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Abstract

Policy monitoring frameworks allow decision makers to assess the performance and progress towards specific strategic objectives that reflect an overall vision. The bioeconomy consists of complex social, economic, and environmental systems. The EU Bioeconomy Monitoring System was developed by the JRC to fulfil the need for a holistic policy monitoring framework and track economic, environmental and social progress towards a sustainable bioeconomy through relevant indicators. Here we present the first assessment based on the EU Bioeconomy Monitoring System.

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Executive summary

The EU Bioeconomy Strategy defines five objectives that a sustainable and circular EU bioeconomy should achieve: 1. Ensuring food and nutrition security; 2. Managing natural resources sustainably; 3. Reducing dependence on non-renewable, unsustainable resources, whether sourced domestically or from abroad; 4. Mitigating and adapting to climate change; 5. Strengthening European competitiveness and creating jobs. The EU Bioeconomy Monitoring System (henceforth 'BMS')[1], developed by the JRC as part of the Action 3.3.2 of the 2018 EU Bioeconomy Strategy (COM/2018/673) to track economic, environmental and social progress towards a sustainable bioeconomy, was developed around a conceptual framework that aims to operationalize the Strategy's five objectives into a vision for a sustainable EU bioeconomy. In parallel to the development of the BMS itself, the JRC is enhancing the broader knowledge base through the European Commission's Knowledge Centre for Bioeconomy and is furthermore pursuing complementary research activities linked to the monitoring of the bioeconomy in order to improve our understanding of the whole bioeconomy system and of the ecological boundaries, through different approaches.

The overarching and cross-sectoral nature of the bioeconomy system is reflected in the diversity of European strategies, at different levels, that make up the broader policy landscape. At the EU level, there is the dedicated European Bioeconomy Strategy and more recently the overarching European Green Deal that confirmed the Strategy's relevance and added value but also triggered a wave of policy initiatives that capture and influence the bioeconomy. Indeed, the bioeconomy can be seen as a catalyst for systemic change, contributing and enabling the Green Deal. Furthermore, a number of instruments are available to provide public financial support to circular bioeconomy projects in the form of grants, loans and equity.

Bioeconomy policies and initiatives also exist, or are being developed, in many of the EU Member States and their regions as well as at macro-regional level. In Europe, there are three large macro-regional bioeconomy initiatives involving governmental authorities from several European countries (BIOEAST, Nordic bioeconomy and a bioeconomy for the Baltic Sea region). Member States have diverse perceptions and priorities for their national bioeconomies, mainly due to the varied biophysical characteristics and industrial specialization of EU regions. As of December 2022, ten EU Member States have national bioeconomy strategies dedicated to the bioeconomy, seven have such strategies under development, six other MS have other policy initiatives dedicated to the bioeconomy, and the remaining four MS have strategies related to the bioeconomy (such as National Energy and Climate Plans, National Strategies on Adaptation to Climate Change and Circular Economy Strategies).

The bioeconomy is a complex and dynamic system and thus decision-makers need new strategies and tools to steer and govern this complex system towards the desired outcomes. Thus, while the status and focus of bioeconomy strategies varies among MS and macro-regions, a common denominator - also with the EU-level bioeconomy - is the necessity to monitor progress towards the respective bioeconomy objectives. While the specificities of the monitoring at different levels will differ, general guidelines can be followed to ensure that a comprehensive picture of the bioeconomies and their trends can be documented through the monitoring initiatives. In partnership with the FAO, the JRC identified and described ten generic steps for setting up and preparing assessments of bioeconomies at different scales in a Guidance note, from the conceptual level, to implementation and finally through to assessments and communication of results.

([1]) *https://knowledge4policy.ec.europa.eu/bioeconomy/monitoring*

Policy monitoring frameworks need to be truly useful and flexible sensors for reflexive governance. Thus, monitoring needs to go beyond a digital web-based tool that uses relevant indicators and aggregates them to show trends and progress. This is why the concept of the EU Bioeconomy Monitoring System is extended towards research and engagement branches that are important in order to be able to explore new and emerging indicators or means to compute them; or even to go further and to assess how the monitoring system may contribute to systemic approaches to bioeconomy assessments. The research component is an on-going set of activities carried out at JRC, whose purpose is to develop an understanding of the social-ecological outcomes of the EU Bioeconomy and reflect on the normative basis for the EU Bioeconomy. The engagement component on the other hand, includes a set of activities that aim to pool the broadest possible expertise in different aspects of the bioeconomy and foster scientific collaborations with other institutions and scientists, for instance by collaborating in defining new indicators or new approaches for the assessment of the bioeconomy, or to iteratively improve the BMS through multi-stakeholder and citizen participatory processes.

The key messages that emerge from this first assessment based on the BMS, are that Europe is generally moving towards the objectives of the EU Bioeconomy Strategy but environmental challenges persist. This points to a need for policy coordination as a consequence of multiple pressures on land from biomass demand. This indicates a need for both a reduction in consumption and a further push to innovate and re-skill the workforce towards more efficient production and especially, towards a recovery and re-use of biomass.

When considering the disaggregated quantitative analysis of the indicators currently published in the BMS dashboard, both scoreboards of individual indicators, as well as the aggregate assessments for a short-term (5-year) and longer term (10-year) trends are given. Results are divided by Strategy objectives.

Objective 1: Ensuring food and nutrition security

Food availability indicators are seen to be generally stable, which is in line with other recent assessments on food-security made by the European Commission. The indicators contributing to the understanding of accessibility to food are showing that while there is more overall food security in the EU, the food purchasing power has slightly declined in the past 5 years (it is stable on a 10-year average). Furthermore, there is an increasing trend in government support to agricultural research in MS, both in the short and in the long term.

Objective 2: Managing natural resources sustainably

Provisioning ecosystem services show a clear positive trend. The indicators focused on pressures on forests and on agro-ecosystems show a decline in sustainable management. On the other hand, indicators on pressures from fisheries show positive trends for the areas monitored (North-East Atlantic and the Mediterranean & Black sea areas), although it should be noted that the level of fishing pressure started from a high level and although it is declining, it is still not at a sustainable level. The biodiversity indicators show stable conditions for farmland birds and grassland butterflies, but they are stable at a much-degraded state compared to the past. On the contrary, the index for common forest birds show a promising positive trend that continues for several years. The surface areas of both marine and terrestrial protected areas continue to increase significantly.

Objective 3: Reducing dependence on non-renewable, unsustainable resources

Trends for resource and energy efficiency are largely positive. For instance, the mass of biomass consumed to generate GDP has decreased. Similarly, energy efficiency and renewable energy use across the whole economy has increased, although the values specific to bioeconomy industries are not isolated here. Biowaste generation has been increasing in the last 5 years, although so has the fraction of biowaste recovered, amounting to more than 90% in 2018. Isolating food waste generation from biowaste, we do not see any significant change in time at any step of the supply chain. Assessing food waste by food category, we do see that there has been, in the past five years,

a significant decline in food waste generation for cereals, fish and oil crops. The total consumption of biomass for energy and materials has been increasing steadily over the past years.

Objective 4: Mitigating and adapting to climate change

The monitoring of progress towards this objective still presents several indicator gaps, in particular on the full set of climate change adaptation indicators. Nevertheless, the existing indicators in two major bioeconomy-related sectors, agriculture a nd LULUCF (Land use, land use change and forestry), do not show promising trends. There is a slight worsening in the emissions from agriculture, the sector is still reporting a large amount of GHG emissions, with an increase from 2012 levels. The trend in the LULUCF sector is more worrisome, as this sink has been shrinking since 2013. LULUCF includes cropland and grassland, and these are relatively stable throughout time, but the fluctuations in the indicator are due to the forests (and to a certain extent, to the harvested wood products). The forest carbon sink is mainly driven by the difference between increment and harvests, and natural disturbances. The Water Exploitation Index is another critical indicator showing the balance between water demand and abstractions vs. water availability. This indicator is particularly critical for water-stressed regions such as the Mediterranean.

Objective 5: Strengthening European competitiveness and creating jobs

The dynamics regarding the share of value added over GDP of the bioeconomy sector are heterogeneous. In general, biomass-producing activities (agriculture, forestry and fishing) are either stable, or negative trends are shown in their share of GDP. This reflects the long-term developments of a lower dynamism of these activities with respect to the total economy. The share of manufacture of food and beverages activities registered a stable to positive trend in the analysed periods. More traditional non-food biomass-processing activities show a stable evolution (e.g. wood products and paper) or, in the case of textiles, a structural decline. The most positive and dynamic trends can be observed for more recent bio-based industrial activities related to chemicals, pharmaceuticals, plastics and the energy-oriented bio-based sectors. Despite the heterogeneous trends among bio-based activities, the gross value added per person employed in the bioeconomy showed a strong increasing trend in the periods considered. This indicates an improvement in the labour productivity within the overall bioeconomy. The above finding relates to the increasing trends in both turnover and value added in the total bioeconomy, but also to a slightly decreasing trend in the number of people employed in the bioeconomy sectors. This decline can be explained by the reduction in the agricultural labour force in the analysed period, which was only partially offset by an increase in the number of employed persons in other bio-based sectors.

While the assessment described here is informative, it is as of yet incomplete because of the gaps in data and knowledge. The JRC continues to further develop the BMS, filling gaps in the system, whilst further research is taking place to improve our understanding of the EU bioeconomy system as such and of the ecological boundaries in which it needs to operate. For instance, the services associated to bioeconomy are not currently part of the BMS, yet we show they are significant and it may be worth considering. Beyond the monetary value of the services associated to the EU bioeconomy, this exercise sheds new light on the interactions within the bioeconomy, namely the importance and position of services into the European bioeconomy and their dependencies.

Still along the lines of identifying approaches that will improve our knowledge and understanding of bioeconomy, this report delves into a method on how the whole bioeconomy can be assessed though an accounting framework that is based on the concept of societal metabolism. The outputs of a scientific procedure of accounting for societal and ecosystem metabolism can then be used to inform deliberation over bioeconomy policies through a process of quantitative storytelling.

