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Bio-economy and the sustainability of the agriculture and food system

OPPORTUNITIES AND POLICY CHALLENGES

Dimitris Diakosavvas,

Clara Frezal

OECD

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BIO-ECONOMY AND THE SUSTAINABILITY OF THE AGRICULTURE AND FOOD SYSTEM: OPPORTUNITIES AND POLICY CHALLENGES

Dimitris Diakosavvas and Clara Frezal, OECD

The bio-economy is gaining increasing prominence in the policy debate, with several countries developing bio-economy strategies to decouple economic growth from dependence on fossil fuel, as well a pathway to supporting some of the UN Sustainable Development Goals (SDGs) and commitments under the Paris Climate Agreement. This report analyses the opportunities and policy challenges facing the bio-economy in transitioning to a more sustainable agro-food system. It provides an overview of national bio-economy-strategies based on a literature review and information provided by governments in response to a questionnaire.

Keywords: Bio-economy, agro-food system, policy instruments, coherence, sustainability, innovation, monitoring

JEL codes: P48, Q2, Q18, Q28, Q52, Q57, Q58

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Executive Summary

The bio-economy is an economic sector primarily based on biogenic instead of fossil resources, and which is increasingly prevalent in policy making across the globe. Approximately 49 countries, including most OECD countries, have bio-economy-related strategies in place or envision doing so. These countries recognise the opportunity the bio-economy offers to address overarching societal challenges, such as food security, climate change, limited natural resources (including fossil fuels), economic growth, and the demand for raw materials.

The agro-food system plays a major role today in the bio-economy policy agenda, and several key lessons have emerged from past experience.

- There are high expectations that the bio-economy can make an important contribution to the sustainable development of the agro-food system. This would largely be accomplished through the creation of new business and innovation opportunities, greater efficiency and productive use of natural resources, and facilitating the adaptation of the agriculture sector to climate change. The bio-economy can increase the value generated from biomass and stimulate value chains via the diligent application of the “cascading use” of biomass and the reuse of waste materials.
- National bio-economy strategies tend to highlight food security (the “food-first-principle”) and environmental sustainability as key goals.
- The development of the bio-economy is not intrinsically sustainable. Economic, social and environmental trade-offs and risks are unavoidable. Determining the most cost-efficient use of biological and other resources to meet food, feed, fuel and fibre needs is a major challenge for private and public policy decision makers.
- While reducing greenhouse gas (GHG) emissions is a key driver in the development of a bio-economy, there are concerns about the overall GHG savings that will result from feedstock production, land-use changes, and bioenergy conversion.
- Concrete empirical evidence on the net overall economic, environmental and social impacts of the bio-economy on the agro-food system is lacking. Better monitoring and assessment are needed.
- The most widespread policy initiatives adopted by governments focus on research, knowledge development, and practical forms of engagement with stakeholders.
- A mix of technology-push and market-pull policy measures are used to increase demand for bio-economy products. This includes the development of labels, standards and certification for new bio-based products, and the use of green public procurement. In general, creating consumer awareness of bio-economy products is at the top of national agendas.
- Initiatives to share knowledge through industrial clusters and partnerships related to the bio-economy are spreading (e.g. co-location of existing and related industries, the provision of shared demonstration facilities and infrastructure). Most bio-economy strategies include establishing centres of excellence and databases, developing networks (e.g. through innovation clusters), and promoting new business models through public-private partnerships (PPPs), training and education measures, building pilot and demonstration plants for bio-refining, and strengthening international collaboration.
- Although most national strategies highlight the need for a coherent set of objectives that touch multiple sectors, the reality is that the terms on how this will be achieved are generally

vague. Yet a coherent set of policies is needed, in particular across policies that deal with agriculture, food, rural development, environment, forestry, energy, research and innovation, waste and climate change as these are perceived to foster the development of the bio-economy of the agriculture and food system.

- Few countries emphasise the importance of reviewing and harmonising the regulatory bio-economy frameworks when these are put in place. However, any successful implementation of a bio-economy strategy requires a holistic approach not only to facilitate market development but to build consumer trust.
- In addition to competing for land use, other challenges and obstacles include: increasing public awareness to improve public acceptance; understanding the financing needs and risks that are involved; overcoming the regulatory restrictions; addressing educational and skills requirements; tackling transport logistics; facilitating market opportunities; and developing the framework and indicators needed to monitor and evaluate performance.

Policy recommendations

Greater clarity is needed in defining the scope of the bio-economy

The concept of the bio-economy is evolving with the growing recognition that it encompasses more than biotechnology or biofuels. While earlier bio-economy strategies were driven mainly by the search for renewable resources as a substitute feedstock for fossil fuels, recent strategies also focus on enhancing the value (valorisation) of bio-resources, including within the agro-food system. In general, national bio-economy strategies seek to play a role in achieving the UN Sustainable Development Goals (SDGs), with green growth – a path of economic growth that uses natural resources sustainably – as a key goal.

Nevertheless, there is no commonly accepted definition and the bio-economy concept is often used interchangeably with other related concepts, such as the "bio-based", or as part of the "circular economy". A clear understanding of the bio-economy concept would help better identify the underlying drivers, define objectives, illustrate the value added of bio-economy strategies compared to other sustainable economic approaches and strategies such as green growth, outline the role of bio-economy plays in the agro-food system, and determine the necessary requirements for the monitoring and assessment bio-economy policies.

Ensure that the bio-economy leads to sustainability

Given the dependence of agriculture on biological resources, agro-food systems are prominent in most bio-economy strategies. The agricultural sector plays a central role in that it is a major provider of biomass for the food and other bio-based industries. This includes energy, materials (wood, plastics, and clothing), bio-chemicals, and bio-pharmaceutical products.

The bio-economy is not intrinsically sustainable. A major risk lies in the increased competition between food supply and non-food biomass production. An important dilemma is that the expansion of the production of industrial products on farms will divert farmland from food production to other uses, and the bio-economy will thus accentuate the "food versus fuel" concerns currently voiced.

It is essential to identify and implement mechanisms for the sustainable production of biomass. Policy incentives to adopt sustainable agriculture methods that help maintain soil cover and health, increase water-use efficiency, and reduce soil erosion are critical. Research focussing on ecosystem services, together with technological developments which help to provide the necessary information and means to make appropriate land-management decisions, and improve the biomass-to-biofuels conversion efficiency are also required.

Policy actions need greater coherence and targeting

Policy and institutional coherence are prerequisites to reaching the full potential of the bio-economy. This requires ensuring sufficient co-ordination across the bio-economy sub-sectors of agriculture, food, forestry, marine, waste and energy. Policies that offer incentives for different economic uses of biomass – such as food, feed, bio-based products and bio-energy – in the context of the strategic goals should be aligned and evaluated. Regulatory frameworks may also need to be assessed and revised, especially with a view to increasing the value generated from biomass and creating value chains.

Several national bio-economy strategies aim to foster coherence across policy levels and areas by: investing in research, innovation and skills; promoting a participatory governance structure; facilitating informed public dialogue; monitoring progress; and strengthening co-operation at the international, national and regional levels. In this respect, several countries have established inter-ministerial working groups and policy advisory bodies. Some countries have established dedicated bio-economy councils or panels, which include various stakeholders, to advise on the

implementation process. These strategies are encouraging and should be shared so that other countries can learn from them.

The bio-economy is complex and entails inter-disciplinary knowledge. Developing a skilled workforce for the emerging bio-economy is a major challenge and development of expertise is one of the main concerns of almost all bio-economy-related policy strategies. The strong promotion of education and training, funding and communication in several countries is an encouraging sign for advancing the sustainable implementation of the bio-economy.

Adopting innovations in the bio-economy is critical

The review of national strategies reveals many commonalities, in particular the emphasis on research, innovation and technology – which are at the centre of all bio-economy strategies – and the encouragement of public-private partnerships.

Most national strategies also seek to promote the opportunities that stem from the adoption of a wide range of other novel technologies, such as in bio-engineering, and the development and wider adoption of technologies for energy- and water-saving. Some strategies also seek to improve food and nutritional quality while reducing waste, and to improve big data techniques and the Internet of Things. Making available the latest research results and best practice approaches, including advances in biotechnologies to the farming community, is key to advancing agricultural productivity in a sustainable way.

Countries should monitor progress

There is no internationally agreed methodology to measure the size of the bio-economy so it is difficult to monitor its development and assess the impact of bio-economy strategies within and across countries. Most countries measure only the direct contribution to GDP, turnover, employment, exports – including agriculture and food –, the number of firms and businesses operating in bio-economy sectors, and the contribution of the bio-economy in the energy matrix of the countries. Such indicators provide only a partial and static picture of the bio-economy in the agro-food system and do not inform its development and impact on environmental sustainability.

Monitoring of progress and outcomes is thus a priority of policy implementation. Several approaches may be used to measure the bio-economy, but each must be clear with respect to what is being measured and how, and any trade-offs must be transparent. There is no one-size-fits-all approach given the complexities due to externalities, uncertainties of opportunities, changing preferences, and the fact that its development is driven by a diverse set of policy measures.

A possible approach is to adopt and adapt the conceptual framework and indicators developed by OECD to monitor progress towards green growth as it focuses on natural resource efficiency and productivity, the environmental performance of production and consumption, on the innovations adopted, and the policy instruments implemented.

Key recommendations for a bio-economy that contributes to a sustainable agriculture and food system

Main findings	Key recommendations
Scaling-up the bio-economy	
Absence of an international consensus on the definition of the concept, objectives, and strategy for the bio-economy	Clearly articulate the purpose and aims of developing a bio-economy strategy. Develop a consensus on a definition of the bio-economy concept as the basis for taking forward a shared policy agenda, which can then be compared and contrasted across countries.
Weak public awareness of the nature and implications of the bio-economy, and engagement with stakeholders	Explore ways to enhance greater awareness of the bio-economy, its products and technologies: through knowledge transfer of best practices; harnessing advisory services; developing sustainable business models; strengthening public procurement; using consumer awareness campaigns; and implementing product labelling initiatives. Provide the public with knowledge-based information regarding: key objectives; costs and benefits; and the challenges, opportunities and trade-offs in advancing the bio-economy to contribute to the sustainability of the agro-food system. Include the full range of stakeholders from industry, government, research institutions and civil society in the discussion, dialogue and development of a bio-economy strategy, through the establishment of social dialogue platforms.
Enhancing sustainability performance	
Potential conflicts among sustainability objectives to achieve food security and other demands on natural resources	Identify drivers and barriers that influence the sustainable development of the bio-economy. Outline the priorities and trade-offs for enhancing the sustainable performance of the bio-economy, throughout the agro-food supply chain. Undertake studies to establish the extent and location of critical pressures on land use, at local, national and international levels. Mitigate pressures and potential conflicts on land-use between food production and production of renewable raw materials for energy and industrial materials by adopting approaches that increase production efficiently and sustainably; improve the efficiency of their use; and boost the use of residual products and non-edible food by-products. Address potential conflicts between goals such as “food security versus biomass for fuel”, and competition for land use, through engagement with different actors in the bio-economy, by expanding international research and technological co-operation, and ensuring that any externalities are fully taken into account in assessing social values.
Insufficient information and data on market potential and business practices along agro-food supply chains to enhance sustainable performance of the bio-economy	Establish an inventory of initiatives, indicators and case studies on the costs and benefits of the sustainability performance of bio-economy. Tap market growth potential in high-value food and feed sectors by fostering research on renewable raw materials such as economically efficient biomass-use as an energy source and the production of second-generation fuels, as well as by fostering innovations in the agro-food system. Where possible, apply the cascading use of biomass whereby higher value existing or new applications are preferentially derived from biological resources (e.g. food, bio-based materials and chemicals) prior to their use in energy and fuel generation. The by-products emerging, as renewable resources should be utilised as fully as possible in high-value uses, while simultaneously reducing waste.
Negative environmental impacts from increasing demand for biomass not sufficiently taken into account	Enhance understanding of the ecological boundaries, the capacity of the environment to replenish itself, and the overall impact on the environment and trade-offs of the bio-economy on the environment through acquiring knowledge of the limits of sustainable biomass supply at the local, regional and global level. Undertake forward looking and cross-sectoral assessments of sustainable biomass supply and demand, including through life cycle analysis.
Enabling policy framework	
Insufficient coherence and targeting of policy measures addressing the bio-economy	Review existing domestic and trade policies and regulations at regional, national and international level which impact on the bio-economy and explore various innovative approaches such as the establishment of inter-Ministerial working groups and stakeholder engagement in order to develop a coherent policy framework for a sustainable bio-economy. Make greater efforts to ensure policy coherence in the design and implementation of a bio-economy strategy as well as among sectoral strategies that impact on the bio-economy. Remove fossil fuel subsidies, phase out biofuel subsidies, and apply the polluter pay and provider gets principles to address the negative and positive environmental impacts.

Main findings	Key recommendations
	Facilitate voluntary agreements (e.g. between actors along the agro-food supply chain); targeted information and advisory services, awareness-raising campaigns (e.g. among consumers, producers and local authorities on ways to reduce food waste).
Weak market uptake and consumer confidence	Use a range of policy instruments, including provision of information on the environmental footprint of bio-economy products, public procurement, development of standards, and product labelling. Ensure that bio-economy policies are clear and implemented for the long-term so that businesses have certainty in making investment decisions, and consumers are confident as to the products they buy.
The emergence of the bio-economy blurs the distinction between agricultural, environmental, and energy policies	Assess the costs and benefits of implementing bio-economy and related policies in an integrated and joined-up manner, including through reform of institutional and governance structures. Adopt holistic and transparent crosscutting approaches and policies for consumer trust-building.
Inadequate diffusion, transparency and adoption of research and innovation	Increase efforts to increase agricultural productivity through investing in innovative R&D such as plant and livestock breeding for precision farming, soil research and measures to adapt to climate change. Encourage deployment of research and innovation through promoting collaboration between research institutions (academia) and industry (e.g. through pilot schemes, demonstrations and benchmarking) in a transparent way. Encourage the development of measures to promote targeted research and knowledge exchange to significantly widen understanding of emerging aspects of the bio-economy, in particular through new and novel technologies. Establish a long-term research and innovation agenda to support the development of new, eco-friendly processes, products and services.
New requirements for education and skills for stakeholders	Build up and expand the expertise necessary for a bio-economy by integrating dedicated curricula and training programmes in the higher education and vocational training systems.
Monitoring progress	
Monitoring performance is insufficiently addressed	Develop a list of key indicators of the bio-economy related to the agro-food system. Establish a multilateral platform to discuss – with the aim of reaching consensus - on the design and implementation of a monitoring system, including governance and institutional arrangements, to track the progress towards a sustainable bio-economy to facilitate cross-country comparisons. The OECD conceptual framework to monitor progress towards green growth – which focuses on natural resource efficiency and productivity, the environmental performance of production and consumption, and on the drivers of green growth, such as policy instruments and innovation activity – could provide a useful tool or blueprint in building such a system.
Lack of empirical evidence of the economic, environmental and social impacts of bio-economy policies	Identify the economic, social and environmental impacts and trade-offs of bio-economy policies at sectoral and economy-wide levels using quantitative approaches such as partial and general equilibrium modelling and life-cycle analysis. Establish inventories of life cycle case studies prioritising agro-food products most relevant for the bio-economy; and carbon accounting to provide evidence on the contribution of agro-food bio-based products to GHG emissions across the agro-food system.

1. The bio-economy is gaining prominence on the policy agenda

Setting the scene

The food and agriculture sector faces multiple challenges. This includes meeting the growing global demand for food and agricultural products due to population and income growth and associated dietary changes, as well as the growing demand for the supply of biomass to satisfy the needs of the energy and industrial raw materials sectors. Moreover, the sector needs to adapt to climate change.

Meeting these demands will place increased pressure on the agro-food sector to supply food and raw materials from scarce natural resources, while preserving the environment in the context of climate change. Meeting these challenges in a sustainable way will require developing new products and improving existing technologies and practices that can mitigate the effects of climate change.

The bio-economy – which is based primarily on biogenics instead of fossil resources – is gaining prominence in the policy debate as technical progress in microbiology provides new opportunities to use natural resources sustainably. It is often argued that the bio-economy can be a key part of the solution to multiple societal challenges, and several strategies have been developed at the international, national and regional levels.

Governments are developing bio-economy strategies with the aim of generating a range of economic and environmental benefits, while also ensuring food security and securing a supply of biomass for other industries (FAO, 2016; Von Braun, 2018; El-Chichakli et al., 2016). An increasing number of countries are developing holistic national bio-economy strategies – rather than related to specific policy areas – to decouple economic growth from its dependence on fossil fuel, and as a pathway to supporting some of the UN Sustainable Development Goals (SDGs) and commitments under the Paris Climate Agreement.

The key objective of this report is to provide an overview of the implications for the sustainability of the agriculture and food system that arise from official national bio-economy-related strategies, based primarily on the literature and material provided by governments in response to a short questionnaire (Annex A).

There are high expectations that the bio-economy can contribute significantly to sustainable development (OECD, 2018a; El-Chichakli et al., 2016; OECD, 2009). Some analysts consider the bio-economy as the pathway to achieve key UN SDGs related to food security and nutrition, health and well-being, and clean water and sanitation (Von Braun, 2018). Indeed, recent bio-economy policy strategies are aligned with meeting several of the UN SDGs, pursuing increased domestic economic growth, competitiveness and employment, while protecting the environment and fostering social inclusion (Biookonomierat, 2018).

Currently, the G7 industrialised countries – and at least 42 others – have a dedicated bio-economy strategy in place (or related policies) and accord them prominence in their policy agendas, including for the agriculture and food system (OECD, 2018a; Biookonomierat, 2018; Biookonomierat, 2015; Staffas, Gustavsson and McCormick, 2013; Priefer, Jörissen and Frör, 2017).

