU Climate and Energy ambitions Implementation Plan 2013–2017.
Elbersen B., Startisky I., Hengeveld G., Schelhaas M.J., Naeff H, Bottcher H., Atlas of EU biomass potentials. Spatially Detailed and Quantified Overview of EU Biomass Potential Taking into Account Main Criteria Determining Biomass Availability from Different Sources, Biomass Futures Project, 2012, .

EU, 2009a. Directive 2009/28/EC of the European Parliament and of the Council on the Promotion of the Use of Energy From Renewable Sources and Amending and Subsequently Repealing Directives 2001/77/EC and 2003/30/EC.
EU, 2009b, Directive 2009/30/EC of the European Parliament and of the Council of 23 April 2009 Amending Directive 98/70/EC as Regards the Specification of Petrol, Diesel and Gas–Oil and Introducing a Mechanism to Monitor and Reduce Greenhouse Gas Emissions and Amending Council Directive 1999/32/EC as Regards the Specification of Fuel used by Inland Waterway Vessels and Repealing Directive 93/12/EEC.
EU, 2009c, Directive 2009/29/EC of the European Parliament and of the Council of 23 April 2009 Amending Directive 2003/87/EC so as to Improve and Extend the Greenhouse Gas Emission Allowance Trading Scheme of the Community.
EurObservER, 2013. The State of Renewable Energies in Europe, 13th EurObservER Report, 2013.
European Council, 2014. Conclusions on 2030 Climate and Energy Policy Framework, EUCO 169/14, 2014 , ⟨http://www.consilium.europa.eu/uedocs/cms_data/docs/pressdata/en/ec/145397.pdf⟩.
European Bioplastics, 2012. ⟨http://en.european-bioplastics.org/market/market-development/potential/⟩, 2014.
Eurostat, 2013. Agriculture, Forestry and Fishery Statistics, ISSN 1977-2262,2013.
Eurostat, 2014. ⟨http://epp.eurostat.ec.europa.eu/portal/page/portal/statistics/search_database⟩, 2014.
EUwood, 2010. Real Potential for Changes in Growth and use of EU Forests, TREN/D2/491-2008, 2010.
Faostat, 2014. ⟨http://faostat3.fao.org/home/E⟩, 2014.
Festel Capital, 2010, Industry Structure and Business Models for Industrial Biotechnology. Research Methodology and Results for Discussion. OECD Workshop on the Outlook on Industrial Biotechnology, Vienna, January, 2010.
Festel Capital, 2012. Märkte und Wertschopfungsketten für biogene Inhaltsstoffe. Maktetpotenziale, Geschaftsmodelle und Hurden, Workshop 'Maßgeschneiderte biogene Inhaltsstoffe für eine biobasierte Wirtschaft', Postdam, 2012.
GEF, 2012. A strategy for a bio-based economy. Green Eur. Found..
Golden, J.S., Handfield, R.B., 2014. Why biobased? Opport. Emerg. Bioecon..
Gosalia A., 2014. To sustain ability in the global lubricants industry. In: The 18th ICIS World Base Oils & Lubricants Conference London, 20th February 2014.
Grand View Research, 2014a. BioLubricants Market Analysis by Raw material (Vegetable Oil, Animal Oil), By Application (Automotive, Hydraulic, Process, De-molding, Lubricating, Chainsaw, Compressor, Turbine, Industrial gear, Metal working), By End Use (Industrial, Commercial Transport, Consumer Automotive) and Segment Forecasts to 2020, ⟨http://www.grandviewresearch.com⟩.
Grand View Research, 2014b. Biosurfactants Market Analysis By Product (Rhamnolipids, Sophorolipids, MES, APG, Sorbitan Esters, Sucrose Esters) And Segment Forecast To 2020 ⟨http://www.grandviewresearch.com⟩.
Grand View Research, 2014c, Enzymes Market Analysis By Product (Carbohydrase, Proteases, Lipases, Polymerases & Nucleases) And Segment Forecasts To 2020, ⟨http://www.grandviewresearch.com⟩.
HM Government, 2013. Strength and Opportunity 2013 The Landscape of the Medical Technology, Medical Biotechnology, Industrial Biotechnology and Pharmaceutical Sectors in the UK.
IEEP, 2014. ⟨http://www.ieep.eu/assets/963/KNOSSOS_Green_Economy_Supporting_Briefing.pdf⟩.
IFBB, 2012. Institute for Bioplastics and Biocomposites, ⟨www.downloads.ifbb-hannover.de⟩, 2014.
IMS Health, 2014. Searching for Terra Firma in the Biosimilars and Non-Original Biologics Market. Insights for the Coming Decade of Change.
JRC, 2013. Technology Map of the European Strategic Energy Technology Plan (SET-Plan). Technology Descriptions, Joint Research Centre.