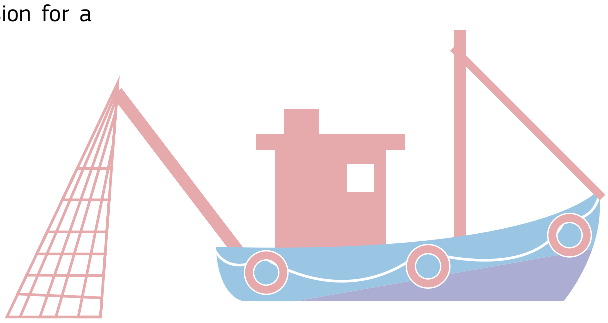
In conclusion, the 2018 Bioeconomy Strategy Progress Report (COM(2022) 283) (European Commission, 2022) contextualizes the EU Bioeconomy within the EGD as both the enabler and the result of the European Green Deal. As an enabler, the bioeconomy is attributed to policy coherence, and vertical coordination at local, national, EU and international levels; as a result, it is partly responsible for a transition in the way of life of Europeans. This lofty responsibility requires good governance, and good governance requires a robust monitoring framework that is properly orchestrated to provide a system's view of the EU Bioeconomy. This assessment, based on the BMS, takes a first step in this direction.

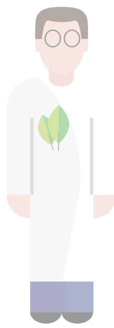
1 Introduction

The European Green Deal (EGD) acknowledges the role of the biosphere as the basis for a healthy planet and envisions a more holistic model of governance. By considering society and ecosystems as interconnected into complex social-ecological systems, the EGD aims to transform the EU production and consumption systems, not only through technological development, but also through changes in lifestyles. The EGD was designed to deeply transform policies and mainstream sustainability. Thus, at the end of 2019 with the adoption of the EGD Communication, a deep revision of the regulatory tools and the adoption of new ones was triggered.

A bioeconomy strategy for the EU was first published in 2012. In its inception, the EU Bioeconomy Strategy aimed to accelerate the deployment of a sustainable European bioeconomy, defining five objectives that a sustainable and circular EU bioeconomy should achieve. The five strategy objectives are: 1. Ensuring food and nutrition security; 2. Managing natural resources sustainably; 3. Reducing dependence on non-renewable, unsustainable resources, whether sourced domestically or from abroad; 4. Mitigating and adapting to climate change; 5. Strengthening European competitiveness and creating jobs.

The EU Bioeconomy Strategy was reviewed in 2017[2] and updated in 2018 (European Commission, 2018), maintaining these five Objectives, with a new action plan based on three priorities. Under the third priority of the 2018 EU Bioeconomy Strategy, that focuses on 'understanding the ecological boundaries of the bioeconomy', Action 3.3.2 addresses the specific need identified in the 2017 review for better monitoring and assessment frameworks to assess the progress a comprehensive monitoring system. The EU Bioeconomy Monitoring System (henceforth 'BMS')[3] establishes a mechanism to measure the progress of the EU bioeconomy towards the five strategic objectives of the Strategy. It was developed by the JRC around a conceptual framework that aims to operationalize these objectives into a vision for a sustainable EU bioeconomy.





(2) European Commission, Directorate-General for Research and Innovation, Review of the 2012 European Bioeconomy Strategy, Publications Office, 2018, *https://data.europa.eu/doi/10.2777/086770*

(3) *https://knowledge4policy.ec.europa.eu/bioeconomy/monitoring*

The progress of the 2018 Strategy was recently assessed (COM(2022) 283) (European Commission, 2022). The progress report contextualizes the EU Bioeconomy within the EGD as both the enabler and the result of the European Green Deal. As an enabler, the bioeconomy is described as facilitating coherence (policy coherence, and vertical coordination at local, national, EU and international levels); as a result, the bioeconomy is attributed to an aspirational way of life for Europeans. The progress report acknowledges that the transition will not take place in a uniform and single step, but instead will take place at different rates within its MS, favoring their different strengths while taking their specific challenges into consideration. While the progress report states that the actions in the 2018 Strategy are on track, it also looks ahead to how the EU Bioeconomy may evolve to be even more impactful and comprehensive.

While the focus of this report is on presenting the trends in the EU Bioeconomy through the lens of the BMS, it also takes stock of the different bioeconomy initiatives developed across Europe, highlighting differences and synergies in the macro-regions, the MS and the regions. It starts with an overview of the EU, macro-regional, national and regional policy initiatives that make up the European bioeconomy's policy landscape. The report then moves into the more technical aspects of monitoring the bioeconomy, describing the approach thus far adopted in EU-level monitoring. An analysis of the data in the monitoring system follows. This assessment is pursued at two different levels: through the individual indicators within the system, and at a more aggregate level whereby a more holistic discussion of the EU Bioeconomy takes place.

The report then takes a deep dive into two main research areas related to understanding the bioeconomy as a system: the inclusion of the services sectors in monitoring, and a metabolic approach to capture the system's level view of bioeconomy. Finally, the report concludes with an outlook for the BMS and associated research topics to address the remarks in the Strategy Progress Report for a more impactful and comprehensive EU Bioeconomy.

2 Bioeconomy policy landscape in Europe

The cross-sectoral nature of the bioeconomy and its diversity within Europe, mainly due to the diverse biophysical characteristics and industrial specialization of EU regions[4], result to a rich multi-dimensional and multi-level policy landscape. The European bioeconomy is therefore shaped by policies at different levels that follow different approaches. At the EU level: the dedicated European Bioeconomy Strategy, overarching policies like the EGD, cross-cutting policies and related programmes such as those on research and innovation, regional development, climate change, environmental protection, the circular and blue economies as well as sectorial policies focusing on specific bioeconomy sectors including the biomass producing sectors and sectors mainly using biomass. Bioeconomy policies and initiatives also exist, or are being developed, in many of the MS and their regions as well as at macro-regional level.

2.1 EU policies and programmes

A Bioeconomy Strategy for the EU was first published in 2012[5], reviewed in 2017[6] and updated in 2018[7]. It aims to achieve five different objectives and therefore provides a coherent framework that favors synergies and addresses trade-offs between sectors and objectives.

To reach its five objectives, the 2018 Bioeconomy Strategy included an Action Plan along three main action areas: (1) strengthen and scale-up the bio-based sectors, unlock investments and markets; (2) deploy local bioeconomies rapidly across Europe; and (3) understand the ecological boundaries of the bioeconomy. A report on the progress made in the Strategy's implementation was published in 2022.[8]

In 2019, the Commission launched the EGD that aims to transform the EU into a modern, resource-efficient and competitive economy, where there are no net emissions of greenhouse gases by 2050, economic growth is decoupled from resource use and no person and no place is left behind. In order to reach these ambitions, the EGD triggered a wave of initiatives across the full EU policy spectrum in the period 2020-2022. Given the importance of the bioeconomy as a major component for the implementation of the European Green Deal, recognised also by the Council[9] and the Commission,[6] many of these initiatives address, or influence, the bioeconomy system e.g. biomass-producing sectors, sectors using biomass and marine and land ecosystems. These included reviews of well-established sectorial or thematic policies resulting to e.g. a new Common Agricultural Policy[10], a new forest Strategy[11], a new industry Strategy[12], a new Biodiversity Strategy[13] and a proposed updated Renewable Energy Directive[14]. They also included the development of fresh policy initiatives that take a more systemic perspective- such as a new farm to fork Strategy[15], a new blue economy approach[16], a new Circular Economy Action Plan[17] and follow-up initiatives e.g. a new EU policy framework on biobased, biodegradable and compostable plastics[18], a long-term Vision for the EU's Rural Areas[19], a sustainable carbon cycles intitiative[20], an EU strategy to reduce methane emissions[21], a new Chemicals Strategy[22], just to name a few.

Furthermore, a number of instruments are available to provide public financial support to bioeconomy projects in the form of grants, loans and equity, starting from the EU's research and innovation programmes. Under Horizon 2020, the European Commission already dedicated substantial public investment into bioeconomy projects in the period 2014-2020, including under the Bio-based Industries Joint Undertaking (BBI JU). Further research on innovative bioeconomy areas is currently being financed through the Horizon Europe programme (2021-2027), including the BBI's successor Circular Biobased Europe Joint Undertaking (CBE JU).

Other relevant EU funding programmes include the LIFE programme and the European Structural and Investment Funds (ESIFs), including the European Agricultural Fund for Rural development fund (EAFRD), the European Maritime and Fisheries Fund (EMFF), which committed €23.9 million to the blue bioeconomy by the end of 2020[6] and was succeeded by the new European Maritime, Fisheries and Aquaculture Fund, the Cohesion Fund (CF) and the European Regional Development Fund (ERDF) focuses its investments on several key priority areas including innovation and research and the low-carbon economy, under which EU regions publish Smart Specialisation Strategy (RIS3) documents which outline priority R&I areas such as agriculture, waste processing and biorefineries.

2.2 Macro-regional initiatives

There are currently three large macro-regional bioeconomy initiatives in Europe, involving governmental authorities:

- **BIOEAST - Central-Eastern European Initiative for Knowledge-based Agriculture, Aquaculture and Forestry in the Bioeconomy[23]:**
  The Central-Eastern European Initiative for Knowledge-based Agriculture, Aquaculture and Forestry in the Bioeconomy – BIOEAST – offers a shared strategic research and innovation framework for working towards sustainable bioeconomies in the Central and Eastern European (CEE) countries. It promotes bioeconomy development in 11 central and eastern European countries, where bioeconomy deployment is currently less advanced. BIOEAST is supported by the European Union's Horizon 2020 Programme for Research and Innovation.

- **Nordic bioeconomy[24]:**
  Under the Nordic Bioeconomy Panel, it draws up proposals for a strategy covering the area and outline options and practical measures to promote sustainable bioeconomies. Under the West Nordic Bioeconomy Panel, the West Nordic Bioeconomy[25] is an initiative whose goal is to suggest a sound strategy for the West Nordic region (Iceland, Greenland and Faroe Islands) in order to maintain and strengthen its Bioeconomy, as well as to communicate that strategy.

- **Bioeconomy in the Baltic Sea Region[26]:**
  Bioeconomy is one of the 13 policy areas covered by the EU Strategy for the Baltic Sea Region (EUSBSR). The Nordic Council of Ministers leads the work on the bioeconomy together with partners from Finland, Sweden and Lithuania. In this capacity the Nordic Council of Ministers provides an access point and support function for stakeholders that wish to pursue bioeconomy cooperation activities that support overall objectives of the EUSBSR.

The European Territorial Cooperation Programmes – Interreg - play an important role in developing regional and, especially, multi-regional bioeconomy strategies. They are the motor behind four additional macro-regional initiatives identified, namely:

- **Danube Region (DanubeBioValNet)[27]:**
  this project launched in 2017 is a cross-regional partnership involving 16 partners from 10 Danube regions to develop three bio-based value chains, Phytopharma, Eco-construction and Bio-based packing (bioplastic) as well as the hemp industry.