The core idea of the bio-economy is the gradual replacement of non-renewable fossil resources used in industrial production and energy supply by renewable biogenic feedstock. This replacement could pave the way for a more sustainable, resource efficient economy and offer opportunities to support growth and jobs, as well as address climate change, food security and resource depletion (OECD, 2009; OECD, 2013; FAO, 2016; Hansen and Bjørkhaug, 2017; Priefer, Jörissen and Frör, 2017).

Food and agriculture is a central part of the bio-economy. Broadly speaking, the term bio-economy means the use of biological feed stocks to generate economic outputs through the production and use of renewable biological resources (biomass) for conversion into commercial products, ranging from food and feed to materials and energy (OECD, 2018a; Allen et al., 2015).

An important development of the bio-economy that has attracted considerable attention is the use of advanced tools of modern biology to transform established economic sectors, such as agriculture, food, chemical industries, pharmaceuticals and construction industries, while also improving the

environment. The bio-economy therefore is not a "new" sector *per se*, but rather a cluster of intersecting value chains in different sectors encompassing agriculture, forestry, fisheries, food processing, and parts of the energy, chemicals and biotechnology sectors.

Although some parts of the bio-economy are long established, the bio-economy has received much attention in recent years due to new technological opportunities and efforts to reduce dependency on oil and fossil fuels, often reflecting changing consumer preferences.

Although the original concept primarily referred to the use of biotechnologies for economic growth, the bio-economy has now moved beyond biotechnology and is being supported by a wide range of multiple scientific areas (e.g. life sciences and agronomy), a wide range of technologies (including biotechnology, nanotechnology and communication), and foresees continuous knowledge transfers. The bio-economy is embedded in the far-reaching transitions that are taking place in energy, transport and industrial production (OECD, 2018a).

The concept of the bio-economy has been associated with green growth. Developing a bio-economy is seen by some as critical because of its potential role to address three main issues: i) the need for sustainable resource use; ii) the growing demand for both food and energy; and iii) the need to decouple economic growth from environmental degradation.

The bio-economy concept is built on two premises, namely that: i) biomass is currently being underexploited as many waste streams are not used in an optimal way, and more materials and energy could be extracted; and ii) the biomass potential can be upgraded by increasing current yields, increasing the amount of productive land, introducing new or improved species that may or may not be generated by various biotechnological advances, and introducing new and improved extraction and processing technologies.

Estimations point at the potentially significant impact of bio-economy on growth, competitiveness and job creation along the entire biomass value chain. According to an OECD (2009) report, a "business-as-usual" estimate is that the bio-economy could contribute up to approximately 2.7% of GDP (of which 39% of industry, 36% of agriculture and 25% of health applications) in the OECD area by 2030. The report suggests that the key factors in shaping the benefits flowing from the bio-economy will be the "quality" of governance and the economic competitiveness of biotechnology.

The actual contribution of the bio-economy to national economies varies from one country to another, but all countries consider that the bio-economy is likely to increasingly contribute to national economies in the future. It is one of the main reasons motivating the development of bio-economy strategies. Some national strategies (Finland and Italy) set economic targets (in terms of job creation, and output or turnover) for the development of their bio-economy, reflecting the high expectations put on its development.

The European Union's *Europe 2020 Strategy* calls for a bio-economy as a key element for green growth, maintaining competitiveness and creating jobs, which presents opportunities for the agriculture- and food-based sectors (European Commission, 2017; SCAR, 2015).The *2012 EU Bio-economy Strategy* identifies five objectives to which the strategy and its action plan contribute: i) ensuring food security; ii) managing natural resources sustainably; iii) reducing dependence on non-renewable resources; iv) mitigating and adapting to climate change; and v) creating jobs and maintaining EU competitiveness. The bio-economy is viewed as a potential major contributor to achieving several SDG goals: zero hunger; good health and well-being; clean water; affordable and clean energy; decent work and economic growth (in rural areas); industry and innovation infrastructure; sustainable cities and communities; responsible consumption and production; climate action; and life on land and below water.

In the United States, the *Billion Ton Bio-economy* strategy suggests that the bio-economy presents significant opportunities for biomass to make positive economic and environmental contributions to the country (US Department of Energy, 2016). It found that a billion dry tonnes of sustainable biomass has the potential, *inter alia*, to produce 1.1 million direct jobs, 25% displacement of transportation fuels with biofuels and 400 million tonnes of CO_{2e} reductions per year. Success, however, is contingent on developing feed stock supplies, lowering producing costs, and enhancing the value of bio-economy products.

In general, there is great optimism about the potential benefits and opportunities for the agriculture and food system associated with a growing bio-economy. However, developing a bio-economy is complex as it includes diverse sectors and stakeholders, and is related to far-reaching changes in production systems and consumption patterns. Essential to the growth of the bio-economy are technologies (e.g. systems to reduce emissions), organisations (e.g. changes in institutional organisation and behaviour), social aspects (e.g. job creation) and policy innovations (El-Chichakli et al., 2016).

Achieving sustainable development in the bio-economy poses many challenges, such as addressing climate change and managing natural resources in a sustainable way, and competition between the different uses of biomass, while ensuring social inclusiveness. Sustainable production of renewable resources will be needed with the conversion of these resources and waste streams into value added products, such as food, feed, bio-based products and bioenergy.

Changes in the production of biomass, which a transition to the bio-economy entails, place the agriculture and food sector in the spotlight. As agricultural, trade and environmental policies influence primary production methods, markets and the quality and quantity of products, policies – including agricultural – can become a critical tool for facilitating or hindering such a transition.

Trade-offs and synergies are likely to occur in the transition to bio-economy not only for production, supply and transport of biomass, but also for skilled labour, land use, new waste streams, market niches and national funds. For example, a study on the prospects of the bio-economy in Europe shows that whichever scenario is considered, there are no “all win” options (Philippidis, M’barek and Ferrari, 2016).

While the development of the bio-economy is in principle consistent with sustainability policies (e.g. green growth), it is necessary to avoid over-exploitation of natural bio-resources. The growth of the bio-economy calls for an integrated, coherent approach with close co-operation and co-ordination between business, policy makers, civil society, and scientists (Philp and Winickoff, 2017). It is timely therefore to analyse how coherent and integrated policy approaches might evolve to arrive at more sustainable outcomes for the agriculture and food system.

Box 1. Defining the bio-economy

The OECD defines the bio-economy as “transforming life science knowledge into new, sustainable, eco-efficient and competitive products” (OECD, 2009). In a similar vein, the first Global Bio-economy Summit held in Berlin 2015 notes that an understanding of “bio-economy as knowledge-based production and utilisation of biological resources, biological processes and principles to sustainably provide goods and services across all economic sectors” is shared by many (Global Bioeconomy Summit, 2015).

The bio-economy encompasses three major elements[1]:

- The use of *renewable biomass* and efficient bio-processes to stimulate sustainable production;
- *Enabling and converging technologies*: Beyond biotechnology, a key development is the combination of digitalisation (precision agriculture) and “biologisation”;
- *The integration of biotechnology knowledge and applications across sectors*: Integration concerns primary production (i.e. all living natural resources), health (i.e. pharmaceuticals and medical devices), and industry (i.e. chemicals, plastics, enzymes, pulp and paper, bioenergy).

For the purposes of the present report, the “bio-economy” is defined as the production and use of biological resources (aquatic and terrestrial biomass) to produce energy, intermediate and final products. It is comprised of two groups: i) sectors upstream in the value chain, namely the primary sector (as the supplier of biomass) and other inputs, including technologies sector (R&D), which provides inputs to production; and ii) sectors downstream in the value chain, namely the users of biomass including food and feed, materials (textile and clothing, wood, paper and pulp), chemical, energy and building sectors.

1. OECD, 2009.

What does the bio-economy encompass in country strategies?

Worldwide, there has been increasing policy development around the bio-economy in recent years. Countries and regions are adopting comprehensive strategies and initiatives fostering the advancement of the bio-economy, albeit with some differences that mainly reflect national and regional priorities (Table 1). Currently, 49 countries have developed policy strategies related to bio-economy development, 15 of which have a dedicated bio-economy policy strategy in place (Biookonomierat, 2018). In Northern Europe, the Nordic countries (Denmark, Finland, Norway, Sweden, the Faroe Islands, Greenland; and Iceland) are developing a common Nordic bio-economy programmes/strategy with 15 action points to boost the transition towards a sustainable bio-economy.

Strategies vary considerably in their scope and focus. Some countries, such as Germany and Finland, take a broad view, encompassing the whole bio-economy within a single strategy at the national level. Others have placed more emphasis on promoting certain aspects of the bio-economy deploying dedicated policies with a thematic focus, such as the Netherlands and Sweden, while others, such as Belgium, adopt a regional approach without an overarching national framework.[1]

The United States (and South-Africa), for example, focus on the health, agricultural and industry sectors, while in other countries bio-economy strategies cover a wider range of sectors, such as food, forestry and marine bio-economy. For example, in Germany and Norway the bio-economy encompasses all sectors and related services which produce, process or use biological resources in any form.

Table 1. Bio-economy strategies in selected countries

Country/ region	Name of strategy	Level of strategy	Date	Sectors of interest	Main focus/ key funding areas
Countries with holistic (across the board) bio-economy strategies					
Belgium (Flanders)	Bio-economy in Flanders: The vision and strategy of the Government of Flanders for a sustainable and competitive bio-economy in 2030	Regional	2014	Bioenergy, bio-based products	
Canada	A Forest Bio-economy Framework for Canada	National	2017	Forestry and bio-based industries	Regional development, supply chain and sustainability; support innovation, productivity and competitiveness
European Union	Innovating for Sustainable Growth: A Bio-economy for Europe	International	2012	Agriculture and forestry, aquaculture and fisheries, bio-based industries, food chain	Research and innovation; Public-Private-Partnerships
Finland	The Finnish bio-economy strategy	National	2014	Forestry, bioenergy, chemical industry, bio-based products, water bodies and the sea, and fresh water	Mostly focussed on important renewable resources as the biomass in the forests, soil, fields, water bodies
France	A bio-economy strategy for France	National	2017	Agriculture, forestry, fisheries and aquaculture, bio-based industries, bioenergy, green chemicals	Bioenergy; green chemicals; clusters; circular economy
Germany	National policy strategy on bio-economy	National	2013	Industrial biotechnology; bio-based products and	R&D on food security, sustainable agriculture, healthy

[1.] The Flemish government, for example, has established a strategy for a sustainable and competitive bio-economy by 2030.

				bioenergy; food and feed	nutrition, industrial processes, bio-energy
Italy	Bio-economy in Italy	National	2016	Agriculture, food industry, forestry, marine bio-economy, bio-based industry	
Ireland	The Irish Bio-economy: Definition, Structure, and Situational Analysis	Interim	2017	Agriculture, food, forestry, marine resources, bioenergy	
Japan	Basic Plan of Biomass Utilisation	National	2010; 2016	Agriculture, forestry and fish	Research and innovation, circular economy; regional development
Norway	Familiar resources, undreamt of possibilities: the government bio-economy strategy	National	2016	Forestry, fisheries and aquaculture	Integrated approach to bio-economy and climate, green shift, circular economy, resource effectivity, low carbon society
Nordic Council of Ministers	Future opportunities for bio-economy in the West Nordic Countries	International	2014	Fishing industry	
Spain	The Spanish bio-economy strategy 2030 horizon	National	2015	Food and agriculture, forestry, conditioned by water availability; industrial bio-products and bioenergy	The Strategy is based on the sustainable and efficient production and use of biological resources
Netherlands	Framework Memorandum for a bio-based economy	Policy paper	2012		
Sweden	Swedish Research and Innovation Strategy for a Bio-based Economy	National	2012	Primary production (forestry, agriculture, aquaculture), bio-based industries, bioenergy	
United States	National Bio-economy Blueprint; Billion Ton Strategy	National National	2012 2016	Health, agriculture and industry	Life Sciences (Biomedicine) and agriculture (multiple areas)
Argentina	Bioeconomia Argentina; Programme on Promoting the Bio-economy	National	2017	Agriculture; food; agro-industry; bio-energy	Sustainable energy supply from biomass; innovation (precision agriculture; circular economy.)
South-Africa	The bio-economy strategy	National	2013	Health, agriculture and industry	The strategy seeks to improve the bio-economy innovation capacity in south Africa.
Countries with bio-economy-related strategies					
Australia	Research and Innovation			Primary industry	Renewable energy technologies; bio-science
Austria	Bio-economy Policy Paper	Policy paper	2013	Agro-industry, chemicals, timber industry, health care	
United Kingdom	Evidencing the bio-economy (2016); Agri-Tech Strategy (2014)	Consultant report ; National	2016 2014	Agro-industry; bio-energy; forestry; marine	Bioenergy; agri-science and technology

There are many definitions and descriptions of what constitutes a bio-economy, but it is not the purpose of this report to produce a definitive one. It is nevertheless interesting to see how countries have defined bio-economy in their strategies so as to have a better understanding of policy makers perceive the concept, its implications and the role of the agro-food system.

Across national bio-economy related-strategies, the bio-economy is mainly defined as a set of sectors or economic activities relating to the invention, development, production and use of biological products and processes. As there is no internationally agreed definition of the term “bio-economy”, national strategies emphasise different sectors. It should be noted that the definition is evolving over time in any given country.

Box 2. Defining bio-economy in national strategies

Belgium (Flanders) (2014): All activities associated with the production of biomass and the various ways in which this biomass and its residual streams are subsequently used.

European Commission (2012): 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. It includes agriculture, forestry, fisheries, food and pulp and paper production, as well as parts of chemical, biotechnological and energy industries.

Finland (2014): An economy that relies on renewable natural resources to produce food, energy, products and services.

France (2017): The whole range of activities linked to the production, use and processing of bio-resources". The strategy further highlights the circular economy component of the bio-economy. In this respect, the focus is on closing the loop (i.e. by reusing and recycling bio-based resources).

German Bio-economy Council Communiqué (2015): The knowledge-based production and utilisation of biological resources, innovative biological processes and principles to sustainably provide goods and services across all economic sectors.

Italy (2017): The integration of "the sustainable 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.

Latvia (2017): The sustainable utilisation of renewable natural resources (including plants, animals, micro-organisms, etc.) for producing food, feed, industrial products and energy.

New Zealand (2017): The set of economic activities relating to the invention, development, production and use of biological products and processes.

Norway (2016): The sustainable, effective and profitable production, extraction and use of renewable, biological resources for food and feed, health products, energy, industrial materials, chemicals, paper, textiles and numerous other products.

Spain (2015): The set of economic activities based on products and services, generating economic value, making efficient and sustainable use of resources of biological origin as fundamental elements.

Sweden (2012): A bio-based economy (bio-economy) is an economy based on sustainable production of biomass and increased added value for biomass materials.

United Kingdom (2015): The economic activity derived from utilizing biological resources or bio-processes for the production of value added products such as food, feed, materials, fuels, chemicals, bio-based products (products that are wholly or partly derived from materials of biological origin) and bioenergy.

United States (2016): The global industrial transition of sustainably utilising renewable aquatic and terrestrial biomass resources in energy, intermediate and final products for economic, environmental, social and national security benefits (The Federal Activities Report).

United States (2016): The sustainable use of domestically produced renewable biomass for fuels, products and power (The Strategic Plan for a Thriving and Sustainable Bio-economy).

United States (2012): An economy based on the use of research and innovation in the biological sciences to create economic activity and public benefit.

South Africa (2013): Activities that make use of bio-innovations, based on biological sources, materials and processes to generate sustainable economic, social and environmental development. (2013): Activities that make use of bio-innovations, based on biological sources, materials and processes to generate sustainable economic, social and environmental development.

Where definitions of the bio-economy exist, they are concerned for the most part with the feedstocks that form the component parts of the bio-economy, almost exclusively those of biological origin, and their ultimate end use. Similarly, the term "renewable" features in most definitions, stressing the sustainability of the bio-economy in the long term compared to a finite fossil fuel alternative.

In general, countries with bio-economy strategies can be classified as those with: i) an abundance of renewable biological resources but a lack of downstream processing industries; ii) both high feedstock

potential and advanced processing industries; and iii) low feedstock potential but advanced processing industries (Bracco et al., 2018).

Overall, the bio-economy encompasses the traditional bio-economy sectors, such as agriculture, forestry, fisheries and aquaculture, as well as related processing and service industries, such as food, paper, textiles, building and construction, chemistry, and bio-pharma. Key enabling and converging technologies, such as bio-, nano- and information technologies, are vitally important.

Even if the scope and content of the bio-economy vision varies, most strategies focus on the production and utilisation of biological resources to generate high-value bio-based products. Generally, national strategies are aimed at growth, new economic opportunities and job creation, but make little reference to production issues and access to biomass. Some refer to the bio-economy in areas dealing with sustainable development (e.g. Finland), while others do not (Staffas, Gustavsson and McCormick, 2013).

In some countries, bio-economy is seen as an opportunity to develop science-based, high-value industries and thus emphasise the application of biotechnology in different sectors of activity (e.g. Australia, the United Kingdom, and the United States). Existing agricultural strategies have been supplemented by research-focused strategies that target the development of industrial biotechnology in the agriculture (and health) sector in particular. In countries with strong industrial structures, such as Germany, France, Japan and Italy, bio-economy strategies emphasise the innovative potential offered by the bio-economy and point to its potential to reinvigorate specific sectors, including agro-food.

Many of the bio-economy strategies, particularly in European Union Member States, highlight its close relationship with the bio-based economy (e.g. Sweden) and circular economy (e.g. Ireland, Italy).[2] For example, the term bio-economy in Sweden is considered equivalent to the bio-based economy based on the sustainable production of biomass and the creation of added value for biomass material (Swedish Research Council (Formas), 2012). In the Netherlands, the government has set up the “Bio-based economy” initiative. However, there are important differences between the two concepts (Box 3).