KBBE, 2014. ⟨http://www.kbbe2010.be/en/kbbe2010/about-kbbe/kbbe-europe⟩, 2014.
Mantau U, 2012, Wood Flows in Europe (EU27). Project Report. Celle 2012.
Mazza L., ten Brink P., Green economy in the European Union, UNEP, May 2012, ⟨http://www.ieep.eu/assets/963/KNOSSOS_Green_Economy_Supporting_Briefing.pdf⟩.
M'Barek, R., Philippidis, G., Suta, C., Vinyes, C., Caivano, A., Ferrari, E., Ronzon, T., Sanjuan Lopez, A., Santini, F., 2014. Observing and analysing the bioeconomy in the EU—adapting data and tools to new questions and challenges 3. Bio-based Appl. Econ. 1 (83-91), 2014.
Meyer, H-P., Werbitzky, O., 2011. How green can the industry become with biotechnology?. In: Tao J., Kazlauskas, R. (Eds.), Biocatalysis for Green Chemistry and Chemical Process Development first ed. John Wiley & Sons.
NNFCC, 2014, Market Review: Biobased Products, Issue 31, October 2014.
OECD, 2009. The Bioeconomy to 2030: Designing a Policy Agenda. OECD Publishing http://dx.doi.org/10.1787/9789264056886-9-en.
OECD, 2014. ⟨http://www.oecd.org/sti/biotech/statisticaldefinitionofbiotechnology.htm⟩.
PBL, 2012. Sustainability of biomass in a bio-based economy, A Quick-scan Analysis of the Biomass Demand of a Bio-Based Economy in 2030 Compared to the Sustainable Supply. PBL Publication number: 500143001.
Platform, 2014, Bioeconomy ERA-NET Actions. European Research Area Networks of the 6th and 7th Framework Programmes. Publication of PLATFORM of Knowledge Based Bioeconomy relevant ERA-NETs, Grant 288422.
Research and Markets, 2014, Biolubricants—A Global Market Overview.
Riese J., White Biotechnology, McKinsey & Company, Press Briefing, 2009 ⟨https://www.dsm.com/content/dam/dsm/cworld/en_US/documents/white-biotech-mckinsey-feb-2009.pdf⟩.
Rødsrud, G., Lersch, M., Sjöde, S., 2012. History and future of world's most advanced biorefinery in operation. Biomass Bioenergy 46, 46–59.
Rouhiainen J., 2012, Bio-based Products—The Market Opportunity, Pöyry Management Consulting OY, Biochem Accelerator Forum, London.
RSB, 2014, Roundtable on Sustainable Biomaterials (RSB), ⟨http://rsb.org/⟩, 2014.
Scarlat, N., Dallemand, J.F., Banja, M., 2013. Possible impact of 2020 bioenergy targets on European Union land use. A scenario-based assessment from national renewable energy action plans proposals,. Renewable Sustainable Energy Rev. 18 (1), 595–606. 2013.
Starch Europe, 2014, ⟨http://www.aaf-eu.org/⟩, 2014.
Statista, 2014, ⟨http://www.statista.com/⟩.

STECF, 2013, Scientific, Technical and Economic Committee for Fisheries (STECF), Summary of the 2013 Economic Performance Report on the EU Aquaculture Sector (STECF 13-30), 2013.
Transparency Market Research, 2014a. Global Solvents Market (Alcohols, Hydrocarbons, Ketones, Esters, Chlorinated and Others) for Paints and Coatings, Printing Inks, Pharmaceuticals, Adhesives and Cosmetics and Other Applications - Industry Analysis, Size, Share, Growth, Trends and Forecast 2012–2018, ⟨http://www.transparencymarketresearch.com/solvents-market.html⟩.
Transparency Market Research, 2014b. Biosurfactants Market- Global Scenario, Raw Material and Consumption Trends, Industry Analysis, Size, Share and Forecasts, 2011-2018. Available from: ⟨http://www.transparencymarketresearch.com⟩.
UNEP, 2011, Towards a Green Economy: Pathways to Sustainable Development and Poverty Eradication, ⟨http://www.unep.org/greeneconomy⟩.
UNEP, 2014 Green Economy Initiative, ⟨http://www.unep.org/greeneconomy/⟩.
US, 2012, National Bioeconomy Blueprint, ⟨http://www.whitehouse.gov/blog/2012/04/26/national-bioeconomy-blueprint-released⟩.
USDA, 2013. EU Biofuels Annual 2013, GAIN Report Number: NL3034: .
Van Dam, J., Junginger, M., Faaij, A.P.C., 2010. From the global efforts on certification of bioenergy towards an integrated approach based on sustainable land use planning. Renewable Sustainable Energy Rev. 14 (2010), 2445–2472.