(4) *https://publications.jrc.ec.europa.eu/repository/handle/JRC121212*
(5) COM(2012)60. Innovating for Sustainable Growth: A Bioeconomy for Europe
(6) European Commission, Directorate-General for Research and Innovation, Review of the 2012 European Bioeconomy Strategy, Publications Office, 2018, *https://data.europa.eu/doi/10.2777/086770*
(7) COM(2018)673 and SWD(2018)431. A sustainable Bioeconomy for Europe: Strengthening the connection between economy, society and the environment.
(8) COM/2022/283. EU Bioeconomy Strategy Progress Report European Bioeconomy policy: stocktaking and future developments
(9) Council conclusions (14594/19) on the updated Bioeconomy Strategy "A sustainable Bioeconomy for Europe: strengthening the connection between economy, society and the environment"
(10) *https://agriculture.ec.europa.eu/common-agricultural-policy/cap-overview/new-cap-2023-27_en*
(11) COM/2021/572 final. New EU Forest Strategy for 2030
(12) COM/2020/102 final. A New Industrial Industry for Europe
(13) COM/2020/380 final. EU Biodiversity Strategy for 2030 Bringing nature back into our lives
(14) COM/2021/557 final. Proposal for a Directive amending Directive (EU) 2018/2001, Regulation (EU) 2018/1999 and Directive 98/70/EC as regards the promotion of energy from renewable sources, and repealing Council Directive (EU) 2015/652
(15) COM/2020/381 final. A Farm to Fork Strategy for a fair, healthy and environmentally-friendly food system
(16) COM/2021/240 final. A new approach for a sustainable blue economy in the EU.
(17) COM/2020/98 final. A new Circular Economy Action Plan For a cleaner and more competitive Europe
(18) COM/2022/682 final. EU policy framework on biobased, biodegradable and compostable plastics
(19) COM/2021/345 final. A long-term Vision for the EU's Rural Areas - Towards stronger, connected, resilient and prosperous rural areas by 2040
(20) COM/2021/800 final. Sustainable Carbon Cycles.
(21) COM(2020) 663 final. EU strategy to reduce methane emissions
(22) COM/2020/667 final. Chemicals Strategy for Sustainability Towards a Toxic-Free Environment
(23) *http://www.bioeast.eu/*.
(24) *https://www.norden.org/en/bioeconomy*.
(25) *https://www.matis.is/media/utgafa/actions_for_sustainable_bioeconomy_in_the_west_nordic_region.pdf*.
(26) *http://bsrbioeconomy.net/*.
(27) *https://www.interreg-danube.eu/approved-projects/danubiovalnet*.

- **AlpLinkBioEco, Linking BioBased Industry Value Chains Across the Alpine Region[28]:** a cross-regional and circular bio-based economic strategy which released the Masterplan towards a joint bioeconomy strategy for the Alpine Space.

- **BIO-ECOnomy Research Driven Innovation for the Adriatic-Ionian Region (Bioeco-RDI-ADRION)[29]:** an initiative to support the development of a regional innovation system for the Adriatic-Ionian area.

- **Bio-Innovation Support for Entrepreneurs throughout NWE regions (BioBase4SME)[30]:** initiative involving organisations from 6 European countries (BE, DE, NL, IE, FR and the UK) to advise SMEs from across North-West Europe on how to develop new ideas into marketable products.

Furthermore, there are additional transnational initiatives with a bioeconomy focus driven by private companies and innovation clusters:

- **The trilateral strategy for the chemical industry[31]:** trilateral Strategy for the Chemical Industry Cross-border Cooperation of the Netherlands, Flanders, and North-Rhine Westphalia to strengthen the competitiveness of the chemical industry and to improve economic growth through cross-border cooperation to be addressed by the representatives of the three partners.

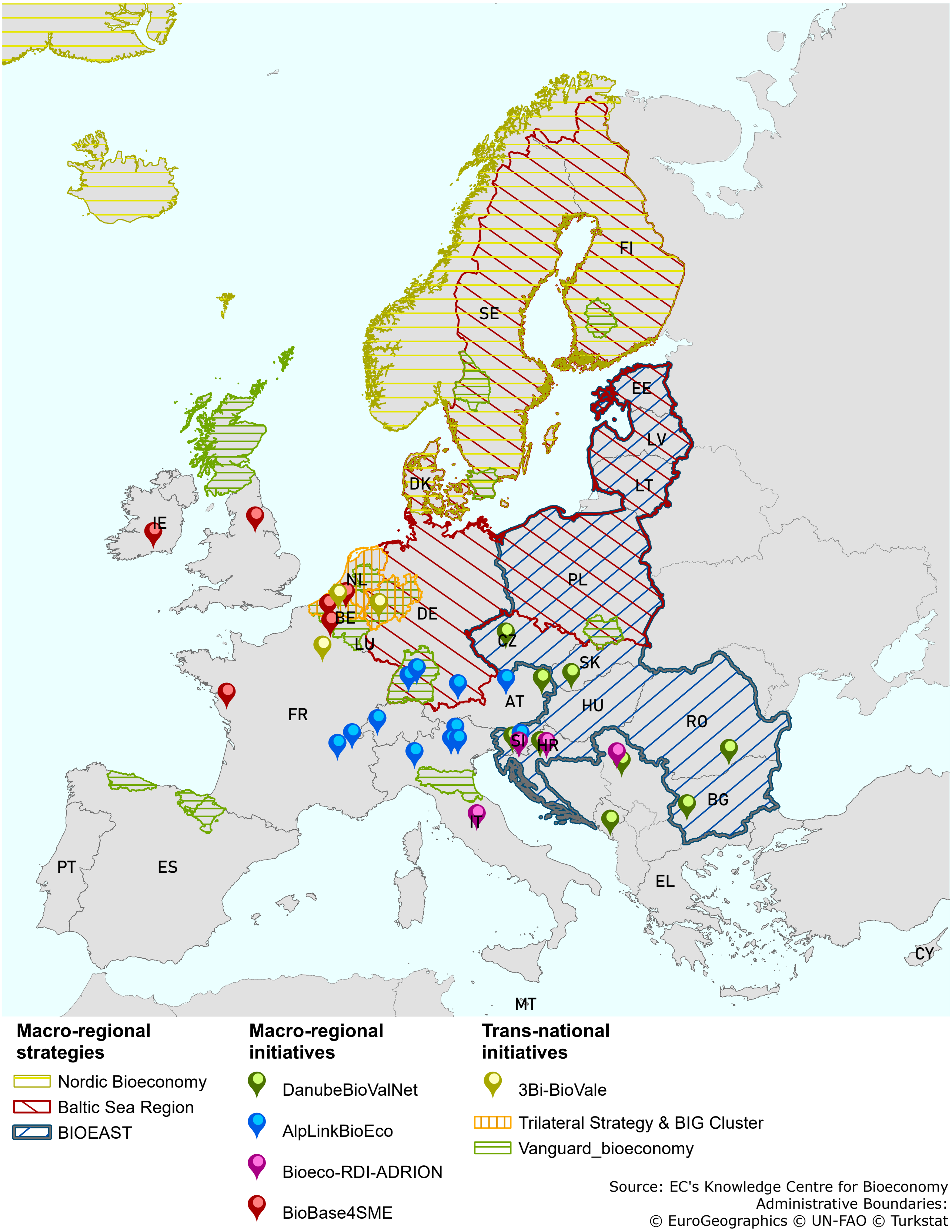
- **BioInnovation Growth mega-Cluster (BIG-Cluster)[32]:** Cross-border 'Smart Specialisation Initiative' aiming at transforming Europe's industrial mega cluster in the Flanders region of Belgium, the Netherlands and the German state of North Rhine-Westphalia into the global leader of biobased innovation growth.

- **3BI intercluster – Brokering Bio-Based Innovation (3Bi-BioVale)[33]:** 3BI is a strategic European partnership that builds on the complementary strengths of four regional innovation clusters: Biobased Delta[34], BioEconomy, BioVale and Industries & Agro Ressources (IAR)[35] to access important new markets based on renewable raw materials successfully. All four clusters use biorefining to convert biological resources into materials, chemicals, fuels, food and feed. They intend to work together in the research, development and deployment of novel high-tech approaches to the conversion of biomass and waste streams into value-added products and applications. The leading bioeconomy clusters in the Netherlands, France, the UK and Germany have joined forces as the 3BI intercluster – Brokering Bio-Based Innovation. Their goal is to support European companies to access important new markets based on renewable raw materials successfully.

- **Vanguard initiative[36]:** the Vanguard Initiative was established in 2013 by ten European regions as a show case of industry-led interregional cooperation, co-creation, and co-investment, on the basis of smart specialization. The Bioeconomy Pilot in Vanguard has a two-fold objective: i) support the deployment of high TRL technologies, through the setting up of trans-regional value chains and ii) identify critical challenges beyond the capabilities of a single region to team up skills, energies and resources that can make a difference in market terms. In framework, seven demo cases are being developed, from lignocellulose biorefinery to food and feed ingredients form algae. The bioeconomy initiative is co-lead by two regions, Lombardia (IT) and Randstat (NL) with 14 additional regions participating (see Figure 1).

(28) *https://www.alpine-space.eu/project/alplinkbioeco/*.
(29) *https://bioecordi.adrioninterreg.eu/*.
(30) *https://www.nweurope.eu/projects/project-search/bio-innovation-support-for-entrepreneurs-throughout-nwe-regions/#tab-1*.
(31) *https://www.trilateral-chemical-region.eu/strategy*.
(32) *https://www.bigc-initiative.eu/index.php*.
(33) *https://www.biovale.org/what-we-do/international/3bi/*.
(34) *https://circularbiobaseddelta.nl/*.
(35) *https://www.iar-pole.com/*.
(36) *https://www.s3vanguardinitiative.eu/pilots/bio-economy*.