Agriculture and food are prominent in most bio-economy strategies

The agricultural and food sector plays a key role in the development of the bio-economy as it is a major producer of biomass for food, feed, and energy. Sustainable agro-food systems have to meet the challenge of producing growing quantities of biomass, while reducing the negative impact on the environment. Hence, while the agriculture and food sectors are included in almost all bio-economy strategies, the emphasis and the way they are covered differ (Table 2).

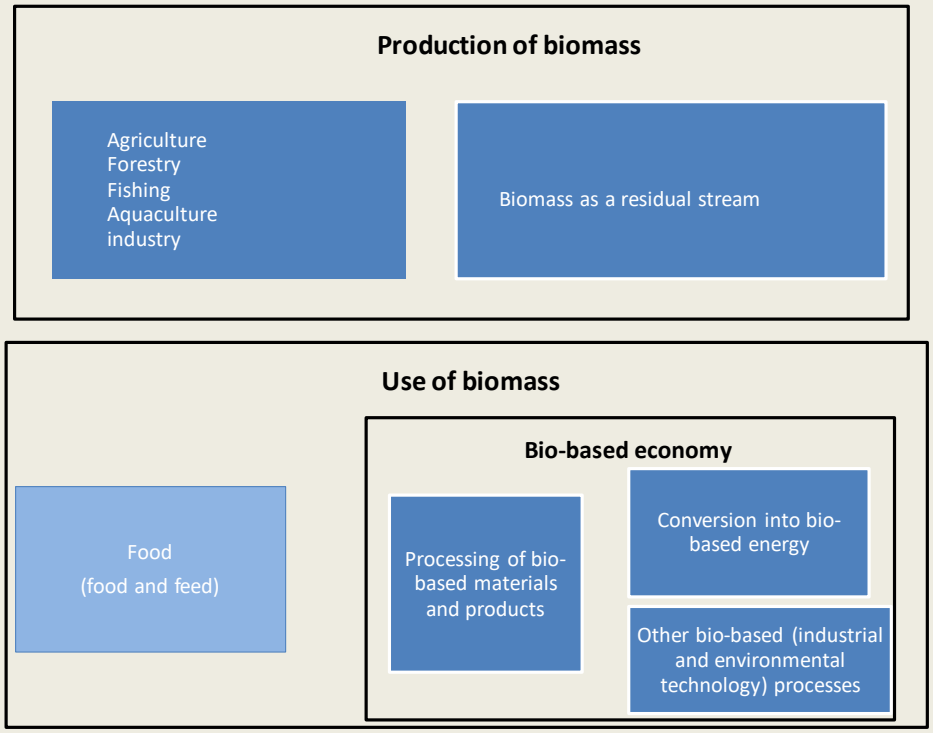
Countries rich in biomass (Argentina, Brazil, Finland, New Zealand, and Norway) concentrate on developing higher added value from primary industries (agriculture, forestry and fisheries). Other countries – such as Australia, France, Germany the Netherlands and the United Kingdom – seek to develop high-tech sectors and to stimulate emerging industries. The strategies put forward by Canada and the United States seek to leverage their huge areas of forest, coastline and arable land, and to increase the value of the agricultural and forestry sectors while promoting rural development. In Belgium (Flanders), the bio-economy includes the traditional and the more technology-oriented sectors, in addition to the consumer and logistics sectors.

In Chile, bio-economy related initiatives are aimed at reducing food-waste, valorising re-use, promoting bio-energy generation (mainly from forestry and pulp waste, and livestock manure) and the development of bio-based agricultural inputs. In addition, there is increasing interest from both the private and public sectors to promote the production and use of bio-based products, in particular bio-pesticides and bio-fertilisers, and food-ingredients extracted from food waste (e.g. natural colorants and enzymes).

[2] The synonyms (i.e. bio-based economy or knowledge-based bio-economy) are often used interchangeably (McCormick and Kautto, 2013).

Box 3. Distinction between the bio-economy and the bio-based economy

The bio-based economy refers only to the production (including residual stream) and use of biomass for non-food applications (materials, chemicals and other bio-based processes). On the other hand, the bio-economy includes both bio-based economy and the production and use of food and feed. Bio-based products can range from high-value added (usually low volume) fine chemicals, such as pharmaceuticals, cosmetics, food/feed additives, to high volume materials, such as biopolymers, biofuels, and fibres. They may also include existing bio-based products, such as paper and pulp, detergents, lubricants, construction materials, or new ones, such as vaccines made from plants or second-generation bio-fuels.



Source: Vlamse overhead, 2013 in turn adapted from MINA-raad & SALV, 2012, as reported in Allen et al., 2015.

Agriculture and the manufacture of food (beverage and tobacco) are dominant sectors of the European bio-economy, thus bio-economy strategies in the European Union tend to put a strong emphasis on these two sectors. For the same reason, the United States' (and South Africa) bio-economy strategy extensively covers the agricultural sector. The Finnish, Norwegian and Swedish strategies focus more on forestry (the use of wood biomass) and marine resources, which are abundant in Scandinavia.

The European Union's bio-economy strategy states with regard to agriculture that its aim is to provide knowledge and tools for productive, resource-efficient and resilient systems for food, feed and bio-based raw materials, in conjunction with policies that support rural livelihoods without comprising ecosystem services. The Spanish strategy seeks to foster positive spillover effects from the primary sector to bio-innovation in other industrial sectors. In the United States, the focus of the bio-economy policy has changed in recent years from a more holistic view of bio- and high-tech innovation across all economic sectors as portrayed in the 2012 Bio-economy Blueprint, to a more agricultural and bio-resources-based vision (Biookonomierat, 2018).

Table 2. Integration of the agriculture and food system in bio-economy strategies

Focus on agriculture	Focus on the food industry	Focus on the food system as a whole
Australia	Australia	European Union
European Union	European Union	Germany
Estonia	Finland	Ireland
France	France	Italy
Germany	Germany	Norway
Italy	Italy	Spain
Japan	Netherlands	United Kingdom
Latvia	New Zealand	
Lithuania	Norway	
Norway	Spain	
Spain	United States	
Sweden		
United States		
South Africa		

Amongst the bio-economy strategies identified, several cover only one of the two sectors. In particular, the United States and Swedish strategies only cover the bio-economy's contribution of agriculture. The Finnish strategy only covers bio-economy's contribution to the food industry, and does not directly refer to its contribution to agriculture. Remaining strategies cover both the agricultural and food sectors. In addition, a few countries (Germany, Italy and Spain) consider the bio-economy's contribution to the agro-food system as a whole by developing the idea of bio-economy "value chains".

In some OECD countries, the agro-food industry is seen as playing a key role in bio-economy related policy strategies, while in others – in particular Australia, France, the Netherlands, New Zealand and the United States – seek to increase the competitiveness and innovations of their food industry. The Italian strategy – in line with the European Union – considers the sustainability and competitiveness of the agro-food sector to be the top priority.

Finally, in several OECD countries, such as Estonia, Ireland, Latvia and Lithuania, the bio-economy is often driven more by ministries responsible for agriculture, forestry, fisheries, rural development or economics, and less by ministries for industry and innovation (Biookonomierat, 2018).

2. An opportunity to foster the sustainability of the agro-food system

Opportunities and challenges

Widespread benefits are expected ….

The development of a bio-economy is viewed as important policy opportunities to address interconnected challenges. The increasing demand for a sustainable supply of food, raw materials and fuels, combined with recent scientific advances are the major economic driving forces behind the growing prominence of the bio-economy in the policy agenda. All strategies point to population dynamics, climate change, food insecurity, resource depletion, new technological opportunities and changed preferences as the main factors favouring a transition to a bio-economy.[3]

[3.] In the European Union, for example, the launching of its Bio-economy Strategy was triggered by the need to respond to societal challenges such as food security, sustainable production, mitigating climate change, and contributing to global sustainable development.

In parallel, there is a growing focus on increasing overall resource efficiency and to make better use of wastes, with varying degrees of emphasis between countries. In some, reducing reliance on industrial raw materials is also considered important in terms of reducing the environmental footprint, fostering the circular economy, and limiting the impact of transport.

The literature on the bio-economy has evolved and is clustered under three major perspectives: i) the biotechnology vision, which emphasises innovations and the utilisation of biotechnology on a commercial scale; ii) the bio-resource vision, which emphasises the improvement of value chains in the production of biomass; and iii) the bio-ecology vision, which emphasises the positive impacts of energy and resource optimisation on ecosystem health (Bugge, Hansen and Klitkou, 2016; Bracco et al., 2018). These perspectives underline the potential of the bio-economy to create opportunities, such as low-carbon economic growth, preservation of natural resources, restoration of environmental and ecosystem health, and development of rural areas.

Governments highlight a number of contributions of the bio-economy to more productive and sustainable agro-food systems. Without exception, all bio-economy strategies – supported by much of the academic literature – emphasise its economic contribution. In particular, bio-economy strategies refer to its potential to boost economy growth, create jobs, enhance the competitiveness of industries, increase value-added and generate new products and businesses through appropriate cascading use of biomass and reuse of waste materials.

The strategies (and academic literature) also point to other potential advantages and opportunities, including: i) using natural resources more efficiently by replacing conventional fossil energy-based sectors with more cost-effective and less polluting bio-based sectors, and by developing novel bio-based production systems; ii) developing new integrated research structures through knowledge and technology transfer; and iii) reducing CO_2 emissions.

The bio-economy is associated with the transition from non-renewables to renewables (biofuel, green chemistry), and the improvement of husbandry systems (better breeding conditions). Processing agricultural products into renewable materials and energy offers countries the opportunity to increase the value-generation potential of their food system, as well as to enhance their economic development while improving food security and nutrition (Von Braun, 2017). Moreover, the bio-economy could potentially reduce GHG emissions (via transition to renewable biofuels and improved crop productivity) and accelerate adaptation to climate change by allowing new cropping systems to be developed in response to varying conditions (Zilberman et al., 2013).

Some argue that the bio-economy could be considered as an overarching framework to assess the sustainability of production chains, adding value to food and agriculture supply chains, integration of digital technologies and management of natural capital (Bellon-Maureel, 2017).

In addition, the development of a bio-economy is often seen as a stimulus to rural development where biomass production is usually located. It is expected to generate new activities and businesses based on the transformation of biological resources (production of bioenergy or bio-based products based on agriculture or forestry biomass/residues), create new jobs, and diversify sources of rural income (Box 4).

Bio-economy strategies, such as those in Canada, Finland, France, Germany, Italy, Japan, Spain and the United States, emphasise the potential of the bio-economy to create rural diversification and revitalisation, creating employment opportunities and improving the regional innovation system.

In the European Union, the CAP Communication on *The Future of Food and Farming* (November 2017) and the Cork 2.0 Declaration 2016 highlight that harnessing the potential of the bio-economy and the circular economy should be considered as a means to address sustainability in rural areas through the establishment of sustainable rural value chains and business models. Moreover, in the new delivery model of the post-2020 CAP, the national strategic plans must contain specific actions with regard to the bio-economy.

Box 4. Bio-economy – an opportunity for rural regions?

The transition to a bio-economy might stimulate new business opportunities in rural areas, for example, around the development of bio-refinery facilities (i.e. the processing of biomass into a spectrum of bio-economy products: food, feed, chemicals, materials and bioenergy, biofuels, power and heat). Because it might be more expensive to transport low-value raw materials, rural areas could have a potential comparative advantage in large elements of the bio-economy, which can to some extent counter any economies of scale associated with the centralisation of higher value-added ends of the chain.

However, as with renewable energy – that is also mainly produced in rural regions – there is no guarantee that the development of the bio-economy will boost rural development. Many barriers to the bio-economy development exist. These include: incompatible regulations and standards around bio-wastes; conflicting policy objectives of different ministries and departments; uncertainty over environmental impacts; "one-size-fits all" policies; and simply an absence of consideration to rural development issues or objectives. Moreover, in countries and regions where fossil-fuel economies are well developed, there are significant path dependencies caused by sunk-investments and interest groups, which bio-economy interests have to address. Evidence collected in 16 regional case studies – across ten countries – demonstrates that the territorial development impacts of renewable energy developments and related policies have been largely over-estimated.

Source: OECD, 2012.

…. but there are obstacles to the development of the bio-economy

While the benefits of the bio-economy are increasingly recognised, there remains a range of obstacles to its development, including weaknesses in policy coherence at different levels (e.g. bioenergy and waste policies), public perception, and lack of consumer awareness. The latter is a major barrier to increasing the market uptake of bio-based products.

One study (Burns, Higson and Hodgson, 2016) identified public perception as a major barrier to the development of the United Kingdom's bio-economy innovation system. Several recommendations for gaining public acceptance of bio-based products are made, including: i) clearer benefits communicated to customers, to put risk and benefit in perspective; ii) stronger regulations to improve public trust and ethical application of new technology; and iii) greater transparency and more genuine public engagement.

Box 5. EU public consultation results

In the preparation of its bio-economy strategy in 2011, the European Commission conducted a public consultation on the bio-economy in Europe, which received over 200 submissions from organisations and individuals across most Member States of the European Union. The consultation drew a number of conclusions. The majority of respondents offered an optimistic outlook on the bio-economy, with more than 60% believing that potential benefits could be achieved by 2020 or 2030. The majority of respondents also believed that there are a number of risks associated with the bio-economy, including the potential over-exploitation of natural resources and negative impacts on food security.

A lack of public information and understanding of the bio-economy were also considered important issues, especially regarding benefits and risks, as well as ethical issues and the question of sustainable patterns of consumption and production. In this perspective, more than 70% of the respondents called for actions related to communication and dissemination of information on the bio-economy. Other key themes that emerged in the public consultation included fostering effective governance, promoting collaboration across disciplines and sectors, investing in interdisciplinary education and training, and ensuring robust linkages between research, innovation and implementation

Source: European Commission, 2011.

The EC Expert Group for Bio-based Products (Expert Group's Lead Market Initiative LMI) also identifies lack of awareness and knowledge as a major obstacle to increasing market uptake of bio-based products and recommends the following: i) create conditions for informed consumer behaviour, using meaningful labels and information campaigns; ii) communicate the benefits of bio-based products across the value chain participants including producers, distributors, users and consumers, public authorities and NGOs; and iii) develop trusted business-to-business guidelines and comprehensible labels.

Overall, the bio-economy is seen as providing major opportunities in multiple sectors and at various levels to create highly skilled jobs and foster competiveness, while opening new markets and developing bio-economy products.

The bio-economy's contribution to primary production

Optimism about the potential benefits …

A majority of the bio-economy strategies consider that the development of a bio-economy can make a significant contribution to the agricultural sector or to primary production in general (agriculture and forestry). These strategies highlight the bio-economy's potential to foster more productive and sustainable production systems. Some strategies also refer to more "resilient" and "resource-efficient" production systems (European Union and France), or to a "sustainable intensification" of biomass production (Sweden, Norway and Spain).

Agriculture has the potential to be at the centre of the bio-economy, providing raw materials for liquid fuels and value-added products (chemicals and materials), as well as healthy and safe food and feed, but which could result in trade-offs in terms of choices across the various products produced.

The bio-economy has many potential applications in agriculture, including: water-use efficiency – producing crops that consume less water; nitrogen-use efficiency – fertiliser-use efficiency; crops that are more disease resistant; and planting varieties of crops (especially rice) that increase yield and produce less CO_2. Among the many opportunities for the agriculture sector, these include:

- New income streams and jobs by utilising new resources and opening up new markets.
- Diversifying farm practices and establishing links to new sectors and businesses.
- Reducing exposure to risk from commodity prices or changes in policy by transitioning to more resource-efficient business models.
- Lowering costs through more efficient use of resources and optimising the use of waste resources.

New technologies could support improved productivity, efficiency and resilience, while reducing the environmental footprint. New plant varieties, along with improved methods of management, would allow for crops that are better adapted to growing conditions and improved yields, while irrigation needs, soil erosion, and salinisation could be reduced.

Concerning climate change, country strategies see a great opportunity to minimise GHGs from agriculture. New sources of energy would replace fossil fuel-based products, and the sustainable intensification of agriculture and forestry would help protect carbon stocks in soils and forests.

The development of the bio-economy is expected to bring about a greater range of useful co-products that could reduce the pressure on food and feed markets (Von Braun, 2018). However, the impact of the bio-economy would depend on how some of the key bio-economy value chains are evolve, both in terms of market development and in terms of technological progress (e.g. biofuels).

Agricultural production recycles many by-products not only from this sector but from others in the form of animal feed or nutrients applied to the soil. These inputs and their by-products are important inputs for other non-food industries to produce bioenergy, chemicals and materials.

The strategy in Spain seeks to foster positive spillover effects from the primary sector to bio-innovation in other industrial sectors – for example, by supporting bio-refining projects and using residues and

by-products from agriculture and the food industry to develop a range of new biomaterials and bio-products (including bio-lubricants, bioplastics, food additives, cosmetics, solvents, chemicals).

… but the potential risks should not be underestimated

In general, while there is great optimism about the benefits and opportunities for the agricultural sector associated with the growing bio-economy, potential risks could arise, particularly if policies are developed and implemented in a partial and non-integrated way. There are also significant risks and trade-offs in the development of a large-scale increase in biomass utilisation.

As in conventional agriculture, a major risk lies in the increased competition between food supply and non-food biomass production. An important dilemma associated with the bio-economy is that the expansion of the production of industrial products on farms will divert farmland from food production to other uses, and thus the bio-economy would accentuate the "food versus fuel" concerns currently associated with biofuels.

Moreover, if the transition to a bio-economy is intended to provide cheap biomass without giving adequate priority to the use of biomass as food, the transition could generate pressure on food prices. Indeed, increased demand for biomass for bio-economy products could undermine food security and have a significant impact in terms of price and price volatility (as already experienced in the past). Bio-economy strategies often acknowledge such risks and point to the competition between food and fuel as an important challenge (Dietz et al., 2018). A serious concern also relates to the sustainability of biofuels for transport, an integral part of the bio-economy.