Figure 1. Macro-regional bioeconomy initiatives in Europe



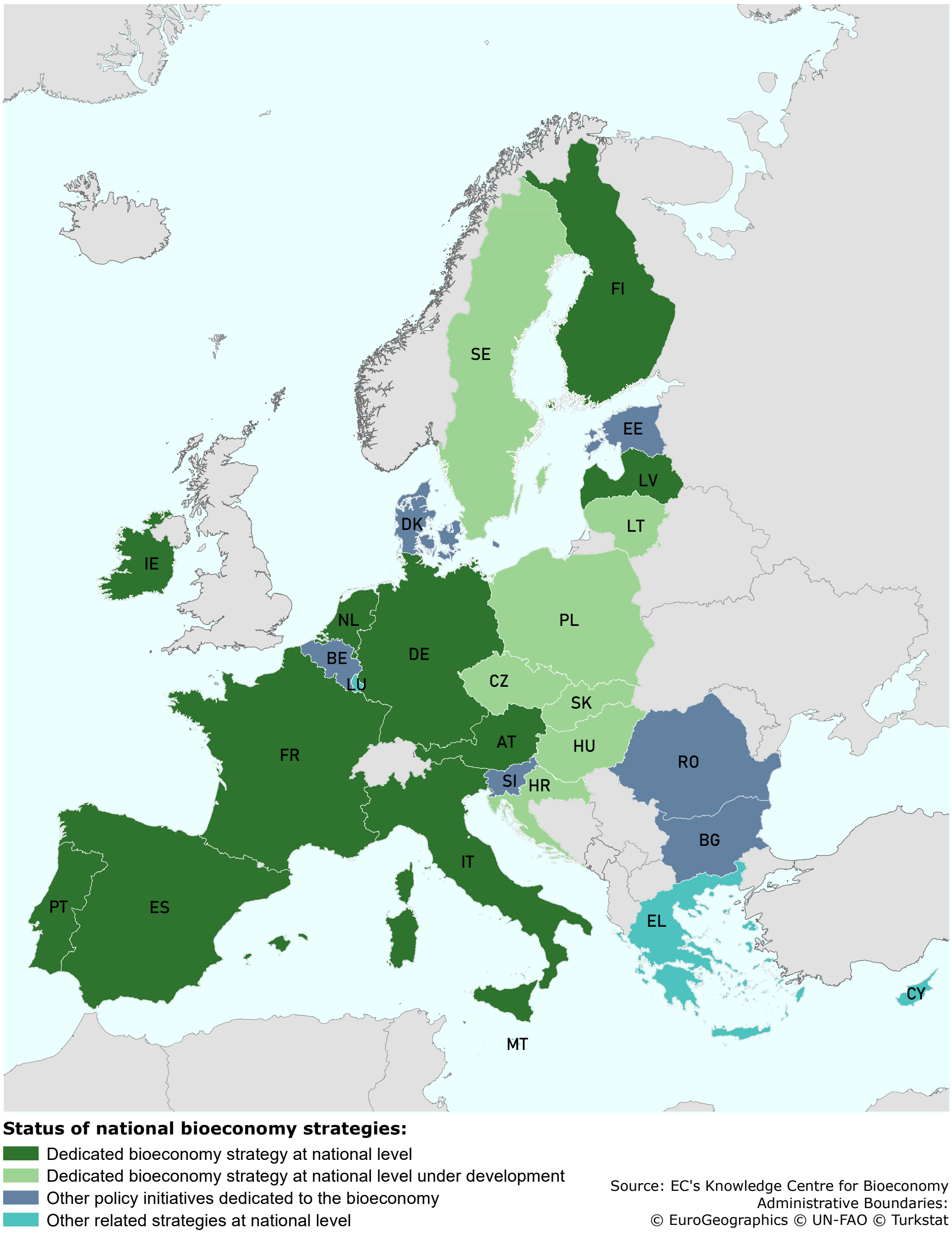
Source: EC's Knowledge Centre for Bioeconomy
Administrative Boundaries:
© EuroGeographics © UN-FAO © Turkstat

2.3 National bioeconomy strategies and other policy enabling measures

As of December 2022, there are ten MS with national bioeconomy strategies dedicated to the bioeconomy (Austria, Germany, Spain, France, Finland, Ireland, Italy, Latvia, Netherlands and Portugal) and seven other MS with such strategies under development (Czechia, Croatia, Hungary, Lithuania, Poland, Sweden and Slovakia). Six other MS have other policy initiatives dedicated to the bioeconomy (namely sub-national bioeconomy strategies in Belgium and the macro-regional strategies described in section 2.2 in Bulgaria, Denmark, Estonia, Romania and Slovenia). The remaining four MS (Cyprus, Greece, Luxemburg and Malta) have strategies related to the bioeconomy such as National Energy and Climate Plans, National Strategies on Adaptation to Climate Change and Circular Economy Strategies (see Figure 2).

The EU Bioeconomy Strategy Progress Report (EC, 2022) adopted in June 2022, provided a comprehensive overview of the developments in bioeconomy national policies since 2018. More recent developments include a new framework for the biomass strategy in Germany[37] and a new National Bioeconomy Action Plan 2023-2025 for Ireland (currently under consultation)[38].

Figure 2. Status of national bioeconomy strategies in the EU-27 as of February 2022.



([37]) *https://www.bmwk.de/Redaktion/DE/Publikationen/Wirtschaft/nabis-eckpunktepapier-nationale-biomassestrategie.html*
([38]) *https://www.gov.ie/en/consultation/fd200-bioeconomy-action-plan-consultation/*

For the ten MS with dedicated bioeconomy strategies, a mapping of the sectors and policy actions included in their strategies and action plans was carried out (see Figure 3). For this analysis, the policy documents were screened to identify: i) the different economic sectors addressed and; ii) specific policy actions and initiatives included in the national strategies or action plans, aiming at enabling the bioeconomies in the different countries.[39] These policy actions were then mapped against a standardized grid, designed to group actions according to their type, in order to provide an overview of sectors and actions in national Bioeconomy Strategies in the EU.

The list of policy documents analysed and a brief description of where the actions were extracted for this mapping is detailed in Table 1.

Figure 3. Overview of sectors and actions in Bioeconomy Strategies of Member States.

Focus / Bioeconomy Strategies of Member States		AT	DE	ES	FR	FI	IE	IT	LV	NL	PT
Sectors covered	Agriculture	●	●	●	●	●	●	●	●	●	●
	Forestry	●	●	●	●	●	●	●	●	●	●
	Fisheries		●	●	●	●	●	●	●	●	●
	Aquaculture	●	●	●	●	●	●	●	●	●	●
	Organic waste	●	●	●	●	●	●	●	●	●	●
	Food	●	●	●	●	●	●	●	●	●	
	Wood, wood products & furniture	●	●	●	●	●	●	●	●	●	●
	Pulp & paper	●	●	●	●	●	●	●	●	●	●
	Biotechnology	●	●	●	●	●	●	●	●	●	●
	Bio-based textiles	●	●	●	●	●	●	●	●	●	●
	Bio-based chemicals and materials	●	●	●	●	●	●	●	●	●	●
	Bioenergy (incl. transport biofuels, bioelectricity and H&C)	●	●	●	●	●	●	●	●	●	
	Ecosystem services	●	●	●	●	●	●	●	●	●	●
	Other specific sectors	●	●			●	●	●	●		●
Policy actions	Embed the bioeconomy into new legislative frameworks				●	●		●			
	Revisit existing regulatory frameworks to include bioeconomy concepts/priorities	●	●		●	●	●	●	●	●	●
	Promote the establishment of intra-governmental groups to support policy coherence or collaboration amongst different bioeconomy stakeholders	●	●	●	●	●	●	●	●		●
	Promote labels and standards for bio-based products	●	●	●	●	●	●	●	●		●
	Promote public procurement of bio-based products	●	●	●	●	●	●	●	●		●
	Enhance land management for new production systems and ecosystem functions	●	●			●		●	●		●
	Promote specific bioeconomy sectors	●	●		●			●	●		●
	Promote the principles of "cascading use", "circularity" and "resource efficiency" for biomass	●	●	●	●	●	●	●	●	●	●
	Enhance the knowledge on bioeconomy by setting-up knowledge hubs, observatories, information systems, web portals, conferences, etc.			●	●	●	●	●			●
	Implement specific studies (feasibility, impact assessments, land use, territorial development analyses, market analyses, foresight studies etc).	●	●	●	●	●	●	●	●		●
	Develop monitoring systems for the bioeconomy		●			●	●	●		●	●
	Promote communication campaigns for awareness raising (e.g. bioeconomy awards, information systems, events, etc.)	●	●	●	●	●	●	●	●	●	●
	Promote educational/training programmes	●	●	●	●	●	●	●	●		●
	Promote investments in bioeconomy research, innovation, market development	●	●	●	●	●	●	●	●	●	●
	Market incentives for bio-based production/consumption (e.g. subsidies, taxes)	●	●		●			●	●	●	

Source: JRC (2021). European Commission's Knowledge Centre for Bioeconomy and EC, 2022.

([39]) Generic and/or broad actions without a dedicated focus, e.g. "Promotion of bioeconomy and public involvement" or "Maintain and developing jobs during the transformation to the bioeconomy", were not considered in this analysis.

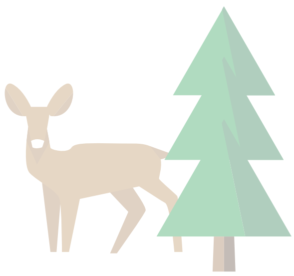
Table 1. Bioeconomy policy documents considered in the mapping of actions.

Country	Source document	Comment / details
Austria	*The Austrian Bioeconomy Strategy.*	In addition to its vision and mission, the Austrian bioeconomy strategy sets six target areas which are broken down into operational targets that "will enable an effective transition to the actions in the Action Plan". Furthermore, the Austrian strategy establishes "fields of action" in 23 different areas (called in the strategy "spheres"), including "circular economy", "Wood as a Construction and Building Material", "science and research", etc. For each of these fields of action, a series of more specific measures are detailed. Overall, 120 specific measures were identified in the Austrian bioeconomy strategy. 107 of them could be mapped into the grid of policy actions.
Finland	*The Finnish Bioeconomy Strategy.*	The Finnish strategy sets a vision and objective for the national bioeconomy, together with generic, but measurable, targets in terms of jobs and turnover. Furthermore, the strategy establishes four strategic actions to help implement such vision and targets, such as "creating a competitive operating environment for the bioeconomy" and "securing the accessibility and sustainability of biomasses". For each of these actions the strategy sets specific (2 to 6) goals; each of these goals is accompanied by a series of (2 to 5) measures. The strategy allocates responsibilities for these measures (namely governmental organisations and ministries) as well as other actors to be involved. Overall, 44 specific measures were identified in the Finnish bioeconomy strategy. 40 could be mapped into the grid of policy actions.
France	A Bioeconomy strategy for France - Action Plan 2018-2020 *(Une stratégie bioéconomie pour la France - Plan d'action 2018-2020).*	Translated from the original document in French. The action plan identifies 5 priority axes, from "enhancing the knowledge on bioeconomy" to "removing obstacles and mobilize funding". For each of those axes, the action plan establishes a series of (4 to 18) operational and specific actions, detailing an estimated timeline, expected deliverables, etc. Overall, 47 concrete actions were identified in the Action Plan 2018-2020 of France. 46 could be mapped into the grid of policy actions.
Germany	*National bioeconomy Strategy from Germany.*	The German strategy sets 6 central action areas for a sustainable bioeconomy to improve the policy framework, from "Reduction of the pressure on land" to "Exploitation of the potential of digitisation for the bioeconomy". Furthermore, an additional cross cutting action area on political coherence linking Industry policy, energy policy, agricultural, forestry and fisheries policy and climate and environmental policy is detailed. Overall, 25 specific measures were identified in the German bioeconomy strategy. All 25 could be mapped into the grid of policy actions.
Ireland	*National Policy Statement on the Bioeconomy* and *the Bioeconomy Implementation Group - First Progress Report.*	The national statement of Ireland identifies 7 broad key actions for the future success of the bioeconomy in Ireland, based on extensive consultation and analysis. These actions include from "Ensuring that there is coherence between all sectoral strategies which impact on the bioeconomy in Ireland" to "examining how greater primary producer, public and consumer awareness of the bioeconomy". The first Progress Report assessed the advancement in the seven key actions from the policy statement by taking stock of the specific milestones achieved at the time of its publication (Q3 of 2019). Overall, 33 specific actions were identified in the First Progress Report of Ireland. 31 could be mapped into the grid of policy actions.
Italy	*Bioeconomy Strategy of Italy* and *the Italian Implementation Action Plan.*	The strategy identifies the R&I agenda and priority actions as well as measures creating and guaranteeing the framework conditions required for its effective implementation. It also sets measurable targets of turnover and employment. The Italian Bioeconomy Implementation Plan identifies operational actions under four broad headings, from "Promoting the development/adoption of policies, standards, labels and emerging market based actions and incentives" to "Promoting awareness, skill upgrading, education, attitude, training, and entrepreneurships across the Bioeconomy". Each action is accompanied by a set of (5 to 14) sub-actions and recommendations. Overall, 43 sub-actions were identified in the Italian Implementation Action Plan. All 43 could be mapped into the grid of policy actions.

Country	Source document	Comment / details
Latvia	*Latvian Bioeconomy Strategy 2030.*	Only the short summary available in English was analysed. The Latvian strategy establishes five key integrated and complementary groups of measures, from "Attractive business environment for the entrepreneurship in bioeconomy" to "Socially responsible and sustainable development". Each of these groups comprise a series of (3 to 10) actions, some quite specific and targeted (e.g. "Replacement of non-renewable resources with bio-resources in public procurement") some others rather brad and abstract (e.g. "Export promotion measures"). Overall, 28 actions were identified in the Latvian Bioeconomy strategy. 21 of them could be mapped into the grid of policy actions.
Netherlands	*The position of the bioeconomy in the Netherlands.*	This document establishes 8 pillars (themes) vital in the development of bioeconomy policy, including "Using resources within the planetary boundaries", "Sustainable resource management" or "Regional strategy and rural development". The position paper also establishes a transition agenda to boost the bioeconomy in the Netherlands, most of them quite general and some others (e.g. "transition agenda for biomass and food") more concrete. Overall, 23 policy measures were identified in the position paper of the bioeconomy in the Netherlands. 13 of them could be mapped into the grid of policy actions. NB. Since this analysis the document "the position of the bioeconomy in the Netherlands" has been recently removed from official websites of the Dutch government.
Portugal	*Action Plan for a Sustainable Bioeconomy. Horizon 2025.*	Translated from the original document in Portuguese. The action plan identifies five axes of action, including "Encouraging sustainable production and intelligent use of regionally-based biological resources"; "promoting research, development and innovation and enhance the national scientific and technological capacity of excellence"; "monitoring the bioeconomy", etc. For each axis, the action plan establishes several objectives and specific measures and points to relevant instruments and other relevant strategic documents. The measures are well described and classified into areas of intervention. Overall, 37 specific measures were identified in the Portuguese Action Plan. 32 of those could be mapped into the grid of policy actions.
Spain	*The 2016 Action Plan from the Spanish Bioeconomy Strategy.*	The "Spanish Bioeconomy Strategy, Horizon 2030" is accompanied by the 2016 Action Plan. This action plan includes 5 groups of actions broken down each of them into a series of measures, some quite generic but some others very targeted and specific. Overall, 34 specific measures were identified in the Spanish Action Plan. From those, 26 could be mapped into the grid of policy actions.

As Figure 3 shows, all bioeconomy sectors are addressed in almost all national bioeconomy strategies. Two exceptions are the Austrian bioeconomy strategy, which does not explicitly address the fisheries sector; and the Portuguese bioeconomy strategy which does not address the sectors of "Food" and "Bioenergy". 'Other specific sectors' addressed in national strategies include e.g. bio-pharmaceuticals (DE), bio-fertilizers, bioplastics, bio-stimulants and bio-lubricants (IT), construction, water treatment and supply; nature tourism (FI), etc.

Figure 3 also shows that the most common policy measures or actions used in national strategies are those related to promote "investments in bioeconomy research, innovation, market development", "communication campaigns for awareness raising" and "the principles of "cascading use", "circularity" and "resource efficiency" for biomass". Initiatives of those categories were found in the action plans or strategies of all 10 MS analysed. Some examples of actions to promote investments are the creation of public funds or funding instruments for innovation partnerships, cooperation platforms and for bioeconomy-specific research and innovation; the creation of open marketplaces based on public sector innovation and procurement needs, etc. The actions found in the national strategies aiming to 'promote the principles of cascading use, circularity and resource efficiency for biomass' are typically generic statements of support to the recovery and valorization of different types of wastes and by-products.



The following groups of actions were identified in the national strategies or action plans of 9 of the 10 MS analysed:

- Actions to ‘revisit existing regulatory frameworks to include bioeconomy concepts/priorities’. These included e.g. promotion of bioeconomy priorities and actions in the frame of national and regional Smart Specialisation Strategies (IT); administrative fees associated with the use of secondary raw materials (PT); removal of regulatory obstacles and facilitation of investment on agricultural methanization (FR), etc.

- Actions to ‘promote the establishment of intra-governmental groups to support policy coherence or collaboration amongst different bioeconomy stake-holders’, e.g. a National Bioeconomy Coordination Board to coordinate and monitor the implementation of the Action Plan (DE); a national bioeconomy panel to step up interaction between the government, the scientific community and enterprises and industry (FI); a Bioeconomy Strategy Management Committee to foster implementation of the strategy’s measures (ES).

- Actions to promote labels and standards for bio-based products, e.g. adaptation of labels for the designation of bio-based products (AT); set up a recognised label “Biobased product” at European scale on the bio-based content (FR); identify existing certifications/logos/labels (such as bio-based, biodegradable and/or compostable certification, eco-labels) and analyze barriers to the adoption of accredited certifications (PT).

- Actions to promote public procurement of bio-based products, e.g. strengthen the acquisition of bio-based products in the review of the National Strategy for Ecological Public Procurement (PT); replacement of non-renewable resources with bio-resources in public procurement (LV); updating government resolutions on public contracts to also cover bioeconomy procurements by 2016 (FI).

- Actions to implement specific studies, e.g. assessment of the institutional and legal framework as well as regional and local effects of the bioeconomy (AT); evaluate the sustainability of biomass use by generally accepted methods (FI); publish a feasibility study on the establishment of National Marine Biomaterials Repository (IE).

- Actions to promote ‘educational and/or training programmes, e.g. provision of excellent education services for the needs of bioeconomy industries (LV); creation of new Bachelors and Masters’ University degree programs in Bioeconomy (IT); inclusion of bioeconomy as topic in new training and further education programmes, courses at vocational and technical schools and technical colleges and universities (DE).

Some other policy actions were found to be less common in the national bioeconomy strategies or action plans (in 6 out of 10 Member States). These included measures to enhance land management for new production systems and ecosystem functions (e.g. in Italy to monitor degraded land areas or lands at risk of climate change impacts to underpin actions for soil health improvement); to promote specific bioeconomy sectors (in Germany where it is encouraged to develop, exploit and deploy digital technologies in agriculture and forestry and analyse associated innovative business models); enhance the knowledge on bioeconomy (e.g. the creation of the Spanish bioeconomy observatory); develop monitoring systems for the bioeconomy (measures to improve monitoring and exploration capacity in the Netherlands and the creation of statistics system on the bioeconomy in Finland, see BOX 1); and Market incentives for bio-based production/consumption (e.g. creation of predictable and stable tax policy for the bioeconomy sector in Latvia).

FOCUS BOX nr. 1:
Bioeconomy monitoring frameworks at national level

As Figure 3 shows, 6 MS (DE, FI, IE, IT, NL, PT) out of the 10 MS with national strategies have in place (or are developing) monitoring systems for the bioeconomy.

The earliest and most advance monitoring systems at national level are those of Germany, Italy and Finland.

Germany initiated a comprehensive monitoring programme for the bioeconomy in 2016. It aims to track trends in the development of the bioeconomy and to better understand dependencies and impacts. It is structured along 3 topic areas: (i) resources and their sustainability; (ii) economic effects and economic development of the bio-economy, and (iii) systemic monitoring, integrating data, indicators and models to provide a systemic, holistic insight into the bioeconomy (Robert et al., 2020).

Finland started with a focus on the socio-economic dimensions of the bioeconomy in its 2014 strategy but in the new ***Finnish strategy***, published in 2022, the monitoring system is broaden up to the ecological, economic and social sustainability mostly by using existing indicators, including ecosystem services-related indicators and those from the EU Bioeconomy Strategy.

Italy in its first strategy (***BIT I***) identified a monitoring system along 8 areas (biomass availability, productive and employment structure, human capacity, innovation, investment, demographics and markets) and an additional set of sustainability indicators structured along 5 environmental and social objectives (in line with the EU Strategy objectives). Besides, in its updated strategy (BIT II), it also aims to adopt a methodological framework and standardised indicators to measure the value of ecosystem services and to align funding mechanisms.

In some MS the work towards a national monitoring system is in its initial stages. For instance, the ***bieconomy national strategy of Portugal*** (2021) foresees an action to develop a system of key performance indicators at national and regional levels to assess/measure the evolution of Bioeconomy in Portugal; while Ireland specifically includes in its ***2019-2020 Action plan*** an action to liaise with the EU Commission on the EU-wide, internationally coherent monitoring system to track the progress towards a sustainable, circular bioeconomy in Europe and to underpin related policy areas.