Excessive emphasis on alternative uses of biomass would shift the focus away not only from food production, but also the conservation and management of cultural landscapes. Biomass production and use should adhere to the objectives of sustainability and biodiversity protection. The transition to the bio-economy needs to be viewed through the perspective of its overall impact on the environment, and on which life cycle analysis can throw some light. This could reveal that certain renewable production processes are inefficient and costly.[4] It should be noted that even after the transition from non-renewable to bio-economy systems, some non-renewable inputs are likely to be needed and used in food production (e.g. phosphorus).

Clear policy and governance priorities are necessary to ensure that the bio-economy is synonymous with sustainability (Lewandowski, 2015).[5] The transition to systems that rely solely on renewable inputs requires innovations that will lead to better management systems in terms of precision in the use of inputs, (recycling, crop rotation and nutrient cycling) and their introduction will take time. It may also require different seed varieties (e.g. crops able to fix nitrogen). However, the development of such technologies and their adoption need to be supported by policies that encourage R&D and prices that make adoption worthwhile.

The increased use of agricultural (and forest) waste streams for bio-economy e-materials could also have negative effects on the level of organic matter in soil and soil biodiversity, with additional negative impacts on the fertility and productivity of soils. 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-economy could also aggravate water scarcity in some areas of the world because it places additional pressure on water demand. Greater demand for land for food and non-food crops could result in more monocultures, negative environmental impacts, and increased pressure on natural habitats and biodiversity.

While the reduction of GHG emissions has been a key driver in fostering the bio-economy, there are several concerns in relation to the overall GHG savings from feedstock production, land-use changes, and bioenergy conversion steps.

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4. For example, life cycle studies found instances where the transition from fossil fuel to biofuels may increase overall GHG emissions (Zilberman et al., 2013).

5. See, for example, Menrad et al. (2011).

The growing demand for agricultural biomass associated with the development of the bio-economy must be met within the context of limited arable land, and declining utilised agricultural areas in many regions/countries, as emphasised in Germany's and the United States' strategies. Moreover, as the updated bio-economy strategy of the European Union indicates, it is crucial to ensure that biological resources are used within their sustainability thresholds and that ecosystems are not pushed beyond safe boundaries (e.g. by exceeding the capacity of specific provisioning ecosystem services). Therefore, the necessary increase in biomass production will need to rely on productivity gains and increased resource-efficiency.

Two major priorities must be met as the bio-economy develops. First, improve the agricultural total factor productivity, and second, reduce waste and increase the efficiency of how agricultural and other products are used. There is a great potential to increase agricultural productivity with existing technologies, and new technologies that are part of the bio-economy suggest a much larger potential to increase the productivity of land and water, while preserving biodiversity (Nin-Pratt and Magalhaes, 2018). Mitigating these risks would require coherent and integrated policies to ensure the long-term economic and environmental sustainability of the bio-economy.

In Denmark, an additional 10 million tonnes of biomass could be produced by 2020 within the existing agriculture and forestry framework without any adverse impact on food and animal feed production (Gylling et al., 2016). It would also be possible to significantly reduce the environmental impact from agriculture and to increase biodiversity. Additional biomass could be generated by a 15% increase in the recovery of straw, changing to cereal varieties with more straw, and by adopting new cropping systems. The first two initiatives could be implemented within a five-year period (2015-20), although a large-scale transition to new cropping systems is unlikely to be implemented before 2020.

Several strategies promote the principle of food first, suggesting that the increase in agricultural biomass production has to be first directed towards meeting the world's food and nutritional needs before supplying raw materials for energy or industrial purposes. This reduces the room for food versus fuel competition, one of the biggest challenges brought about by development of the bio-economy.

There have been questions about the sustainability of the large-scale use of biomass for energy production (OECD, 2009). Although the bio-economy is concerned with the uses and conversions of biomass, a striking feature in strategies is how seldom the sustainability aspect is mentioned as a driving force.

The amount of biomass available is not sufficient to simultaneously cover a large share of today's energy demands for power generation, industry, construction, and transportation. For example, a study by the Thünen-Institute found that, notwithstanding the fact that more than 10% of the agricultural area in Germany is currently dedicated to the production of raw materials for energy and material uses, the potential for the generation of energy from residual and waste materials is estimated to be small.[6] Similar results are found in the case of Japan (see OECD, 2019).

It is essential to identify and implement mechanisms for the sustainable production of biomass. Policy incentives to adopt sustainable agriculture methods that help maintain soil cover, increase the overall water-use efficiency at the basin level and reduce soil erosion are critical. Furthermore, research focussing on ecosystem services that help to provide the necessary information to make appropriate land-management decisions is also required. Second, technological developments are needed in order to improve the biomass-to-biofuels conversion efficiency.

… and the bio-economy cannot be considered as inherently sustainable

The contribution of the bio-economy to environmental protection and sustainability in general is highlighted in all bio-economy strategies. However, there is no consensus in the scientific literature on its future impact on sustainability. Pfau et al. (2014) reviewed 87 journal articles from different academic disciplines dealing with the link between the bio-economy and sustainability. It appeared that visions about the relationship between the bio-economy and sustainability differ substantially among the articles reviewed. The most recurrent one refers to "conditional benefits", meaning that the bio-economy can contribute to sustainability, but only under certain conditions such as sustainable

6. https://literatur.thuenen.de/digbib_extern/dn053498.pdf

biomass production, assessment of production chains and impact, assessment of sustainability, and efficient use of biomass resources.

Overall, the main concerns are the following: over-exploitation of renewable natural resources, over-use of soil and water resources, competition between food and fuel, the impact of new crop varieties on soil fertility, unsustainability of bioenergy production. The over-exploitation of biomass would have severe consequences that could result in worsening climate change – deforestation, soil damage and destruction, imperilled water security. In addition, the amount of biomass that could be grown and harvested sustainably – the biomass potential – is not known and estimates for the future vary widely (OECD, 2018a).

The contribution of bio-economy to the food industry

The bio-economy is expected to make a significant contribution to the food industry. Even though the contribution of the bio-economy to the food industry has received less attention than its contribution to primary sectors, it is still emphasised in several bio-economy strategies.

Improved food safety and healthier diets

A key area for the food sector is improving food safety. In the livestock sector, for example, the control of animal diseases will continue to be a priority. Advances in biomedical sciences in the developing bio-economy could be strong linked to this sector. In other areas of the food system, the detection and treatment of problems with mycotoxins, E. coli, and other health threats to grains, vegetables, fruits and other products – either in their primary or processed form – will continue to demand greater application capacity.

The European Union, Spanish and Italian strategies cover the potential contribution of the bio-economy to enhance food safety and to promote consumer health and healthy diets. In light of the important increase in food safety incidents which have increased consumer concern worldwide, the strategies emphasise the need to further invest in research and innovation (R&I), and develop innovative approaches to strengthening food safety, from production to consumption.

In several countries – including Argentina, France, Italy, Latvia, New Zealand, Norway, Spain and the United States – innovations in the agro-food bio-economy are increasingly considered as important for improving human health. As such, innovations in the agro-food sector, for example, should ensure the nutritional quality of foods and food safety, while promoting long-term benefits for human health. In this context, R&D for functional foods (foods that have a potentially positive effect on health beyond basic nutrition) and healthy diets is emphasised. Alternative food resources, such as insects and algae, are also considered promising in countries such as France and Italy in order to meet future demands for protein (Biookonomierat, 2018). Finally, with the development of a bio-economy, the food industry could exploit the alternative food sources such as insects and algae, which can be used as protein sources in the food and feed industries. The Finnish Ministry of Agriculture and Forestry recently announced that the cultivation and sale of insects as food is now permitted.

The Italian strategy highlights the need to develop fast on-line detection tools for food and feed safety (to deal with pathogens, allergens, toxins, chemical residues, nanomaterials, etc.) and integrates such tools in risk analysis. The development of innovative ICT tools, devices, and apps for smart food utilisation and domestic food management is also expected to enhance food safety. Moreover, greater integration and communication throughout the supply chain is considered essential.

The European Union and Italian strategies emphasise the need to raise consumer awareness of the link between food and health, and to create incentives for informed food choices. In addition to information and re-formulation policies, some innovative solutions could contribute to better nutrition and dietary choices. The Italian strategy, for instance, proposes the development of smart nutrition solutions (e.g. with improved nutrient bio-availability) to establish how food production technologies, new delivery methods, and ICT approaches could be used to provide tailored nutrition solutions and health care. Tailored and targeted nutrition responses to address obesity and ageing populations will have an important market potential according to the Irish strategy. The German strategy highlights the

market potential for "highly-refined food with a high level of value-added, produced in conformity with the requirements of sustainable agricultural production".

New business and markets opportunities in the food industry

According to the Finnish and the Italian strategies, the development of the bio-economy will bring new business opportunities to the food industry in both traditional and novel food sectors. Exploiting the opportunities offered by closed systems, bio-refineries, domestic animal production side streams and field biomasses could generate completely new businesses.[7] By-products and streams and waste from the food industry can be converted into added-value food ingredients and bioactive products, bio-chemicals, biomaterials (packaging) and biofuels.

Increased resource-efficiency in the food-chain

The development of a bio-economy is expected to increase resource-efficiency in the food chain. According to the European Union, Italian and Spanish strategies, important reductions in water and energy use and of waste could be achieved through improvement of existing processes, the adoption of new technologies and processing methods, and increased circularity and recycling along the food chain (in processing, transport and distribution). Increased resource-efficiency and waste reduction would increase the food industry's competitiveness by reducing costs, while providing a positive impact for the environment.

New packaging materials for the food industry

Several strategies highlight the advantages of developing biodegradable food packaging (European Commission, Sweden, Spain, Italy and Ireland). These "new, biodegradable, thinner and/or lighter packaging materials that can be fully re-used, recycled or recovered as energy sources" (EC, 2012) are expected to reduce the environmental footprint of the food industry, contribute to enhanced food safety and shelf-life, preserve taste, and boost the competitiveness of the food and packaging industries.

The Spanish strategy emphasises the contribution of "new processing, wrapping, packing, conservation and cold chain technologies which preserve for a longer period the organoleptic and nutritional qualities" in promoting consumer health and guaranteeing food safety. The Italian strategy identifies several innovative biodegrable materials that could benefit the food and agricultural sectors, such as for carrier bags and waste bags, bags and gloves for fruits and vegetables, and mulching film. In addition to biodegradable and compostable packaging materials, the Irish bio-economy strategy also promotes innovative ideas such as the development of clean labels from fruits and vegetable waste, and packaging for agricultural produce derived from agricultural waste sources using upcycled wheat straw, tomato plant waste, or olive tree residues, for instance (O'Reilly, 2017).

Box 6. Integrating primary production into the bio-economy value chain: The Matrica complex in Italy

The Matrica complex in Sardinia, established in 2016, is a third-generation biorefinery, functioning as a green chemistry plant for the development of bioplastics in Italy. The plant utilises local thistle weeds – common weeds that grow throughout the year on poor Sardinian farmland where wheat is no longer profitable – as the main input in bio-lubricants, bio-fillers and bio-plastics. The project was initiated in 2011, when one of the region's most polluting petrochemical plants (which produced petroleum-based polymers) was shut down. The decision was taken to transform it into one of the most innovative green chemistry complexes in the world. Providing economic, social and environmental benefits for the local community, at full capacity the plant will produce up to 70 000 tonnes of bio-products annually, employing almost 700 people and drawing on local raw materials.

Source: Bioplastics News (2015).

[7]. See, for example, Appleyard (2014).

Bio-economy contribution to the agro-food chain

In addition to its contribution to the agricultural sector and the food industry, the bio-economy is expected to positively impact the agro-food chain as a whole, mainly through increased resource-efficiency. In this regard, the concept of bio-economy is closely related to the circular economy, as the bio-economy promotes the idea of waste reduction, and recycling and reuse all along the value-chain. The overall aim of developing a bio-economy is to strengthen existing value-chains while creating new ones.

Increased resource-efficiency in the agro-food chain

The development of the bio-economy entails the more efficient use of all types of resources. The European Union and Italian strategies emphasise the need to improve resource-efficiency in the "food supply chain'' and "food making value chain". In this regard, both strategies agree on the need to reduce water consumption and energy use, as well as minimise raw material losses and waste production, and to maximise recycling from food processing, through to transport and distribution. This is expected to result from increased resource-efficiency along the food chain by efficiency improvements of existing processes and the adoption of new technologies (water- and energy-saving technologies in particular) and processing methods.

The Spanish and German strategies go a step further by considering the need to improve resource-efficiency in the food system as a whole and along the agro-food chain: starting from production and via transport, storage, processing and marketing, through to consumption. These strategies mainly highlight the importance of cutting residues and minimising losses and fostering the recovery of all waste and by-products as raw material for other productive processes. In this regard, the development of technologies for facilitating the recycling and recuperation of raw materials will be essential.

Box 7. Selected flagship projects for agro-food waste and increasing the value of by-products in the European Union

So.Fi.A (Sustainability of Agrifood supply chain) is an Italian project providing innovative technological solutions for the improvement of the sustainability of the national agro-food sector at every level of the supply chain, through climate change adaptation, scrap recovery and waste reduction. Examples of current incentives are the following: valorisation of dairy by-products, especially residues of ricotta cheese and cheese whey, for recuperation of their bio-molecules; strategies for the re-utilisation and valorisation on beef processing by-products and wastes; and new solutions for increasing the efficiency of processing fresh-cut vegetables.

Agrimax is an EU-funded project that is developing and demonstrating the production of multiple, high-value products from crop and food-processing waste. The project aims at maximising the EU's sustainability, while providing new bio-based compounds for the food, packaging and farming sectors. Agrimax will develop two pilot processing plants, one in Italy and one in Spain, to demonstrate the technical and commercial feasibility of extracting high-value compounds from agricultural and food processing waste. By applying them sequentially, Agrimax will produce a cascade of bio-based compounds with high-value applications, such as: packaging (bio-polymers, bio-composites, bio-based coatings, active packaging, stabilising agents), food (additives, ingredients, natural flavourings, edible coatings, microbial growth media) and agricultural materials (biodegradable pots, mulching films, bio-fertilisers).

Agrocycle, an EU Horizon 2020 research and innovation project, addresses the recycling and valorisation of waste from the agro-food sector. The project takes a holistic approach to understanding and addressing how to make best use of the full range of waste streams associated with the agro-food industry. It will deliver the AgroCycle Protocol, a blueprint for achieving sustainable agro-food waste valorisation.

AgriBioMéthane is a French project using manure from four cattle farms – as well as by-products and waste from local agro-food enterprises – to produce biogas, which is refined into biomethane. The biomethane is then injected into the gas network of the town of Mortagne-sur-Sèvre and used as fuel for school buses.

Source: http://www.clusteragrifood.it/images/progetti/Poster%20-20SOFIA%20-%20ENG.pdf; http://agrimax-project.eu/#overview; http://www.agrocycle.eu/ ; http://www.agribiomethane.fr/.

Strengthening existing value chains and developing new ones

It is characteristic of the bio-economy that the value chains of its products in the various business sectors become increasingly interlinked, and that by-products and residual materials are used in such a way as to achieve the highest possible value. In many instances, synergies exist between various paths of biomass use. For example, feed products are generated as by-products when plant oil is made, or the production of cereals generates straw, which can be used as a material or as an energy source.

Within the general realm of the bio-economy there are many examples of how materials from one value chain can feed into the development of a new value-added chain. The EU AgroCycle project, for example, outlines some of these possible pathways (Box 8).

Several bio-economy strategies (European Union, Germany, Spain and Flanders) promote the principle of the *cascading use of biomass* and waste streams. This refers to the idea that biomass from primary production as well as from residual and waste streams must provide sources of: firstly, food and animal feed (guaranteed to meet food safety standards); then raw materials; and subsequently energy (OECD, 2018a; Government of Ireland, 2018). The cascading use principle gives priority to higher value uses that allow the reuse and recycling of products and raw materials and promotes energy use only when other options are starting to run out.

The cascading use of biomass is seen as a way to increase the productivity and efficient use of scarce and valuable raw materials. The basic idea is that, along the chains, the biomass must be kept in the production chain for as long as possible in its various forms through reuse, being split into different fractions and by utilising residual streams. In this way, economic and societal value can be generated several times from the same biomass. However, proper implementation of the biomass cascading should take into consideration regional and local economic and technological circumstances, maintenance of the necessary carbon stock in the soil, and the quality of soil and ecosystems.

Future development of the bio-economy may also bring about a radical redesign of products and processes and create a demand for new skills and open new markets for the agro-food sector. At the same time, it may make some of the old products, processes and skills obsolete (SCAR, 2015). The net effect will depend on the way bio-economic strategies are implemented. A bio-economy based on large-scale industrial plants may result in a concentration and intensification of international trade, with an uneven geographical and social distribution of costs and benefits and a net loss of jobs. Focusing on bulk biomass production may generate low-skilled and low-paid jobs, while focusing on high-added value would generate demand for skilled jobs.

Box 8. The principle of cascading use of natural resources

The principle of the cascading use of natural resources has risen to prominence in recent years and it has become a commonly recurring concept within the European Union in policy discussions about renewable energy, the bio-economy economy and the “circular” economy.

Cascading can be useful as a descriptive framework for how to increase natural resource efficiency, but its implementation is complex and needs to address questions such as: which specific objective should be achieved through cascading? How to determine the value of a specific use (e.g. the actual “value” of a specific use of biomass strongly depends on the local needs and the specific infrastructure)? Which economic, environmental and social aspects should be taken into account?

Assuming that cascading is always sustainable can be misleading. Implementation of the cascading principle to promote the highest economic added value must also consider its environmental and social impact. For example, its implementation should optimise synergies between the cascading use of biomass and its externalities in each specific case (e.g. in terms of emissions, social impacts, environmental damage, loss of biodiversity or other impacts).