Some MS such as Spain and Finland aim to monitor specifically the implementation of the strategy (i.e. not the progress of the Bioeconomy) mainly by assessing a few socio-economic indicators (e.g. employment, value added, investment, etc.). Spain in 2016 additionally foresaw the establishment of the Spanish Bioeconomy Observatory in charge of developing a monitoring system for the national bioeconomy, for which an initial set of 20 biophysical and socio-economic indicators was set (e.g. number of companies, biomass produced, etc. - see plenary session day 2 in the ***community of practice workshop, JRC 2020***). However, nor the Spanish observatory nor the monitoring system have been developed yet.

Besides, other MS showed initial initiatives to collect statistics specifically on the bioeconomy sectors like in Denmark and BIOEAST countries (see plenary session day 2 in the ***community of practice workshop, JRC 2020***).

The types of policy actions less contemplated by the national bioeconomy strategies are those aiming at embedding the bioeconomy into new legislative frameworks. In Finland, for example, the development of a bioeconomy regulation is planned, while in Italy it is encouraged to embed the bioeconomy strategy into law framework to guarantee its recognition and application, according to a biannual implementation plan.

The regulatory frameworks such as strategies, roadmaps, action plans, etc., set a direction where European, national or regional governments want to direct their policies, i.e. outline the public policy objectives, but do not usually imply binding regulations, laws, etc. Thus, some of the policy actions and measures mentioned above may not be eventually deployed.

In order to identify which bioeconomy enabling policy measures are actually in place in the different EU Member States, the JRC also coordinated a specific task in the context of the European Bioeconomy Policy Forum (EBPF), as part of a Working Group on "Knowledge for bioeconomy". The goal was to identify policy measures that foster the bioeconomies in the MS and their relative importance. Indeed, despite the limited geographical coverage of this exercise (11 MS[40]), the data collected show that diverse policy measures and instruments are already in place which collectively create an encouraging environment for public institutions and the private sector, as well as for researchers, consumers and citizens to ultimately foster a sustainable and circular bioeconomy.

The online questionnaire structured along 6 main blocs, aimed at collecting factual information of the policy measures and initiatives in place in the different countries that:

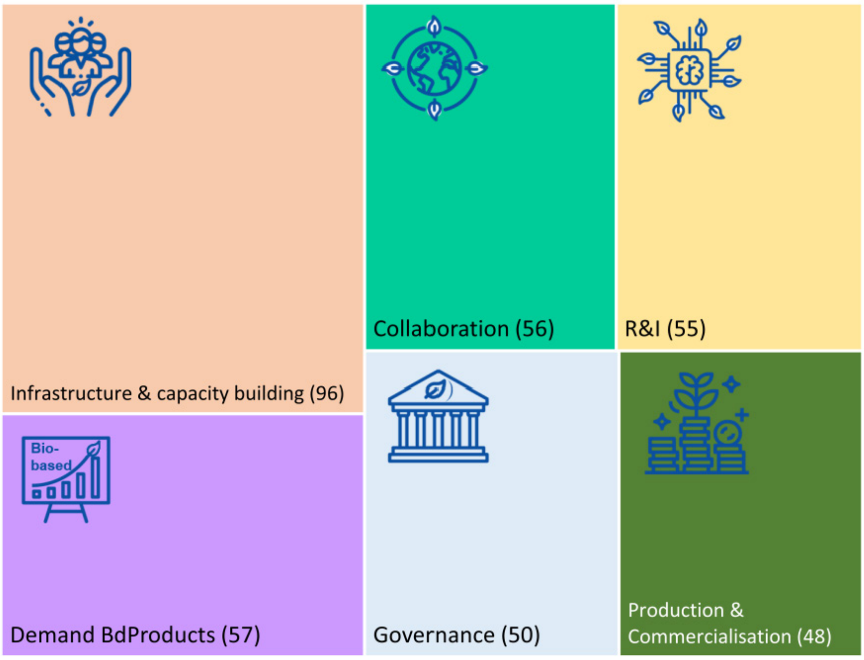
- Enable the governance of the bioeconomy across sectors, policies and institutions. These measures include the presence of an advisory council, monitoring systems of the national bioeconomies and strategies, as well as the existence of national register / list (or statistics) of bio-based industries or bio-refineries.
- Support infrastructure and capacity building with instruments that promote pilot and demonstration facilities, bioeconomy-specific educational programmes, develop cooperation platforms to mobilise biomass resources or promote industrial clusters.
- Initiatives that promote research & innovation like the creation of bioeconomy-specific research centres and Public-Private Partnerships (PPP), the funding of research and innovation specifically on the bioeconomy, etc.
- Measures that promote the production and commercialisation of bio-based products such as bio-based quotas or bio-tickets, mandates or subsidies for bio-based products, access to capital, regulated prices of bio-based products, etc.
- Measures that facilitate the demand for bio-based products, including national standards and labeling systems of bio-based products, public procurement programmes, campaigns of aware raising, etc.
- And initiatives that promote collaboration in the bioeconomy, for example promoting multi-stakeholder involvement, transfer of technology, etc.

Figure 4 shows the number of policy measures collected by block type. The most numerous type of measures were those dedicated to support infrastructure and capacity building (96 measures, i.e. 27% of the total).

All the other groups of measures were equally distributed, i.e. 16% to facilitate the demand for bio-based products; 15% to promote collaboration in the Bioeconomy; 15% to promote research & innovation; 14% to enable the governance of the bioeconomy across sectors policies and institutions; and 13% to promote production and commercialisation of bio-based products

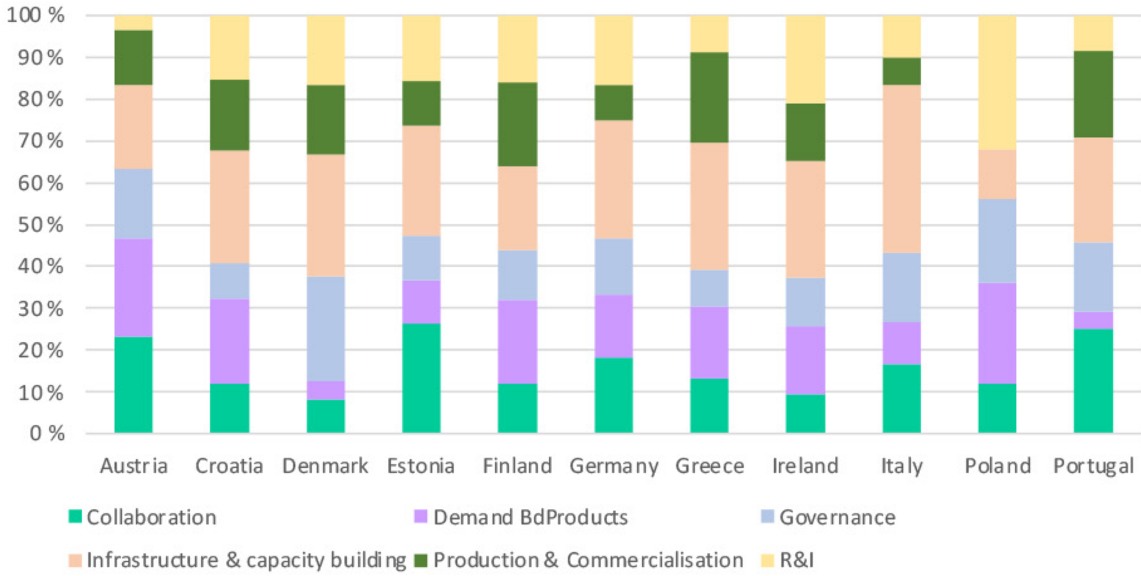
([40]) Data were collected from 44 experts from 33 different organisations in 11 Member States (AT, HR, DK, EE, FI, DE, EL, IE, IT, PL, PT).
([41]) *https://knowledge4policy.ec.europa.eu/visualisation/bioeconomy-different-countries_en.*

Figure 4. Number of policy measures collected from the online survey by block type.



Source: Own compilation based on inputs from the "Knowledge for bioeconomy" Working Group of the European Bioeconomy Policy Forum

Figure 5. Share of bioeconomy enabling policy measures by block type for each Member State.



Source: Own compilation based on inputs from the "Knowledge for bioeconomy" Working Group of the European Bioeconomy Policy Forum

The type of bioeconomy enabling policy measures are equally distributed also across Member States (see Figure 5).

Only Poland did not report any policy measure aiming at promoting the production and commercialization of bio-based products. Interestingly, the analysis indicated a high number of measures at the national level dedicated to support the infrastructure and capacity building in Italy (40% of all the Italian measures identified), Greece (30%), Denmark (29%), Germany (28%), and Croatia (27%). Similarly, a high number of measures dedicated to promote collaboration in Estonia (26%), Portugal (25%) and Austria (23%) was also reported. Other interesting insights include the high number of measures dedicated to facilitate the demand for bio-based products in Poland (24%) and the low number of measures dedicated to facilitate the demand for bio-based products in Denmark (4%) and Portugal (4%).

The specific measures collected for each MS can be explored in the Knowledge Centre for Bioeconomy's website[41].

2.4 Regional bioeconomy strategies

A study commissioned by the JRC mapped and analysed the deployment of strategies related to the bioeconomy at regional level in the EU-27 (Haarich and Kirchmayr-Novak, 2022). According to this study, 194 regions (at NUTS1, NUTS2 or NUTS3 scale) in the EU-27 have in place a strategic framework dedicated to the bioeconomy, or are in the process of doing so. Of these, 28 regions have fully dedicated bioeconomy strategies, while another region is elaborating such a strategy. 62 regions have strategic frameworks with a strong bioeconomy focus, with another 7 regions elaborating such a strategy. Lastly, 94 regions have strategies with minimum bioeconomy content, while another 2 regions are elaborating a strategy of this type (Figure 6).

Overall, there are 359 bioeconomy-relevant strategies at regional level in the EU. Of those, 334 frameworks are published in the form of documents such as strategies, action plans, roadmaps, and the rest are under development. From the strategies published, 32 fully are fully dedicated to the bioeconomy, in 209 the bioeconomy is embedded within a wider strategic framework (e.g. circular economy) while in 83 the bioeconomy is covered within a sectoral strategy (e.g. forestry or waste strategy).