Overall, increased knowledge and better understanding of biological systems, their functioning and their interactions, is expected to foster new production methods. The Italian strategy highlights the need to "explore the sustainability potential" of different models of agricultural production, such as: climate-smart agriculture, precision farming, ecological intensification, agro-ecology and regenerative agriculture. The French strategy also emphasises the need to adopt "balanced and diversified production systems more integrated into natural systems", such as agro-ecology and organic farming.

Towards circular agro-food chains

The concept of bio-economy is in certain ways related to the circular economy (Box 9). The main objective of the bio-economy is the production and use of biomass, while the circular economy is focused on the use and reuse of products and on closing the loop within major cycles. The circular economy strives to meet these objectives via reuse, recycling and closing loops, while the bio-economy focuses on renewable raw materials (D'Amato et al., 2017).

In bio-economy strategies, the use of biological resources has been increasingly linked to this circular economy concept. For example, in December 2015 the European Union adopted a circular economy strategy to promote resource efficiency across industries and member states.[8] Practically all of the European bio-economy-related strategies published since 2015 highlight the compatibility of the concepts and the contribution of the bio-economy to circular economy approaches (including those of Finland, France, Italy, Latvia, Norway, Spain, and the United Kingdom). The Italian bio-economy strategy even introduces the term "circular bio-economy".[9] In Argentina and Canada, the circular economy concept has received considerable attention within bio-economy-related policy strategies.

The German and Italian strategies both highlight the potential of urban agriculture in fostering a more circular economy. For example, residual materials and waste materials generated locally and exploitable for energy purposes can be used in "urban farming", as can waste heat. In turn, small industries and agriculture can increase production if side streams from urban and peri-urban and local food production are utilised for nutrient recycling and local bioenergy production.

Both concepts promote the idea of increased resource-efficiency through generating less waste and increasing waste recycling. There is an important degree of scope for reducing waste and losses along the agro-food chain. New cultivation and harvesting technologies, for instance, can help by reducing biomass waste from the beginning of the chain. Post-harvest losses and storage losses could also be reduced, as well as waste generated by processing, trade and consumption. Further reducing waste along the agro-food chain will require increased integration between sectors and better communication and co-ordination along the value-chain.

Thus, most bio-economy strategies include some reference to waste, either by the identification of genuine waste streams, or through promoting the use of industrial side-streams, such as agricultural or forestry residues and paper pulp. Such strategies highlight the importance of reducing waste and residues and recovering remaining waste and by-products as raw material for other productive processes or the creation of new value-added products. Bio-economy strategies point out that bio-waste, including agro-food waste, are currently under-used and under-valued, with possible negative consequences on the environment.

The strategies therefore focus on promoting R&D on new and improved bio-based products. Many countries consider bio-refinery development as important for converting bio-based resources into innovative products. It is equally important to develop new resource alternatives for industrial use, such as organic waste and residues and by-products from agriculture, forestry and fisheries (Biookonomierat, 2018).

8. https://ec.europa.eu/commission/priorities/jobs-growth-and-investment/towards-circular-economy_en.

9. The European Union uses this term in its present roadmap for preparing an update of the bio-economy strategy and action plan of 2012.

Box 9. The circular economy and its implications for the food system

The circular economy can be defined as the transition from the existing linear economy (harvesting, producing, waste), with final resources to an economy in which raw materials and products remain in a closed cycle. The circular approach embraces a system view and considers the efficiency of the system as a whole by combining all production chains rather than the single production chain itself.

Current agro-food systems largely take the form of the linear production chain: a commodity is converted into food, and waste is generated along the process. Some recycling of production waste is performed, but it is not complete circularity, which is an integrated system and means zero waste.

Increased circularity in food production systems offers ways to increase food production without increasing biomass production, through waste reduction and re-use. The main idea is to make full use of all the biomass generated. This can be achieved by the adoption of an integrated approach of crop and livestock production within a circular production system, which maximises the overall production of nutritious food for human consumption, while minimising the environmental impact, and enhancing carbon sequestration in the soil. It mainly implies adding value to multipurpose cropping and of animal manure.

Adding value to multipurpose cropping entails the production of biomass for food, feed and non-food purposes from the same crop, by exploiting crop biomass to the fullest extent (increasing synergies between food and feed, and food and non-food products). First, smart food processing can make it possible to extract all the biomass that can be converted into human food. Then, the remaining biomass (that can be digested by animals, but not by humans) can be converted into feed. Finally, any resulting waste that has nutritional value can be composted, and insects (or fungi mushrooms) can be grown on the compost. Insects can, in turn, be used as a source of protein for food and feed. Finally, ecological intensification of grassland areas can also contribute to producing more food. Adding value to animal manure is achieved by “loading up” the soil with organic matter to increase carbon sequestration.

Circular crop and livestock systems would lead to reductions of GHG emission due to: lower product emission intensity, as more products are produced out of the same crop; increased carbon sequestration (due to manure organic matter); and better management of livestock production.

Note: For more information see the workshop on the Circular Approach and the Sustainability of the Agro-food System: Closing Resource Loops to Improve Sustainability organised by the OECD and the Dutch Ministry of Agriculture, Nature and Food Quality (https://oe.cd/casafs).

The Italian strategy gives a number of possible ways of recovering and valorising agro-food waste. The strategy considers that, by adopting innovative processes, by- and side-products and waste from agro-food processing industries can be exploited and placed on the market as new foods or fodders, ingredients or bioactive compounds with a high nutritional value, or transformed into biodegradable food packaging. It also highlights the importance of using agro-food waste for composting, which contributes to reduce the depletion of soil organic matter (when used as fertiliser).

Box 10. Efficient energy recycling using biomass in the biogas plant in Hokkaido (Japan)

A centralised biomass treatment facility (biogas plant and composting plant) collects and treats manure from livestock farming (mainly dairy farming) which is a key industry in the area. A key objective of the plant is to improve the local environment by reducing the odour from cattle waste and lowering nitrogen leaching. It aims to produce high-quality compost derived from waste biomass, establishing systematised technologies to utilise biomass by using biogas energy. In the case of the biogas plant in Shikaoi Town, Hokkaido the power generated from biogas is primarily used in the facility and the rest of the power is sold to the Hokkaido Electric Power Corporation. Liquid derived from the biogas plant is used as fertiliser in farmland and thus promotes at local level the recycling-based society. Greenhouse cultivation of agricultural products and aquaculture is also conducted by using the heat generated by the biogas plant. The plant generates a daily total of roughly 6 200kWh, which is equivalent to the amount of electric power used by 490 Japanese households every day. The power generated by the plant will be used in the facility, and the surplus electricity will be sold to pay for the facility's operating costs.

Innovating for growth of sustainable agriculture and food

Historically, technological advances have contributed significantly to the development of the agro-food sector, and research and innovation are essential to the development of the bio-economy. Some of the applications envisaged in the bio-economy are innovative and require additional R&D. The production and use of the necessary biomass also require innovative approaches. Moreover, systemic approaches focused on the bio-economy as a whole and its economic, environmental and social impacts also need to be underpinned by research (Gouvernement Francais, 2018; Zilberman et al., 2018).

A 2009 OECD report (OECD, 2009) proposed boosting agricultural and industrial research through increased research funding from the public sector, reduced regulatory constraints and encouragement of public–private partnerships in these sectors. This is because 75% of the future economic contribution to the bio-economy is likely to come from agricultural and industrial applications. It also proposed the use of biotechnology to address global environmental issues by supporting international agreements to create and sustain markets for environmentally sustainable biotechnology products.

All bio-economy strategies agree that a positive contribution to the agro-food sector will be brought about mainly through increases in research and innovation, and the development and adoption of new methods, techniques and technologies. A prime example of what can be achieved in the bio-economy through research and innovation is the success of Glanbia in Ireland in transforming whey protein, a side product of the dairy industry with limited value, into a critical ingredient in the global human nutrition market (Box 11).

Research and innovation are at the centre of all bio-economy strategies. In particular, the bio-economy is seen as closely related to ongoing key technology trends in industry (such as in the fields of synthetic biology, big data techniques, additive manufacturing and the Internet of Things (IoT),[10] nanomaterials, and artificial intelligence).

Technology features as a key, defining component in the bio-economy in many strategies, including in the United States; as a central part in Italy with reference to the bio-refinery concept; with reference to the knowledge-based use of biological materials in Germany; and explicitly as a necessary enabling tool in the Flanders's vision.

The United States strategy is focused on research and innovation in the biological sciences. The Swedish strategy (which focus on research and innovation) defines the main priorities for the development of a bio-based economy, while the Netherlands places the emphasis on biomass production, innovation, sustainability and coherent policy. Germany has established a national Bio-economy Council, which focuses on the economy, innovation, education and policy. Overall, most bio-economy strategies include a research and innovation agenda and support the development of an innovation-driven and knowledge-based bio-economy. In the United Kingdom, the use of technology in the development of the bio-economy is made explicit in the House of Lord's report on waste.

Countries rich in bio-resources such as Argentina, Brazil, Canada, France, Italy, Latvia, New Zealand, Norway, Spain and the United States promote innovations in their primary industries, including agriculture, forestry, fisheries and aquaculture, to ensure sustainable development. Consequently, R&D in sustainable intensification, climate-smart agriculture and forestry, precision agriculture and livestock farming are considered promising.

The purpose of the Swedish strategy – published by the Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning in collaboration with the Swedish Energy Agency and the Swedish Innovation Agency – is to form a basis for a research and innovation bill from the government. In the United Kingdom, the use of technology in the development of new aspects of the bio-economy is made explicitly. In the European Union, bio-economy related research and innovation (R&I) is a

[10.] IoT refers to an ecosystem in which applications and services are driven by data collected from devices that sense and interface with the physical world. In the IoT, devices and objects have communication connectivity, either a direct connection to the internet or mediated through local or wide area networks. Important IoT application domains span almost all major economic sectors, such as health, education, agriculture, transportation, manufacturing and electric grids.

priority for most EU countries and regions in 2014-20, and an "agro-food" focus is most common within bio-economy related research and innovation.

Box 11. Transforming low value by-products to high-value bio-commodities: The case of the Glanbia-led AgriChemWhey project in Ireland

Based on a new bio-economy campus, this innovative research project aims to convert low-value by-products from the dairy industry into a series of high value-added bio-based products, including biodegradable plastics. This flagship plant represents Ireland's first major industrial venture to convert residues from food processing, as second-generation feedstocks, to value-added bio-based products.

AgriChemWhey will build a state-of-the art, industrial-scale bio-refinery with integrated symbiotic industrial and agricultural value chains that will valorise more than 25 000 tonnes (100% dry matter) per annum of excess whey permeate and delactosed whey permeate to several added-value products, including biodegradable plastics, bio-based fertiliser and minerals for human nutrition.

The plant will investigate the techno-economic viability of the innovative bio-refinery technology and will establish a new value chain for industrial symbiosis with other local companies for the production of high-value sustainable food and feed products from other side-streams. It offers the opportunity for greater resource efficiency (less food waste, more products from raw milk, and the integration of food and non-food material production) and for harnessing the potential of by-products from the dairy processing stream, both of which are important elements in creating a circular bio-economy for the dairy industry. The AgriChemWhey will also strengthen the environmental sustainability of the sector, while offering new opportunities for rural employment and development.

AgriChemWhey is based on ground-breaking technology developed and patented by Glanbia Ireland, in collaboration with University College Dublin and Trinity College Dublin. The overall cost of the project is EUR 30 million, of which EUR 22 million is EU funding from the Bio-Based Industries Joint Undertaking (BBI JU) under the European Union's Horizon 2020 research and innovation programme. If successful, the project will serve as a flagship for Europe's growing bio-economy, with potential for replication in other regions across Europe. The project runs until end-2021.

The bio-economy entails the use of biotechnology on a large scale. The OECD has estimated that by 2030 biotechnology could contribute up to 50% of primary production, 80% of pharmaceutical production and 35% of industrial production in sectors where biotechnology has potential applications (OECD, 2009).[11] Advances in biotechnology are considered as the basis for addressing the main challenges impacting the agricultural sector in the context of the bio-economy. The majority of bio-economy strategies that address this point recognise the importance of bio-technology in achieving a more productive and sustainable agricultural sector.

Against the backdrop of the debate on trade-offs between food security and renewable energy, priority is increasingly being given to R&D on non-food feedstock and on biotech innovations enabling 2nd- and 3rd-generation biofuels (e.g. Japan, Denmark, United States).

Opportunities for plants and animal breeding

In the context of the bio-economy, advances in breeding techniques are seen as a way of developing plants and animals with "desirable traits" (Zilberman et al., 2018). Bio-economy strategies highlight the potential of breeding techniques in: i) increasing the adaptive capacity of plants and animals by a changing environment (e.g. improving the heat-resistance and drought-tolerance of crops); ii) addressing biotic and abiotic stresses (mainly linked to the need to adapt to climate change); iii) enhancing disease resistance; iv) increasing production, yields, efficiency; v) creating opportunities

[11.] 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, 2009).

for alternative animal feeds;[12] vi) reducing the need for external inputs (fertilisers, insecticides, water); and vii) increasing nutritional value.[13]

Policy strategies in Argentina, Brazil, the People's Republic of China (hereafter "China"), France, Latvia, New Zealand, Norway, Spain and the United States highlight the potential of genetic improvements to increase yields and the quality of crops, while the Italian and French strategies also include enhancing the photosynthetic capacity of plants (Biookonomierat, 2018).

Opportunities for managing plant and animal diseases

Alternative technologies and practices such as integrated pest management or the use of robotics for weed control are gaining ground. Scientific advances are also providing new opportunities for managing livestock disease, both in terms of new diagnostic methods, as well as new vaccines. Advances in plant breeding that allow plants to photosynthesize more efficiently and capture more carbon dioxide could positively affect climate change mitigation, yields and nutrition, while reducing pressure on land.

The European Union's strategy, for instance, emphasises the need for further progress on bioremediation – a biotechnology application used to clean up polluted soils and water by removing toxic compounds. The United States' bio-economy strategies highlight the role of biotechnology institutions in developing vaccines and diagnostic kits to mitigate the risk of potentially devastating outbreaks of livestock diseases.

Opportunities from engineering technologies

Precision agriculture and related technologies such as digital technologies (e.g. sensors, digital platforms, robots, internet applications, drones) hold the promise of achieving more resilient, productive and sustainable agriculture and food systems. They can also provide an opportunity for governments to improve the efficiency and effectiveness of existing policies (OECD, 2016; Bellon-Maureel, 2017; Tripoli and Schmidhuber, 2018; OECD, 2018b).

Italy, France, Germany, Norway and Spain all refer to the potential of *precision* farming in increasing agricultural sustainability, mainly though the more efficient use of fertilisers and plant-protection products. Further research into precision farming is therefore considered a priority.

Argentina, Brazil, France, Italy, Latvia, New Zealand, Norway, Spain, the United Kingdom and the United States mention the importance of converging technologies, such as biotechnology, nanotechnology, the "omics" technologies and ICT, to facilitate the development of innovative bio-based processes, products and services.

Only a few countries link bio-economy development directly to *digitisation*. Brazil, China, New Zealand, the Spanish region of Extremadura and the United Kingdom highlight the potential arising from combining both digital and biological technologies for modernising existing industries and businesses and for developing completely new sustainable industries and business models.

Increased research into biodiversity and ecosystem services

As a prerequisite for the sustainable production of any bio-resources, most strategies support R&D for the purpose of ecosystem conservation, recovery and restoration. Several strategies emphasise the need to improve resource management and increase soil, water and air quality by using modern

12. Estimates show that 58% of the world's biomass was used for animal feed in 2011, but with the potentially competing uses of biomass as the bio-economy grows, this may not be sustainable.

13. The OECD Conference on Genome Editing: Applications in Agriculture – Implications for Health, Environment and Regulation, held 28-29 June 2018, explored the safety and regulatory considerations raised by genome edited products, including the regulatory questions associated with genome editing applications in agriculture (see https://link.springer.com/journal/11248/28/2/suppl).

technologies, such as bio-technology.[14] Agro-ecological and organic farming management approaches are also considered important in Brazil, France, Italy, Latvia, and Spain, while the newer concepts of urban greening and urban farming receive greater attention in the Canadian and the Italian bio-economy strategy.

Aside from the need to further advance on research and innovation, most bio-economy strategies acknowledge the need for "better knowledge of how plant nutrients and water circulate and are released or fixed by the ecosystem". Additional research and innovation in these underlying areas should foster more productive and sustainable production systems by transforming resource management and agricultural practices.

Box 12. Seaweed supplements that aim to reduce GHGs from livestock

Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO), in collaboration with James Cook University and Meat and Livestock Australia, has developed a cost-effective seaweed feed additive called FutureFeed, which uses a variety of Australian seaweed that significantly reduces methane emissions from livestock and has the potential to increase livestock productivity. FutureFeed has been found to reduce the production of enteric methane by more than 99% at addition rates of below 1% by weight in diets, with the reduction being dependent on addition rate and seaweed quality. CSIRO estimates that if just 10% of global ruminant producers adopted FutureFeed as an additive to their livestock feed, it would have the same impact on the climate as removing 50 million cars from the world's roads, and would improve the feed efficiency of livestock production in feedlots and dairies.

Bio-economy strategies agree on the need to foster *sustainable soil management* in agriculture. The European Union strategy highlights the potential of research in promoting the sustainable management of soil and exploiting advances in conservation agriculture. Germany's strategy emphasises the contribution of progressive farming methods, maintaining and improving soil quality, to enhance productivity without damaging the environment.[15] Finally, Italy stresses the importance to invest in agricultural practices and farming systems that improve the fertility and quality of soils, and their various ecosystem functions are researched and implemented by farmers.

Better *management of soil nutrients* is considered essential for the development of a sustainable bio-economy. Sweden, Germany and Spain emphasise the need for the more efficient use of fertilisers and plant-protection products. Italy's strategy stresses the need to reduce the use of nitrogen and phosphates in order to lower agriculture's GHG emissions. Ireland's strategy stresses the positive contribution that new fertiliser technologies and the increasing awareness of soil nutrient management have had on improving yields, while Norway promotes the increased use of organic fertilisers.