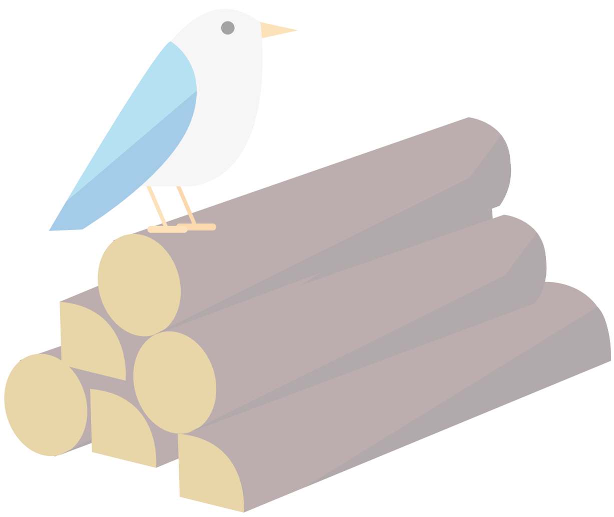
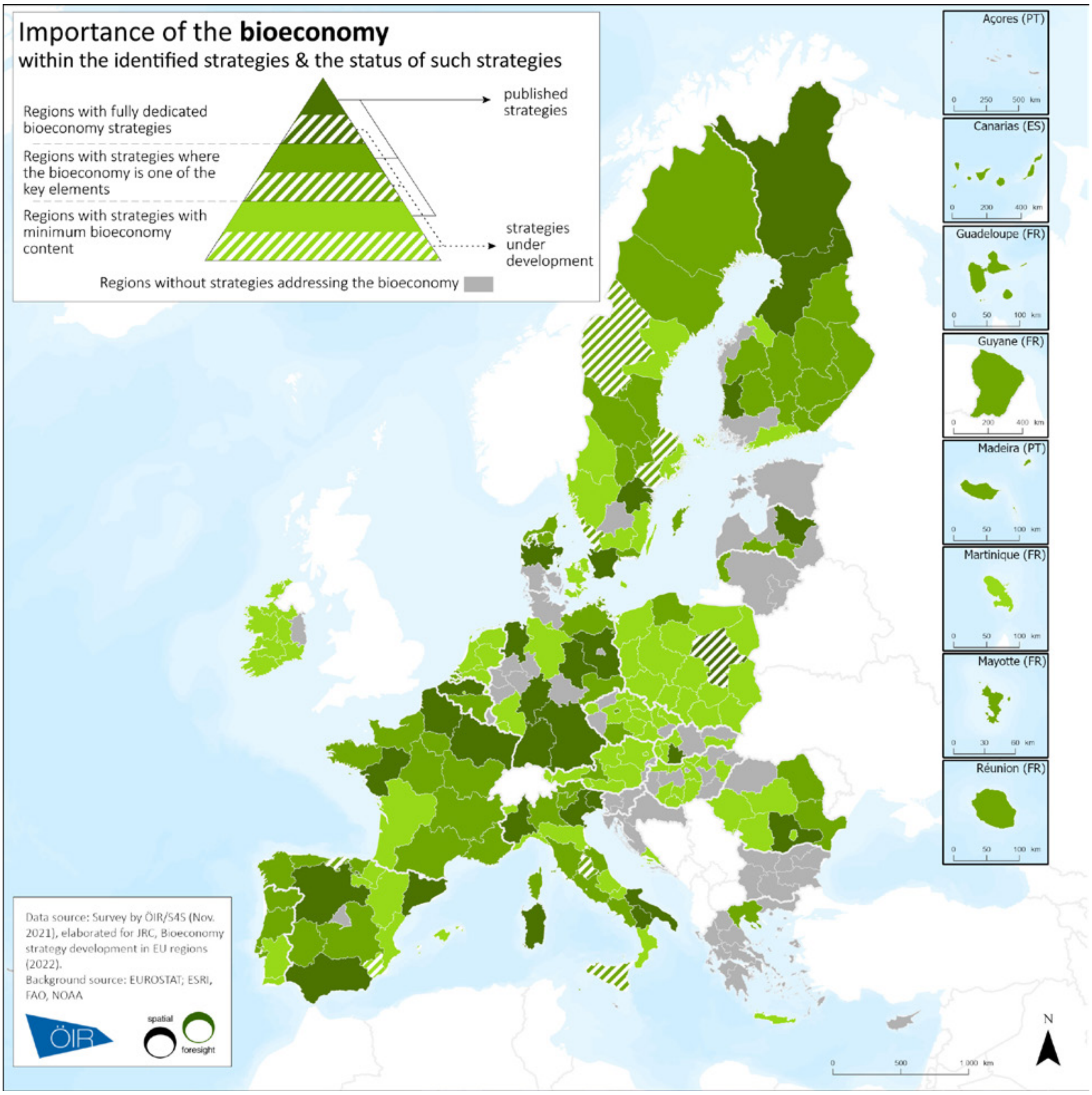


Figure 6. EU regions with bioeconomy strategies



Source: (Haarich and Kirchmayr-Novak, 2022)

In absolute terms, Italy is the country with the largest number of regions with strategies related to the bioeconomy (21), followed by Sweden (20), France (18), Spain (17), Finland (16) and Poland (16). In relative terms, i.e. in relation to the overall number of regions per country, all regions in Belgium, France, Italy and the Netherlands have developed bioeconomy-relevant frameworks.

3 Bioeconomy monitoring

Monitoring systems allow decision makers to assess the performance and progress towards specific strategic objectives that reflect an overall vision. The bioeconomy consists of complex social, economic, and environmental systems. Most direct and indirect impacts are unpredictable, and trade-offs are unavoidable. There is therefore a need for comprehensive, reliable and comparable information on the bioeconomy and its progress to support decision making across sectors and across the EU territory at different scales.

This section describes the rationale behind the EU BMS, the roadmap leading to this first assessment report, and the actual activities that constitute the EU BMS.

3.1 EU BMS as a sensor for effective governance in complexity

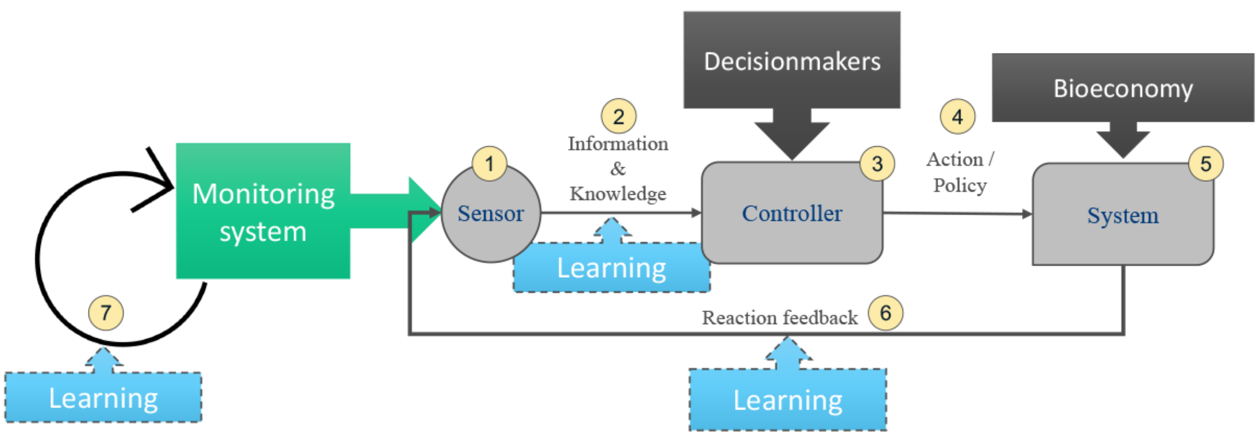
The bioeconomy as a system is inherently unpredictable and thus decision makers need new strategies and tools to steer and govern this complex system towards the desired outcomes. (Giampietro and Bukkens, 2022) poignantly state that governance strategies need to shift from a paradigm of prediction and control to a new paradigm of governance in complexity. Adaptive governance strategies are considered key in this process. (Berkes, 2017) states that: "*Adaptation is a problem-solving process, whereby priority is given to communication, perspective sharing, social learning, negotiation, and the development of adaptive collaborative strategies for moving forward*".

In Figure 7, we depict this process of iterative learning as a cybernetic loop, in which the BMS constitutes the sensor (nr. 1) to provide useful information (nr. 2) to decision-makers (nr. 3) to inform action and policy decisions (nr. 4) to intervene on the bioeconomy system (nr. 5). At the same time the BMS must be able to capture changes in the state of the system following implementation of decisions (nr. 6).

The monitoring system itself cannot be considered a static and "final" item, but it also needs to be flexible and able to change (nr. 7), for instance to adapt to:

- Changes in priorities, concerns, and values, e.g.:
    - Defining 'desirability': e.g. defining the direction of 'progress' or the system aspects to be monitored;
    - Inclusion of unknown knowns within the monitoring ("Uncomfortable knowledge" (Rayner, 2012))
- Changes in understanding of the system:
    - Learning about known unknowns: i.e. filling gaps in indicators;
    - Discovering new relevant unknown unknowns: i.e. including important aspects of the bioeconomy which were unforeseen or unknown in the past iteration.

Figure 7: The role of the BMS in an adaptive governance approach.