Efficiency *improvement in the use of water* in agriculture is also considered a priority, especially in the context of climate change. The German strategy refers to the growing importance of irrigation and the more effective use of water, necessitating the introduction and wider adoption of water-saving technologies. Water-saving technologies can contribute to reducing energy consumption. The Italian strategy emphasises the need to improve water use and management in agriculture, particularly through innovative tools and strategies (such as sensors, networks, DSS) that help rationalise water use.

14. Examples include: i) the use of bioremediation – using micro-organisms to remove toxic compounds from soil, water or air; ii) improved crop varieties that require less tillage (reducing soil erosion and compaction) or fewer pesticides and fertilisers (reducing water pollution); iii) and industrial biotechnology applications that reduce GHG emissions from chemical production (e.g. biotechnological processes to produce chemicals and plastics) (OECD, 2016).

15. For example, the German national research programme aims to strengthen soil research: "Soil as a sustainable resource for the bio-economy" https://www.ptj.de/lw_resource/datapool/_items/item_4725/bonares_bekanntmachung_e.pdf.

The development of a bio-economy is expected to foster *climate change mitigation*. New plant varieties that require less fertilisers and plant-protection products, combined with increased plant carbon sequestration, are expected to contribute to lower GHG emissions. Modern animal breeding techniques and better management of livestock would also help to reduce the harmful environmental impacts of animal production. In addition, a number of countries agree on the need to adopt more sustainable production methods, such as climate-smart agriculture, precision farming, ecological intensification, agro-ecology and regenerative agriculture. Increased integration of information and communication technology (ICT) would support resilience to climate change, as well as model-based adaptation and mitigation and connectivity along the product chain.

Bio-economy strategies stress the need to develop adaptation measures in order to cope with climate change, and limit the negative effects on crops and livestock. These strategies highlight the importance of increasing the resilience and adaptive capacity of plants, crops and livestock to rapidly changing climate conditions and environments.

In the context of climate change, there is a need to promote a more efficient use of water in agriculture and bio-economy strategies support the introduction and wider adoption of water-saving technologies. The further development of irrigation measures in regions with increasing dry periods and the fostering of optimal management practices for irrigation and water recycling is essential. Italy's strategy emphasises the importance of developing nature-based solutions to cope with climate change and hydrological risks in the Mediterranean area, which is already suffering from high levels of hydric stress.

3. Policy approaches to develop the bio-economy of the agro-food system

Policy instruments

Seizing the opportunities and mitigating potential risks of the bio-economy depends heavily on how policies and regulations are employed in governing the transition process. But, due to its crosscutting nature, the design of policies for the development of the bio-economy is especially challenging. As acknowledged in some bio-economy strategies, multiple policy instruments from a wide spectrum of policy spheres influence the development of the bio-economy across different levels of government.

Box 13. Policy approaches and tools for the emerging bio-economy

Research subsidies: Uses public resources to generate knowledge inputs such as private and public sector research and development and human resources through the education of researchers, scientists, technicians, etc. This could include both mission-oriented research to support a specific technology and multidisciplinary research.

Market creation: Puts in place an incentive structure that could include, among other things, procurement guidelines, production subsidies, pricing incentives, trade barriers (either their establishment or removal), and competition policies.

Regulations/standards: Mandates actions concerning, for example, safety, product registration, advertising, environmental mandates (e.g. tradable carbon markets, life cycle assessment). Can also be used as a tool for market creation.

Infrastructure investment: Creates the underlying framework for systems such as for public healthcare, collaborative science, databases, transportation, energy production and distribution.

All bio-economy strategies stress the need to adopt a mix of technology-push and market-pull measures. Social dialogue, policy coherence, and collaboration at the national, regional and international levels are essential. Box 13 summarises policy approaches and tools recommended in the 2009 OECD report on the bio-economy.

Overall, the most widespread initiatives focus on research, knowledge development, and the practical forms of exchange. Initiatives to increase the sharing of knowledge through industrial clusters and partnerships related to the bio-economy are increasingly extensive (e.g. co-location of existing and related industries, the provision of shared demonstration facilities and infrastructure). Table 3 presents selected examples of measures promoting bio-economy innovations related to the agriculture and food sectors.

Table 3. Examples of measures that promote bio-economy innovations related to agriculture and food

Country	Public R&D	Stimulating private sector R&D	Social innovations	Research networks, consortia
Australia	Advance Queensland Initiative: grants to research organisation			
Austria				
Canada	Growing Forward 2 Programme (funding programmes agricultural research projects, particularly cluster projects.			Canadian Biomass Innovation Network
European Union	Horizon 2020 (funding projects in universities and research organisations)			
France	Establishing inter-disciplinary INRA meta-programmes in the area of food, ecology and agriculture; European Centre for Biotechnology and Bio-economy (CEBB)		Agro-ecology Farm 112	
Germany	Plant breeding (IPAS); Federal Organic Farming programme.			Bio-economy International (international collaboration on R&D projects with non-EU countries)
Italy	National Smart Specialisation Strategy; EU Cohesion Policy Funds; Horizon 2020 (PRIMA initiative)			
New Zealand	Primary Growth partnership	PPPs	Citizen science projects	Global Research Alliance
Norway	Action plan between the most important public actors			BIONAER (Research Programme on Sustainable Innovation in Food and Bio-based Industries); Programme on Bio-economy
Spain	Horizon 2020;	PPPs		
United Kingdom	Innovative technologies and bio-refineries; UK Global Food Security Programme; Centres for Agricultural Innovation to promote sustainable intensification (Agri-tech Strategy 2014-18)			
United States	Transportation Energy Resources from Renewable Agriculture (TERRA) Program; Biomass Research and Development Initiatives; Agricultural and Food Research Initiative; research into organic farming and special crops.	PPPs (Foundation for Food and Agriculture Research)		Industry-led consortia

Note: PPPs = Public-private partnerships.
Source: Based on the reports of the German Bio-economy Council.

Technology-push measures

Bio-economy strategies generally focus on increasing public and private funding for bio-economy research, technology and innovation (R&D/I) to enhance research collaboration, and reducing regulatory barriers to innovation. All agree on the need to increase investment and funding for bio-economy R&D/I programmes in order to encourage the generation of knowledge and its application to the development of innovation.

In order to foster innovation in bio-economy-related areas, basic and applied research on key enabling technologies, as well as strengthening links between science and business through interdisciplinary co-operation between universities, research institutes and business is encouraged.

Establishing centres of excellence and databases, promotion of networks (e.g. through innovation clusters), promotion of new business models such as public-private partnerships (PPPs), training and education measures, building pilot and demonstration plants for bio-refining and strengthening international collaboration is common in most bio-economy strategies.

Overall, the bio-economy strategy of the European Union aims to support better alignment of EU funding in research and innovation with the priorities of the bio-economy. Under its Horizon 2020 Research and Innovation programme – that seeks to leverage national research and innovation strategies and to foster international research co-operation – almost EUR 6 billion will be dedicated to research for energy efficiency, clean and low carbon technologies, and smart cities and communities. In addition, between 2014 and 2020, EUR 23 billion will be available under the European Structural and Investment Funds for its Thematic Objective “Shift to low-carbon economy”.

In the Netherlands, the government supports research in a variety of ways, such as reduction of income tax and national insurance contributions, investment subsidies and financial support for research programmes. In 2016, companies in the bio-based economy invested over EUR 200 million in research and development.

Public R&D funding is widely considered a key policy measure to enhance the innovation ecosystem for the bio-economy. In this respect, recent policy strategies highlight the importance of promoting links between basic and applied research and supporting multidisciplinary research alliances. Other proposed measures include tax incentives, business support, and access to research capacities.

Several strategies underline the importance of encouraging more private investment in bio-economy research, development and innovation (R&D/I) through active collaboration between stakeholders. The establishment of research networks and centres of excellence which aim to ensure continuous stakeholder co-operation and dialogue is also noted (Biookonomierat, 2018). In Spain, the strategy points to the need to “promote knowledge of the bio-economy among private financial institutions and risk-capital companies” in order to boost private investment in bio-economy. In Ireland the *Food for Health Ireland* initiative links researchers with industry partners to collaboratively develop, manufacture and market functional food ingredients (Devaney and Henchion, 2017).

In Chile, various policies on research, development and innovation have supported the development of bio-economy initiatives, particularly research on microorganisms as agricultural inputs, such as bio-pesticides and bio-fertilisers.

Industry-driven initiatives are increasing in the bio-economy policy. For example, the Japanese Bio-industry Association (JBA) has developed a Vision Document for the Japanese bio-based industry, which is comprised, of agriculture, fisheries, food processing, health and medical sectors and environmental technologies. Key innovations are expected from advances in genome editing and synthetic biology. The JBA estimates the future bio-economy will contribute JPY 20 trillion (around USD 190 million) to GDP in 2030 (Japan Bio-industry Association, 2016).

The promotion of PPPs is considered essential in almost all the countries analysed to ensure jointly funded innovation projects. In France, for example, innovation partnerships between stakeholders in the primary sector and the chemical industry are encouraged. In the United States, it is argued that successful PPP with shared risk, defined responsibilities, and deliverables to achieve mutual benefit and grow the bio-economy need to be identified and supported (The White House, 2012). The Spanish strategy emphasises the need to analyse successful public-private collaboration models in generating business innovation based on public research (e.g. Bioaster, Novo Nordisk, Wageningen) and to encourage their introduction as part of the focal points for innovation in the field of the bio-economy.

Box 14. Bio-based Industries Joint Undertaking (BBI JU) in the European Union

The BBI JU, established in June 2014, is a PPP between the European Union and the Bio-based Industries Consortium. It invests in research and innovation projects, including integrated bio-refineries and the acceleration of innovative bio-based chemicals and products such as polymers, packaging and fertilisers. Its budget for the 2014-20 period is EUR 3.7 billion, with 25% of the funding provided by the European Union from Horizon 2020 and the remaining 75% by the business sector. Project outcomes are monitored through key performance indicators.

To date, 65 projects have been funded, consisting of 20 demonstration projects and 6 flagship projects, and which correspond to a total of 729 beneficiaries from 30 countries for a total amount of EUR 414 million. The first flagship "First2Run" aims to set up a commercial scale bio-refinery in Sardinia (Italy) to convert low input oil crops grown in arid or marginal lands to produce added value chemicals, feed products and energy. It represents a total investment of EUR 58 million (of which 70% comes from industry).

Source: European Commission (2017).

Building human capital

The development of the bio-economy depends heavily on a highly qualified workforce as a wide range of knowledge and technological expertise is needed for different bio-economy related activities. This requires well-trained workers with specific qualification and competences, capable of adapting to innovation and structural changes. There will be an increasing need for highly-skilled individuals with expertise in biological sciences, natural resources, agronomy, biotechnology, bioengineering, as well as strong entrepreneurial skills and innovation culture, including cross-disciplinary education and training programmes.

Several bio-economy strategies (e.g. the European Union and the United States) have identified that an information and knowledge transfer gap exists between innovators, researchers, biotechnologists and the farming community. In the United States, current education and training programmes are deemed inadequate to meet the *Billion Ton Bio-economy Strategy* and the Bioenergy Technologies Office BETO will co-ordinate with USDA to promote a new generation of farmer development. The European Union strategy places particular emphasis on reinforcing informed dialogue between bio-economy research and policy making to ensure that public research provides a sound scientific basis for responsible policy decisions.

To enhance innovation adoption, several programmes focus on the transfer of knowledge and technology to farmers. Such measures aim to bridge gaps between research and practice, and mitigate persisting concerns regarding the capacity of farmers to adapt to and adopt new technologies.

Schmid, Padel and Levidow (2012), however, highlight the importance to fully recognise the potential of farmers and small- and medium-sized enterprises (SMEs) have to contribute to the development and diffusion of bio-innovation, and to improve local knowledge and capabilities. According to the authors, there is a need to move from knowledge transfer to *knowledge exchanges* by building knowledge based on the involvement of a wide range of stakeholders (farmers, foresters, fishers, advisory services, all industries involved in the supply chain, and consumers). The EU SCAR Working Group on Agricultural Knowledge and Innovation Systems (AKIS) also recommends building on models of joint knowledge-production, spanning the boundary between knowledge generators and users (SCAR, 2015).

Several countries have established bio-economy-related education and capacity building programmes (European Commission, 2017). The support for education and human capacity building measures, for example, is deeply rooted in several national bio-economy-related strategies, including Argentina, Canada, France, Italy, Latvia, New Zealand, Spain, the United Kingdom, and the United States. Measures for promoting capacity development include publicly-funded training courses for professionals in entrepreneurship, innovation management, technology transfer and IP rights; new training programmes that relate to the needs of the private sector; and promoting the career path of graduates by connecting them with industry and business.

In general, the strategies prioritise the establishment of inter-disciplinary academic bio-economy courses (including master's and doctoral programmes) to improve both technical and soft skills, life-long learning opportunities and education programmes for policy-makers at all levels of government, although these efforts are frequently only in their infancy.

While Finland, France and the United States foster training of experts, others, including Austria and Germany also promote stakeholder platforms and cross-sectoral alliances as the basis for interdisciplinary exchange. In France and the United States, specific measures for the improvement of education in schools and universities are part of bio-economy-related strategies. Specific educational programmes have also been developed in Belgium (Flanders) and Germany.

In the United States, the 2016 *Billion Ton Bio-economy Strategy* underlines the need to mobilise and develop a qualified workforce for the bio-economy. It focuses on training programmes for professionals and technical students and pledges support for career path information for high school students.

In France, educating and training the workforce for the future bio-economy is considered a priority. In its strategy, inter-disciplinary education and capacity building, including technical and vocational training as well as life-long learning opportunities are highlighted. In 2015, the European Centre for Biotechnology and Bio-economy was established. Its mission is to promote multi-disciplinary research for the sustainable production of biological resources, to foster bio-refinery development and the agro-food industry. In June 2017, the public research institutes INRA and IRSTEA hosted a European workshop on bio-economy which was attended by more than 300 European and international bio-economy experts.[16] As a result of the event, recommendations on bio-economy-related research and development were published. They focus, *inter alia*, on promoting multi-disciplinary and multi-sectoral co-operation, modelling the externalities of the bio-economy and implementing bio-economy-related policies.

In Italy, the range of measures proposed encompasses new technical programmes for schools, academic bio-economy courses and post-graduate education in the bio-economy. In 2017, the first European masters programme in "Bio-economy in the Circular Economy" was launched through a PPP between four Italian universities, three industrial partners and an Italian banking group.

In order to enhance access to bio-economy knowledge the Spanish strategy proposes the creation of tools and materials for self-training and professional recycling through "online" platforms, allowing access to study in the various fields of the bio-economy.

In Estonia, the University of Life Sciences aims to become an internationally recognised university in the field of bio-economy and defined their development plan for 2016-25 via a bio-economy value chain approach.

In Latvia, the Institute of Energy Systems and Environment (IESE) in Riga Technical University (RTU) is working to increase knowledge about the bio-economy through activities at different levels – higher and social education, research and innovation. RTU IESE is oriented towards a trans-disciplinary approach in addressing bio-economy-related issues, including technological, environmental, climate, and economic and socio-economic aspects.

The Lodz Declaration on a European Bio-economy Education Platform was announced within the Poland Congress on Bio-economy in November 2017. The platform is intended to foster exchange between multi-disciplinary bio-economy education programmes to build a skilled working force for the new generation (Biookonomierat, 2018).

Promoting and creating markets

Bio-economy development is expected to potentially create entirely new markets or enter markets dominated by fossil-based products. National bio-economy strategies include advocating a number of market-pull measures to expand demand for bio-economy products. Proposed measures mainly consist in: increasing consumers' awareness of bio-products; the development of labels, standards

16. http://institut.inra.fr/en/Events/INRA-Irstea-Workshop-on-Bioeconomy-2017.

and certification for new bio-based products; and the use of green public procurement to promote bio-economy products.

Creating *consumers' awareness* of the bio-economy is at the top of national agendas as reflected in the recently published French Action Plan, for example. While national bio-economy strategies agree on the need to organise conferences and forums open to the general public in order to increase awareness and promote bio-economy products among society, most of the strategies remain vague with regard to the promotion of concrete measures (Biookonomierat, 2018).

Social attitudes to bio-economy products and technologies have important implications and a number of bio-economy strategies highlight the contribution of *social dialogue* with the public as a crucial requirement in stimulating the demand for bio-economy products.

The ethical views of citizens can influence the bio-economy through its impact on regulations and other laws that affect research (what is permitted and the level of public support for research), markets (what people will buy and at what price), and business models (what business strategies are legally permitted). Enhancing social dialogue and other initiatives supporting public understanding of the technologies underpinning the bio-economy could be achieved through appropriate incentives. The involvement of scientists, and the research and innovation community in this process is essential.

In Germany, measures to address consumer behaviour by providing information on sustainable consumption and food waste are an example of enhancing the dialogue. In Sweden and Finland, measures to communicate the benefits of the bio-economy and bio-based products to society in order to shift consumption away from fossil-based products are highlighted.

Public forums and *conferences* can increase awareness of bio-economy alternatives and provide end-users, and citizens in general, with more information about bio-products. In particular, consistent information can be provided on the characteristics of bio-products with regard to, for example, production methods, environmental sustainability or nutritional benefits. Clear information about bio-products and the impact of consumption patterns and lifestyle (e.g. the issue of waste) would enable more responsible and informed consumer choices.

While most strategies mention public forums and conferences as the main platforms for social dialogue, *online platforms* have been established in recent years and are a useful communication tool. In Finland, Germany and Spain, for example, exclusive websites on the bio-economy have been launched to provide information about recent developments, to publicise upcoming events, and to outline national and international policies. The European Commission launched the Bio-economy Knowledge Centre in July 2017, and its website provides data and relevant publications on bio-economy in Member states to ensure better knowledge sharing.[17]

Even if bio-economy strategies underline the need for consumer information and communication, concrete measures are seldom foreseen to communicate the benefits of bio-economy products and services to customers or to address the role of the media. The SCAR group confirmed there is a clear need to develop and implement a coherent communication strategy to raise consumer awareness on the bio-economy and the opportunities for and barriers to its development (SCAR, 2015). It recommends this should be done in the context of the big challenges facing future generations, such as climate change, resource efficiency, energy, and food security. Among its recommendations is the dissemination of more case studies and establishing a European Bio-economy Week.

The introduction of *public procurement* as a way to enhance awareness and to stimulate demand for bio-economy products and services is seen as promising by most countries. Proposed measures range from introducing standards for bio-economy public procurement to reviewing the present regulatory framework on public procurement.

The rationale for using public procurement to accelerate the development of bio-economy markets is that it allows the public sector to act as a "launching pad", early adopter, or first buyer. The public sector also acts as a market development facilitator by establishing a buyers group for the market with

17. https://biobs.jrc.ec.europa.eu.

critical mass that triggers industry to scale up its production chain to bring products on to the market with the desired quality/price ratio within a specific time.

Overall, bio-economy strategies consider that public procurement should contribute to "the reduction of environmentally degrading effects and an advancement of climate friendly solutions" and provide incentives for the replacement of non-renewable natural resources by renewable ones. Public procurement of bio-based products is also expected to promote innovation, as well as create jobs and open new markets in rural areas, as being the main location for biomass production and manufacturing (Box 15; The White House, 2012).

Developing *standard, labels and certification* for bio-economy products appear as the main instrument to facilitate product identification, provide consumers with guarantees regarding products quality, safety, as well as the source and processes used (origin of biological resources and products), and "elucidate the various advantages of bio-based products". In particular, bio-economy strategies agree on the need to develop clear and unambiguous standards for bio-based products and to ensure their consistency across sectors. Bio-economy strategies mainly discuss the importance of determining comparable criteria for bio-based products sustainability. Standards for bio-economy products deal with bio-based content, biodegradability, sustainability and functionalities of products.

Standards are also central for the *development of labels* for bio-based products. Labelling can play an important role for the commercialisation of bio-based products as it can provide consumers with information on the environmental performance of the products and guide purchasing behaviour towards sustainable choices. Labels can also be critical for the uptake of bio-based products by green public procurement.

As part of these efforts, standards and certifications for bio-economy products have been discussed in Norway. In Japan – in addition to a uniform feed-in tariff for renewable energies (including biomass) set up in 2012 – state departments are also required to purchase environmentally-friendly products and various labels to identify environmentally-friendly and bio-based products for consumers have been introduced. In France, in order to attract greater attention to bio-based products and services the building codes and standards have been updated to increase the share of hemp in construction.

Market development and expansion of the bio-economy requires the improvement of and investment in the *transport* and *storage infrastructure* as well as the development of the necessary logistics for the "cascading use of biomass" at the national and regional levels. Denmark and New Zealand also specify measures targeting international marketing and market development.

Finally, bio-economy strategies highlight the importance of investing in and providing access to *demonstration and pilot plants* to foster the commercialisation of bio-economy products and technologies, and to contribute to better linkages between researchers and industry.

Box 15. The US BioPreferred® Program

Created by the 2002 Farm Bill and re-authorised and expanded by the 2018 Farm Bill, the USDA BioPreferred® programme aims to increase the purchase and use of bio-based products. The two major parts of the programme are: i) mandatory purchasing requirements for federal agencies and their contractors; and ii) a voluntary labelling initiative for bio-based products. Products that meet the minimum bio-based content criteria may display the USDA Certified Biobased Product label. To date, USDA has identified 97 categories (e.g cleaners, carpets, lubricants, paints) that include approximately 14 200 products of bio-based products on the market today for which agencies and their contractors have purchasing requirements. For purposes of the BioPreferred® program, bio-based products do not include food, animal feed or fuel. The 2018 Farm Bill authorised mandatory funding of USD 3 million for each of FY2019-23 for bio-based products testing and labelling, similar to the 2014 Farm Bill. The 2014 Farm Bill authorised discretionary funding of USD 2 million annually, although from FY2013-18 no discretionary funding was appropriated.[1] The 2018 Farm Bill increased the authorisation for discretionary funding to USD 3 million annually from FY2019-23

1. For more information on the programme, see OECD (2019).

Reviewing, updating and simplifying regulations

Bio-economy strategies stress the need to reduce regulatory barriers to technology development and research-based innovation in order to foster the development of the bio-economy. Regulations play a central role in reducing safety and security risks as a result of new technologies and products. However, due to the rapid evolution of technologies, and its associated products and services, there is the possibility that some regulations have become inadequate or unnecessarily restrictive (The White House, 2012). Therefore, there is a need to carefully review regulatory frameworks impacting bio-economy technologies and products to identify possible negative effects of compliance on innovation. There could be a need for new, more appropriate and efficient regulatory processes and the reform of some regulations. In particular, the United States and European strategies emphasise the need to reduce the cost of compliance with regulation, and increase predictability and timeliness of regulatory processes in order to achieve the promise of the future bio-economy more rapidly and safely. Clear, predictable, and efficient regulations are powerful drivers of R&D investments in all sectors.

Although most bio-economy related strategies highlight the need to create bio-economy-friendly framework conditions, only few countries emphasise the importance of reviewing and harmonising the regulatory framework. While some countries such as Argentina, New Zealand and the United States focus more on reviewing regulations that govern new biotechnologies, other countries such as Italy, Norway, Spain and the United Kingdom focus on reviewing circular economy regulations (especially regarding the use of waste and residues for higher value applications). New Zealand also highlights the need to review the policy framework for intellectual property rights. Interestingly, only a few countries (Canada, New Zealand and Norway) mention carbon taxing and global data policies.

The imperative to develop a coherent policy framework for the bio-economy

Due to its broad scope, the development of the bio-economy is complex from a policy perspective. In principle, developing a bio-economy strategy is an essential first step towards policy coherence and co-ordination at the national level. Due to its nature, the bio-economy encompasses a wide range of sectors and its advancement depends on efforts across a wide spectrum of policy spheres. Policies offering incentives for different economic uses of biomass – including food, feed, bio-based products and bio-energy need to be aligned with strategic goals for the bio-economy.

The development of the bio-economy demands a coherent policy approach that enhance synergies. Coherence needs to be sought in particular across agriculture, food, rural development, environment, forestry, energy, research and innovation, waste and climate change policies that are perceived as vital to foster the development of the bio-economy of the agriculture and food system.

Overall, governments suggest reinforcing policy interaction and stakeholder engagement, and increasing dialogue between the different actors. The creation of bio-economy dedicated bodies or working groups in charge of ensuring policy coherence and monitoring is also proposed by several strategies. All bio-economy strategies stress the importance of improving policy coherence and co-ordination at the international level.

While the importance of coherence is highlighted in most strategies, this report shows that in general they are vague. In the European Union, for example, it is stated that the bio-economy strategy will seek synergies with the EU Common Agricultural Policy (CAP). Yet, notwithstanding recent initiatives, there is little direct alignment between the current CAP and the bio-economy strategy. A public consultation by the European Commission in 2011 (predating the Strategy and White paper) identified lack of policy coherence as another barrier to developing a bio-economy. However, the new European Commission's proposal for the post-2020 CAP (running from 2021 to 2027) provides EU Member States with enough flexibility to link their CAP national strategic plans to national bio-economy strategies.

National strategies agree that policy coherence could be heightened through enhanced communication and co-ordination between stakeholders, in particular the private sector, science, and civil society. Organising discussions or co-ordination platforms, as well as public debates involving a

wide range of stakeholders is seen as a way to foster the exchange of knowledge and information flow between related policy areas, sectors and disciplines.

Institutional issues are also important and dedicated bio-economy advisory bodies or working groups have been created in several countries. Inter-governmental and federal-state co-operation is considered critical for any bio-economy policy, specifically in terms of policy coherence and effectiveness (e.g. Australia, Denmark, Germany, Ireland, the Netherlands, Italy, Norway, Spain and the United States).

An increasing number of countries are addressing the issue of accountability by establishing dedicated *bio-economy advisory councils*. Most often, these represent public, private and civil society stakeholders, including research institutions, and provide advisory services for bio-economy policy development. Such panels have been nominated in Germany, Denmark, the European Union, Nordic countries, the Netherlands, and the Czech Republic.

In the European Union, two platforms have been created: the Bio-economy Stakeholder Panel and the Bio-economy Knowledge Centre (replacing the Bio-economy Observatory) (Box 16). The European strategy encourages Member states to create similar bio-economy bodies in order to enhance policy coordination and coherence at the national and European levels.

In Denmark, the Ministry of Environment and Food set up a Bio-economy Council in 2017. Its members represent bio-economy-related expertise from academia, business, associations and clusters. Also in 2017, a “Bio-economy Federation” was formed in the Netherlands. While developing a strategic bio-economy agenda, it seeks to connect bio-economy stakeholders, strengthen international co-operation and showcase successful bio-economy stories. More than 70 members from companies, research organisations and NGOs have joined the Federation. To date, the work of the organisation has been financed on a crowd-funding basis. The Federation foresees the creation of a Scientific Council, a Council for Sustainability Issues, and a student platform as the next steps.

In Ireland, an inter-ministerial working group was established in late 2016. It is chaired by the Department of the Prime Minister and aims primarily at reconciling bio-economy-related activities and identifying opportunities for a national policy strategy. In Austria, a sub-working group on bio-economy has evolved as part of the inter-ministerial working group on climate change and resource scarcity.

Box 16. European bio-economy platforms

Bio-economy Stakeholder Panel: Set by the EU's Bio-economy Strategy, the Panel seeks 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 (European Commission, 2017).

Originally set up in 2013, the membership of the Panel was renewed in 2016 to strengthen the diversity in stakeholders' representation. The Panel has 29 members, representing different groups: business and primary producers, policy-makers and public administrations, scientists and researchers and civil society organisations. The members of the Stakeholders Panel, in its new configuration, have been appointed for a two-year period, from 2016 to 2018 with a possibility of renewal.

Bio-economy Knowledge Centre: In July 2017, the European Commission launched the new Bio-economy Knowledge Centre to better support EU and national policy makers and stakeholders with science-based evidence in this field. Its objective is to gather data and indicators to assess the progress of bio-economy markets and socio-economic, scientific, technological, market and the impact of legislation impact. It will produce foresights and forecasts on bio-economy, scenario analyses for aiming at supporting policies and derive research and innovation directions. The Knowledge Centre is being created by the Commission's in-house science service, the Joint Research Centre, in co-operation with Directorate-General for Research and Innovation

Source: https://ec.europa.eu/research/bio-economy/.

In Germany, an inter-ministerial working group was established in 2013 to address inter-ministerial collaboration and coherence. In addition, the German Bio-economy Council plays a central role in advising the Federal Government on the implementation of the bio-economy strategy with the overall goal of creating optimum economic and political framework conditions for a bio-economy (BMEL, 2014).

Spain and Italy plan to create similar bio-economy bodies or working groups. The Spanish strategy sets out the creation of a "Spanish Bio-economy Observatory" with two components: a "monitoring group" responsible for tracking the strategy, co-ordinating the introduction of new measures in the field and promoting co-operation between the different administrations; and a "management committee" whose objective will be to foster implementation of the measures established as part of this strategy and the annual action plans (State Secretariat for Research Development and Innovation, 2016).

The Italian strategy plans the establishment of a permanent working group on the bio-economy composed of representatives of ministries, other public administration and national technological clusters involved in the bio-economy domain, in order to define a proper and coherent legislative framework and minimising duplication and fragmentation. Their main responsibilities will be to collect and share data and information, guarantee the policy coordination among public authorities, and monitor the implementation of the bio-economy strategy (Italian Government, 2019).

In Japan, in line with the policy direction of the *Basic Plan for Promotion of Biomass Utilisation*, regional biomass industrialisation networks are being promoted. The purpose of these networks is to implement the concept of biomass industrial cities, to create bio-based, environmentally friendly and disaster-resistant communities (Box 17). Furthermore, a liaison conference office on biomass utilisation co-ordinates the departments to ensure comprehensive and effective promotion of biomass utilisation. It is housed within the Ministry for Agriculture, Forestry and Fisheries (MAFF).

In the United States, policy coherence related to the bio-economy includes increased inter-agency collaboration to fully leverage governmental expertise (Box 18). For example, a Bio-economy Federal Strategy Workshop was organised by the Biomass R&D Board and aimed to share information on existing agency programs and activities, identifying processes for working together, and building a national federal government coalition to coordinate agency efforts.

Box 17. Biomass Industrial Cities: The case of Japan

The *Biomass Industrial City Concept* centres on the biomass industry taking advantage of the characteristics of the area, and aiming for environmentally friendly, disaster-resilient communities. As of November 2018, relevant Ministries had selected 84 municipalities as Biomass Industrial Cities. These cities are expected to develop regional value chains from material production, collection and transportation to use of biomass-derived products and energy. Local stakeholders will make partnerships and form a consensus for realising the projects under the municipalities' initiative. The government periodically requests the Biomass Industrial Cities to report on the progress of each project.

Box 18. Inter-agency collaboration in the United States: Founding partnerships, breaking barriers

The United States Department of Agriculture (USDA), the Department of Energy (DOE) and the Environmental Protection Agency (EPA) jointly released a progress report on the Biogas Opportunities Roadmap of 2014. The Roadmap identifies voluntary actions that can be taken to reduce methane emissions through the use of biogas systems. It outlines strategies to overcome barriers limiting further expansion and development of a robust biogas industry in the United States.

Source: Federal Activities Report on the Bio-economy (2016), www.energy.gov/sites/prod/files/2016/02/f30/farb_2_18_16.pdf.

Monitoring progress

There is no internationally agreed methodology at present to measure the size or monitor progress in attaining the targets set by the bio-economy strategies (Bracco et al., 2018; OECD, 2018a; Vandermeulen et al., 2011). The bio-economy targets of the strategies often reflect the country's priorities and comparative advantages. However, comprehensive approaches to measure the size of the bio-economy as well as to monitor its development and assessing its impacts are still lacking (Staffas, Gustavsson and McCormick, 2013).

The difficulty of measuring progress could be due to the lack of a clear definition of what constitutes a bio-economy and the lack of clear goals. It is essential, however, that measurements for progress are defined and applied. This a key finding of the 2017 EU Bio-economy Strategy Review, which emphasised the need for better monitoring and assessment frameworks (e.g. indicators of biomass supply and demand).

Measuring the performance of the bio-economy through indicators is complex because the bio-economy comprises a wide range of different products, commodities, intermediate goods, and technologies. Moreover, a large part of this economy will emerge from markets and transformation and from new market creations, for which statistical data and indicators are immediately not available.

Most countries only measure the contribution to gross domestic product (GDP), turnover, employment, exports of the bio-economy sectors – including agriculture and food – and the number of firms and businesses operating in bio-economy sectors (Bracco et al., 2018; Box 19). Such indicators, however, usually provide only a partial picture of the size and impact of the bio-economy of the agriculture and food system, and underestimate its contribution to society as sustainability impacts are overlooked (Wesseler and Von Braun, 2017).

Measuring and monitoring the implementation of strategies for the bio-economy need to address its impact on environmental, social and economic outcomes (the three dimensions of sustainability) (OECD, 2018a; Fritsche and Iriarte, 2014). Only the updated EU bio-economy strategy, and the indicators identified in the Italian and Finnish strategies, currently propose to measure and monitor the sustainability of their bio-economies.

Box 19. What is the direct economic impact of the bio-economy?

In the European Union, it is estimated that – with an annual turnover of around EUR 2 trillion (of which 18% are contributing by agriculture and 46% by food) and contributing to approximately 9% of the workforce (55% agriculture, 20% food) and 80% of land use – the bio-economy is already one of the biggest and most important components of the EU economy. In addition, as in other sectors, each euro invested in EU-funded bio-economy research and innovation is estimated to generate EUR 10 of value-added in bio-economy sectors by 2025. Significant growth is expected to arise from sustainable primary production, food processing and industrial biotechnology and bio-refineries. The food and agriculture sectors are the ones contributing the most to the EU-28 bio-economy, both in terms of employment and turnover. While more people are employed in the agricultural sector, the food sector generates a higher turnover. The same situation applies for France, Ireland, and Italy. In Belgium, Finland, and Germany, the food sector is making the biggest contribution both in terms of employment and turnover.

In Germany, approximately five million employees, representing 10% of all employees, and EUR 140 billion, representing 6% of GDP, were identified in the bio-economy in 2010 (Efken et al., 2016).

In Ireland, agriculture, food (and beverages), fisheries and forestry are the main sectors that contribute to the country's bio-economy.

In Italy, it was estimated that the whole bio-economy sector in 2013 (which includes agriculture, forestry, fisheries, food and beverages production, paper, wood and biochemistry) accounted for around EUR 244 billion, ranking third in turnover after Germany and France, with around 1.5 million employees. According to these estimates, the food industries and agriculture contributed to more than half of the total bio-economy's turnover (Intesa San Paolo, 2015). The overarching goal of Italy's bio-economy is to increase turnover from EUR 250 billion (2015) to EUR 300 billion by 2030, at which time the entire bio-economy sector should account for more than 2 million jobs.

In the Netherlands, the bio-economy contributed 7.7% to national GDP (of which 26% from agriculture, forestry and fisheries, and 60% food and feed), 4.9% to national value added (of which 37% from agriculture, forestry and fisheries, and 47% food and feed) and national employment (of which 47% from agriculture, forestry and fisheries, and 38% food and feed) in 2013, with the contribution of the primary, food and feed sectors was dominant (Van Meijl et al., 2016).

In New Zealand, the "traditional" bio-economy (the primary sector and the food industry) contributes to more than two-thirds of exports and is a key pillar of the economy.

In Norway, the bio-economy accounts for 6% of the economy (of which 46% is due to agriculture and food). Moreover, more than a three-fold increase in total GDP is estimated in 2050 (from EUR 33 billion to EUR 110 billion), with agriculture and food sector's contribution estimated to rise from EUR 15 billion to EUR 27 billion (Bardalen, 2016). The bio-economy sector in Norway with the largest value added is the food and drink industry, and with NOK 37 billion in 2014 it was nearly three times as high in terms of value added as the second largest, agriculture, at NOK 13 billion.

In Spain, the bio-economy accounts for an estimated 6.5% of the GDP (with agriculture accounting for 2.5% and the food industry 2.7%) and employs around 9% of the working population. Overall, the food and agriculture sector, with more than 900 000 farms and 30 000 companies, was responsible of more than 17% of all Spanish exports in 2014 (State Secretariat for Research Development and Innovation, 2016).

In the United States, the bio-based economy (excluding food, feed, livestock, pharmaceuticals and energy) generated about 4.2 million jobs and about USD 393 billion in 2014, including direct, indirect and induced effects (Golden et al., 2018). Moreover, the World Economic Forum estimates that the revenue potential for new business opportunities in biomass value chains could amount to approximately USD 295 billion globally, by 2020 (World Economic Forum, 2010). These revenues generated at the different stages of new biomass value chains include the manufacturing of agricultural inputs, biomass production and trading, bio-refining inputs (e.g. biomass pre-treatment methods), the actual biomass conversion in the bio-refineries and the sale of end products.

Bio-economy strategies that report indicators on its size include the European Union, Finland, Spain, France and Italy. Some of the bio-economy-related strategies, including Australia, Italy, Latvia and the United Kingdom, also provide concrete quantitative targets for bio-economy development. These targets range from increasing the bio-industry share of GDP or annual sales of biotech products, to raising the general bio-economy turnover and creating more bio-economy-related jobs. The Latvian Bio-economy strategy, for example, defines a range of quantitative targets for bio-economy development: employment in the bio-economy should increase by 128 000 employees by 2030; the added value of bio-based products should increase up to at least EUR 3.8 billion (around USD 4.7 billion) by 2030; and the value of bio-economy-related exports should be boosted to at least EUR 9 billion (around USD 11 billion) by 2030. Nevertheless, most countries only define qualitative targets. Spain, however, provides concrete budget targets within their bio-economy policy strategies by listing funding opportunities.

With a view to accountability, an increasing number of governments, including Australia, Canada, France, Italy, Latvia, New Zealand, Spain, the United Kingdom and the United States, are promoting measuring activities to measure the bio-economy in order to monitor new technologies (particularly new biotechnologies), biomass supply and demand, as well as bio-based products and services and their economic, ecological and social impacts (Biookonomierat, 2018). In the United States, for example, trends in the bio-based economy are analysed using various indicators, including those for agriculture (Golden et al., 2018).[18]

Other countries promote the evaluation of policy programmes. For example, with regard to monitoring the implementation of the German bio-economy policy strategy, the Ministry of Food and Agriculture (BMEL) released a progress report in late 2016, with first results expected by 2019.

[18.] For agriculture, the indicators take into account: i) the various organic inputs into bio-fuels, renewable chemicals and bio-based products; ii) crop production; iii) crop consumption for bio-fuels (i.e. maize for ethanol and soybeans for bio-diesel); and iv) the relative price of each crop.

Work is in progress at the European Union level to establish indicators to monitor the development of the bio-economy. The European Commission, for example, has funded several activities to monitor bio-economy development in Europe under the "Bio-economy Observatory" project led by its Joint Research Center (JRC). The results were published in its *Bio-economy Policy Report in 2016* (Ronzon et al., 2017).[19]

In Japan, various surveys provide information on the supply of and demand for biomass (e.g. survey on discharge and disposal of industrial waste; survey on disposal of general waste; status survey on recycling of circulating food resources; and woody bioenergy usage trend survey).

In Canada, biomass inventory work is carried out regularly to monitor the state of forest resources. In the case of agriculture, annual crop maps are prepared and satellite imagery is being increasingly used to improve the resolution. Fallow land and marginal lands have been identified as areas that could potentially be available for additional crop production. The publicly available Biomass Inventory Mapping and Analysis Tool (BIMAT) identifies the crop residue available across the country based on the crop production of the past 30 years.

In the Netherlands, data are compiled since 2012 to provide a quantitative and qualitative overview of solid and liquid biomass import flows and assess, to extent possible, whether biomass is produced sustainably (van Lieshout Marit and Scholten Thijs, 2017).

In Italy, the indicators monitor five sustainability objectives of the bio-economy: ensuring food security, managing natural resources sustainably, reducing dependence on non-renewable resources, coping with climate change, and enhancing economic growth.[20]

In Finland, among the range of indicators proposed to monitor implementation of the bio-economy strategy, the aim is to measure its environmental benefits, as well as its sustainability. Environmental indicators deal with raw material inputs used and reduced GHG emissions, whilst sustainability indicators concern the use of natural resources and waste. In addition, the strategy aims to develop a range of sustainability indicators for ecosystem services, environmental and resource-efficiency as well as environmental assets.

The use of life cycle assessment

The bio-economy is a highly complex system with many interconnections and impacts. In order to improve sustainability, it is imperative that the bio-economy is developed in a way that helps reduce environmental pressures, values biodiversity and contributes to enhance the provision of all ecosystem services. To ensure that the bio-economy operates within planetary boundaries, a robust sustainability assessment of the amounts, types, qualities and impacts of the sustainable production and use of biomass from all sources is needed. Impacts include the implications of different land uses (and changes) on biodiversity, as well as on the local, regional and sometimes global socio-economic systems.

The updated bio-economy strategy of the European Union – in addition to the actions to enhance understanding of the ecological boundaries of the bio-economy, such as collecting data and information on biomass and biomass change – advocates the building of an EU-wide internationally coherent monitoring system to track economic, environmental and social progress towards a sustainable bio-economy.

Some bio-economy strategies highlight the importance of environmental impact assessments for the development of a sustainable bio-economy (e.g. Box 20). In France, for example, the strategy emphasises that the bio-based content of a product does not in itself provide a guarantee of its sustainability or its quality *per se*, and suggests taking into consideration the following:

[19.] Efforts are also underway at the EU level to increase the statistical information available on the bio-economy, taking into account the work done by the JRC and in some research institutions (e.g. Nova Institute).

[20.] The indicators are based on the results of Sat-BE consortium, "Systems Analysis Tools Framework for the EU Bio-Based Economy Strategy" (https://www.wur.nl/en/project/satbbe.htm) developed by Wageningen University of Research.

- greenhouse gas balances
- resource-efficiency (direct and indirect energy and water consumption, phosphorus, land use, biomass use)
- maintenance of ecosystem services (biological dimension) and landscape (cultural dimension)
- waste and by-products management, recyclability of end products.

The transition to a bio-economy must be viewed through the perspective of its overall impact on the environment, to which life cycle analysis can make a contribution. Because of the interdependencies between processes involved in growing, harvesting, manufacturing, distributing and disposing of a product, sustainability requires such a life cycle analysis encompasses the whole supply chain. This includes the production of biomass (e.g. land use, consumption of water, energy, pesticides and fertilisers), the processing of biomass, and the production and use of final products. Such assessments may reveal that certain renewable production processes may be inefficient and costly in terms of their requirements for market and non-market inputs.

Several bio-economy strategies also highlight the contribution of Life Cycle Assessment (LCA) in measuring the environmental performance of the bio-economy's products and processes (OECD, 2018a). In particular, bio-economy strategies stress the LCA contribution to the development of methodological standards for bio-based products. LCAs can also contribute to determine the most efficient use for biomass and bio-waste.

In Spain the strategy emphasises the use of LCA for comparing the environmental footprint of primary production systems (farming, livestock, forestry and aquaculture) and products (food products, bio industry by-products) depending on the technology used. In this case, LCA enables an assessment of the change in the environmental footprint of production systems and products brought by the incorporation of new technologies. Overall, LCAs is expected to contribute to improving the sustainability of products and processes. The German strategy considers that the further development of norms, standards and life-cycle analyses can support the implementation of sustainability initiatives by the business community in the area of use of biomass.

The literature to date points to an important limitation of the vast majority of methods: their inability to aggregate the different sustainability issues in a consistent way. Aggregation requires making complicated trade-offs between sustainability aspects with different dimensions. In order to address this limitation some suggest the Total Factor Productivity (TFP) approach (Cremaschi, 2016). TFP reflects the rate of transformation of inputs (capital, labour, materials, energy and services) into outputs (biomass stock), where negative social and ecological externalities associated with different sustainability issues are included in terms of "bad" outputs.[21]

Box 20. France: Database for environmental impact assessment of agricultural products

L'Ademe (the French Environmental Agency) co-ordinates "Agribalyse", in partnership with l'INRA, agricultural technical institutes, the CIRAD, co-operatives, and the Ministry of Environment. The aim is to develope a database allowing the assessment of environmental impacts of agricultural products. The programme aims at developing a harmonised methodology, adapted to French production, as well as indicators calculated according to the international framework of LCA. Since the publication of the first version of the database in 2013, these data are providing an important contribution to a number projects linked to the environmental assessment of sectors, food practices as well as projects providing environmental information to consumers. Data and methodologies are regularly updated and improved. This tool also contributes to the environmental assessment of agricultural bio-economy's products.

Source: The French Government (2017).

21. See for example, the discussions of the meetings of the OECD TFP and the Environment Network http://oe.cd/eatfp.

Another approach is to measure the share of renewable bio-based content embedded in the products and services in the economy. However, this approach overlooks sustainability issues, for example, on the origins of resources and how their production and utilisation relate to sustainability. On the other hand, approaches based on outcome indicators such as reduced carbon emissions and sustainability of water, soil and biodiversity improvements are more promising, although most demanding in terms of data and methodological challenges (Wesseler and Von Braun, 2017).

International collaboration

As the bio-economy has an international scope, policy co-ordination and coherence needs to be achieved at the international level. International policy dialogue on bio-economy is essential to ensure the harmonisation between different policy objectives and requirements, as well as coherence in legislation and regulation at international level. Additionally, enhanced co-operation at the international level is essential to ensure that bio-economy-related global challenges – such as the supply of sustainable biomass – are well addressed at the appropriate level, and to develop common standards, coherent surveillance and regulations that do not impede trade.

International collaboration is mentioned as important in most policy strategies, but it broadly lacks implementation beyond bilateral research co-operation. Even if the need for bi- and multi-lateral co-operation is often mentioned (e.g. to promote R&D), substantially less importance is attached to issues relating to the discussions on how to harmonise international trade and policy frameworks, promote capacity building, knowledge sharing and technology transfer between countries and foster international monitoring activities. The global inter-connectedness of the bio-economy with respect to trade in biomass resources, to global industrial value chains and transfer of technologies has hardly been addressed in policy strategies so far. According to the European Union strategy, little transnational collaboration and co-ordination between national public R&D programmes is one of the causes for sub-optimal returns from R&D spending.

The International Bio-economy Forum (IBF) is a platform for multilateral R&D collaboration in areas of common interest launched in 2016. The IBF is currently made up of seven members – European Commission, New Zealand, South Africa, India, China, Argentina, Canada and the United States. It aims to foster co-operation in the bio-economy through policy dialogue and scientific co-operation between the partners. The work of the IBF is undertaken in organised *ad hoc* working groups. Established working groups include microbiome and ICT in Precision Food Systems. New IBF Working Groups are currently being proposed (e.g. Plant Health, Bio-economy Indicators).

The *Global Alliance for Climate-smart Agriculture* (GACSA) is a partnership of countries and international organisations committed to mitigating GHGs in agricultural systems. Partners currently include 23 countries and 7 United Nations organisations, with Brazil and Italy as co-chairs. The GACSA focuses on providing support for research and monitoring, data standardization and outreach activities.

The *Nordic Council of Ministers* developed a bio-economy strategy in 2014 for the west Nordic countries. Given the importance of fisheries in the economies of these countries, the strategy focuses on the fishing industry for creating value added. Within the agricultural sector, the strategy highlights opportunities for value creation by means of expanded research on soil conservation, grazing pressure and new crop varieties. To address harsh climatic conditions in the region, the strategy recommends establishing a research centre to support efforts for adapting crops to the unique environment. An advisory body – the Nordic Bio-economy Panel – was established in 2015 to identify key issues and opportunities for the region-related bio-economy.

Finally, the *Central-Eastern European Initiative for Knowledge-based Agriculture, Aquaculture* and *Forestry in the Bio-economy* is promoting a strategic vision for bio-economy development in Eastern Europe, including the Czech Republic, Estonia, Hungary, Poland and the Slovak Republic, as well as in South East European countries, Bulgaria, Romania, Slovenia, and Croatia.

Box 21. Increasing value creation in Norwegian aquaculture and agriculture

The case of Foods of Norway

Foods of Norway is a Centre for Research-based Innovation (CRI) at the Norwegian University of Life Sciences, funded by The Research Council of Norway and the Centre`s industry partners (www.foodsofnorway.net/). Foods of Norway uses new technology to increase value creation in the Norwegian aquaculture, meat and dairy industries. It targets three key research areas: Biomass, feed efficiency and product quality. A key research area is the use of novel biotechnology to develop sustainable feed resources from blue and green biomass (trees, seaweed and animal-co-products). New feed products will be developed from forestry, agriculture, and marine resources through industrial exploitation of cutting-edge research on processing and (bio) technology. Foods of Norway consists of a multidisciplinary research team with academic partners from Europe, Australia and the United States, as well as 19 industry and innovation partners.

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Annex A. Questionnaire

For the purposes of this study, the bio-economy is defined as the production and use of biological resources (aquatic and terrestrial biomass) to produce energy, intermediate and final products. It comprises two groups: i) sectors upstream in the value chain, namely the primary sector (as the supplier of biomass) and the technologies sector (R&D) which provides inputs to production; and ii) sectors downstream in the value chain, namely the users of biomass including food and feed, materials (textile and clothing, wood, paper and pulp), chemical, energy and building sectors.

1. Which bio-economy strategies/initiatives related to the agriculture and food system are being undertaken in your country (at the national or regional level)?

Bio-economy strategy / initiative (for example, these might include knowledge generation; knowledge transfer; generation of value chains; public awareness; and partnerships?	What is the **aim** of the strategy / initiative?	What are the expected **outcomes** of the strategy/ initiative (for example, environmental, societal, including the effects on innovation)	What **policies** have been in place to support these strategies/initiatives, in order to achieve the expected outcomes?	How is progress being **monitored** (such as indicators of take-up, share of value-added and employment, and environmental impacts)?

2. What do you think are the main opportunities that can help achieve the sustainable development of the bio-economy of the agro-food system?

Opportunities for example, the policy and regulatory environment; technological, infrastructural, and institutional structures; training, educational/skills; and consumer acceptance/resistance).	How are the opportunities being **used**? (for example, this might include stakeholder engagement).

3. What do you think are the main obstacles / challenges to the sustainable development of the bio-economy of the agro-food system?

Challenges/ obstacles (for example, this might include the policy and regulatory environment; technological, infrastructural, and institutional structures; training, educational/skills; and consumer resistance).	How are the challenges / obstacles being **addressed**? (for example, this might include stakeholder engagement)

4. Is there any information or study being undertaken to assess the current and potential supply and demand for various biomass types (agricultural, forest-based, and marine sources)?

Please provide details if possible.

Annex B. Synopsis of priority areas, opportunities and barriers to the bio-economy

Country	Priority areas			Opportunities			Barriers					
	Agriculture and food	Forestry	Bioenergy	Economic	Environmental	Social	Market scale	Lack of strategy	Regulatory framework	Skills	Public awareness	Policy coherence/co-ordination
Australia				X	X		X				X	
Belgium												
Canada		X	X	X	X	X		X			X	
Chile				X	X			X				X
Denmark												
Estonia												
European Union	X	X		X	X	X	X			X	X	X
Finland		X		X	X	X						
France	X		X	X	X	X					X	
Germany	X	X	X	X	X	X						
Ireland	X		X	X	X	X	X		X	X	X	X
Italy	X		X	X	X	X	X			X	X	X
Japan	X		X	X	X	X	X		X	X		
Korea	X		X	X	X	X						
Latvia	X	X	X	X	X		X		X	X		
Lithuania	X	X	X	X	X		X		X	X		
Netherlands	X		X	X	X		X				X	X
New Zealand	X	X	X	X	X							
Norway	X	X	X	X	X	X						
Portugal	X		X	X	X	X	X		X	X	X	X
Spain	X	X	X	X	X		X		X	X	X	X
Sweden	X	X	X	X	X							X
United Kingdom	X		X	X	X							
United States	X		X	X	X							

Annex C. Synopsis of policy approaches, governance and monitoring

Country	Policy approaches					Governance			Monitoring	
	R&D&I	PPPs	Human capacity building	Labelling and certifications	Regulations, public procurements	Inter-ministerial co-operation	Bio-economy advisory council/action plan	Social dialogue	Quantitative targets	Indicators
Australia	X	X	X	X	X	X			X	
Belgium	X		X	X	X					
Canada	X	X	X	X	X	X				
Chile	X	X								
Denmark	X						X			
Estonia										
European Union	X	X	X	X	X	X		X		X
Finland	X	X	X	X	X	X	X	X		X
France	X	X	X	X	X		X	X		X
Germany	X	X	X	X	X	X	X	X		
Ireland	X	X	X	X	X	X	X	X		
Italy	X	X	X	X	X	X		X	X	X
Japan	X	X	X	X	X	X	X	X	X	X
Korea	X	X	X	X	X	X				
Latvia	X		X						X	
Lithuania	X		X							
Netherlands	X	X	X							
New Zealand	X	X								
Norway	X	X			X	X				
Portugal	X	X	X		X	X	X			
Spain	X	X			X	X			X	X
Sweden	X	X	X							
United Kingdom	X	X	X		X				X	
United States	X	X	X		X	X				