Source: own representation

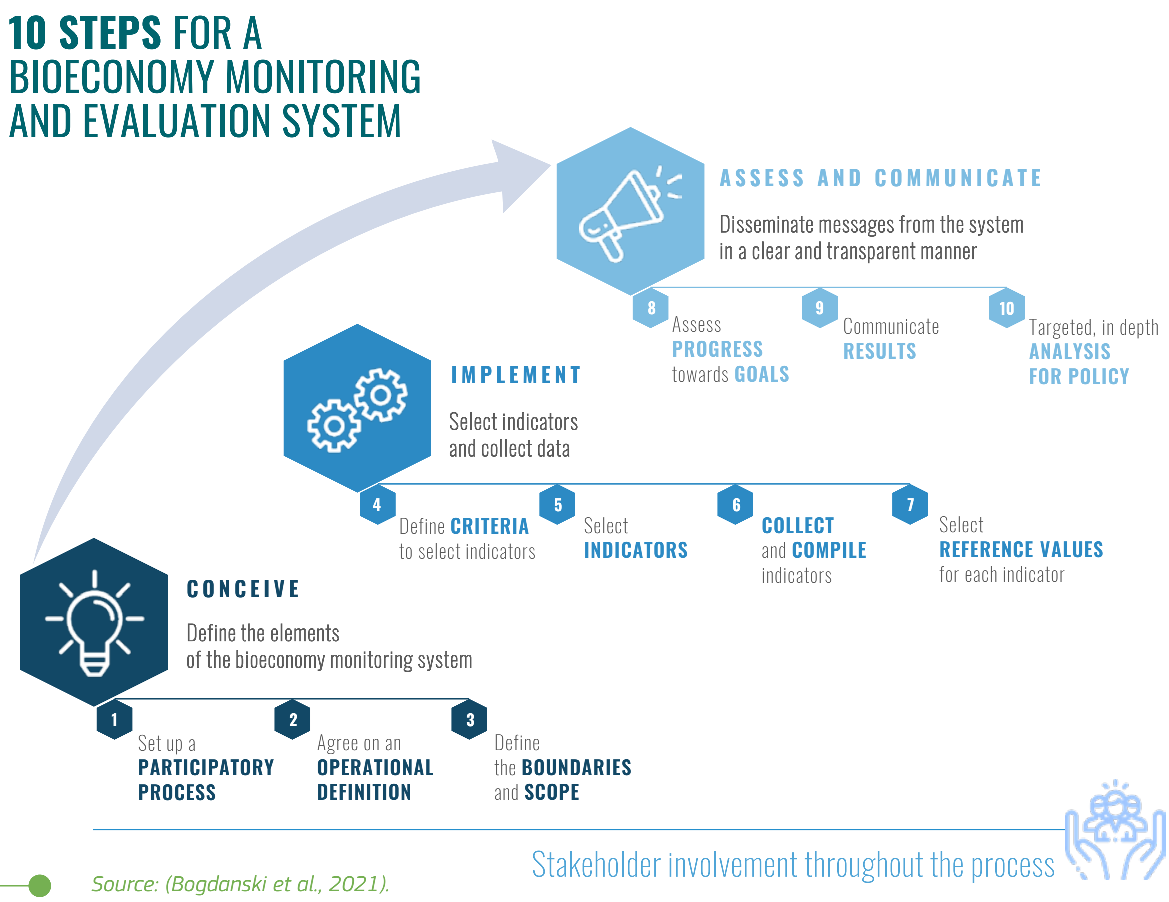
3.2 Roadmap to the BMS

(Bogdanski et al., 2021) provides a general guidance to design and implement an effective monitoring system for a sustainable bioeconomy. The guidance document was produced for policymakers to give general guidelines on how to monitor the sustainability of the bioeconomy at any geographical level and across the globe. In any geographical context, the bioeconomy will encompass the primary production sectors (crop and livestock production, forestry, fisheries and aquaculture) and the ecosystems that supply the primary materials and services to these sectors. It will also comprise secondary production sectors, such as food manufacturing and processing industries; and tertiary (service) sectors, such as research and innovation, the retail sector, the food service industry, and waste management. Thus, parts of the monitoring can be generalised, although as highlighted in Chapter 2, the exact composition of the bioeconomy depends on the context of each country or macro-region. A series of general steps that should be followed to establish an effective and robust system to monitor and evaluate a sustainable bioeconomy were grouped in three stages:

1. A conceptual framework, where all the elements of the monitoring system are defined;
2. An implementation framework, where the conceptual framework is populated with indicators and data collection methodologies are selected; and
3. An assessment and communication framework, where the trends are evaluated and communicated.

These main stages are then disaggregated into ten steps (Figure 8).

Figure 8: General steps toward and effective and robust monitoring system for a sustainable and circular bioeconomy.



Source: (Bogdanski et al., 2021).

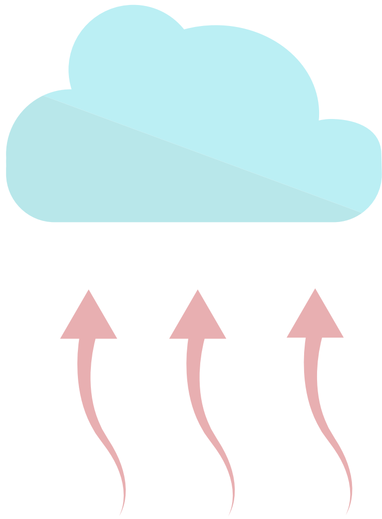
Figure 8 is a schematized description of the process to develop a monitoring system, and does not include the political process of developing the goals and targets of the Bioeconomy Strategies themselves, nor does it include the scientific dimension of developing new indicators. We have learned, based on the practical experience, that ideally indicators are defined and selected to measure progress towards goals. Thus, indicators for Bioeconomy Strategies with concrete goals and possibly targets, are easier to interpret. The basis of this diagram is the participatory process. However here we specify that each member of civil society and other stakeholders must have defined roles in this process.

The EU BMS design and implementation have indeed followed closely these steps and Table 2 summarizes this roadmap as well as all the relevant reports and papers where additional details are provided.

Table 2: Main steps to define and implement the EU BMS and references to literature detailing each step.

Stage	Step nr.	Step definition	Application in the BMS	Relevant References
Conceptual stage	1	Set up a participatory process	Collaboration across academia, institutions, etc..	Workshop reports (Joint Research Centre, 2020; Joint Research Centre, 2019)
	2	Agree on an operational definition of 'sustainable' and 'circular' bioeconomy	Definition of the BMS conceptual framework	Giuntoli et al., 2020; Robert et al., 2020)
	3	Define the boundaries and scope	• Sectorial composition of the Bioeconomy was defined • Multiple geographic scales are considered • Mainly territorial level indicators complemented with product-based ones.	(Robert et al., 2020; Ronzon et al., 2020; Ronzon et al., 2017; Ronzon and M'Barek, 2018)
Implementation stage	4	Define criteria to select indicators	Selection criteria defined	(Giuntoli et al., 2020)
	5	Select indicators	List of indicators (and gaps) collected based on existing data sources, internal research, and participatory process	(Giuntoli et al., 2020; Robert et al., 2020)
	6	Collect and compile indicators	• Indicator datasets and relevant metadata collected in a database and public dashboard • Research work to compile new indicators to fill gaps	Camia et al., 2018; Kilsedar et al., 2022; Melin-McCleod et al., 2022; Ronzon et al., 2020; Ronzon and M'Barek, 2018)
	7	Select reference values for each indicator	Definition of 'directionality' for each indicator	(Giuntoli et al., 2020; Robert et al., 2020)
Assessment and Communication stage	8	Assess progress towards goals		This report
	9	Communicate results		This report
	10	Targeted, in depth analysis for policy		This report

Source: Own compilation.



3.3 Capturing a vision for a sustainable bioeconomy: the BMS conceptual framework

Combining the 5 EU Bioeconomy objectives, with the Principles & Criteria from FAO (FAO, 2021), we produced a conceptual framework that operationalizes a vision for a sustainable and circular bioeconomy (Figure 9), including three hierarchical levels:

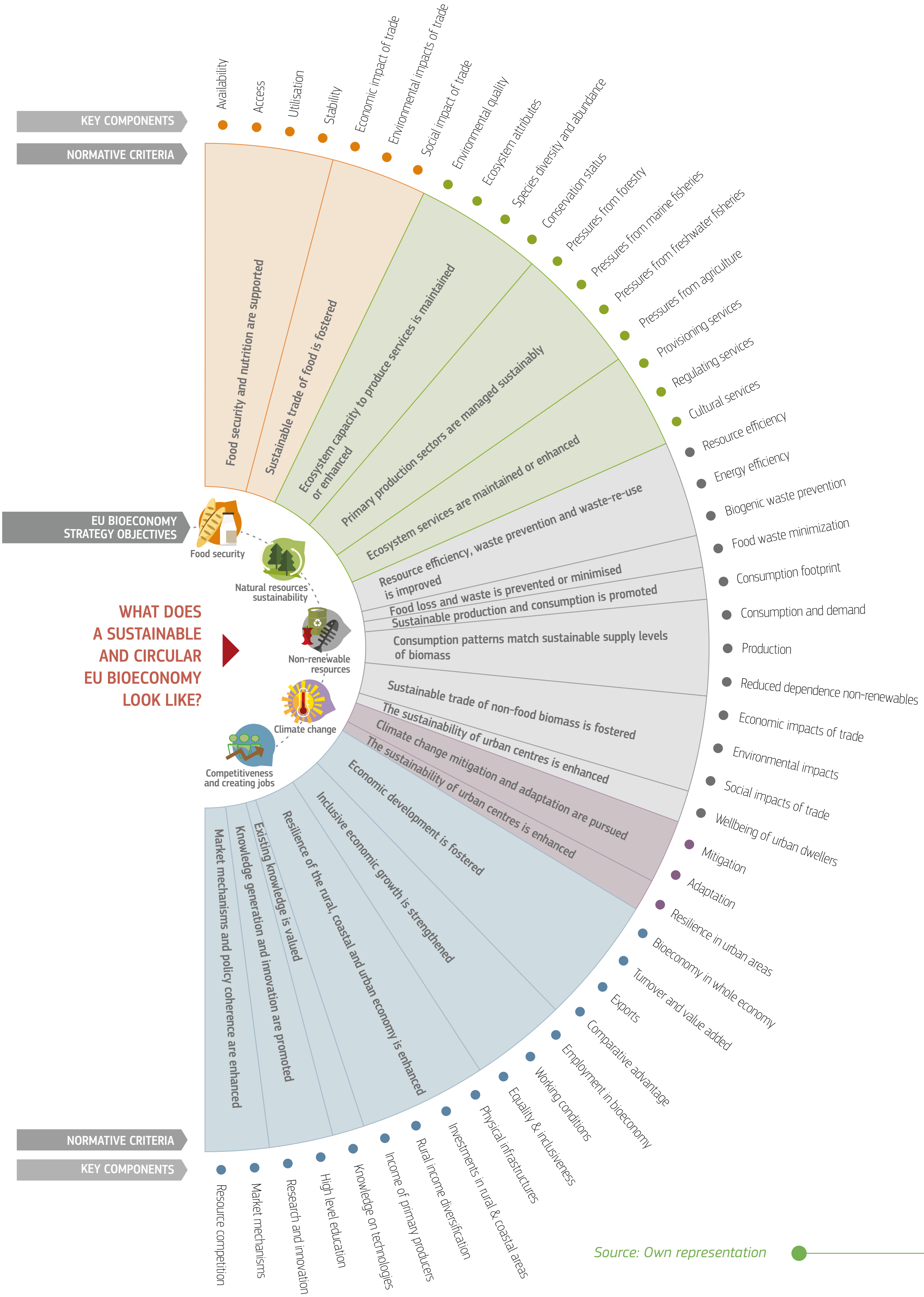
1. Objectives: the overarching objectives set by the s trategy,
2. Normative Criteria (NC): defining how each objective can be achieved,
3. Key Components (KC): reflecting more specific aspects within each criterion.

A more detailed description of the process and ideas that led to the framework can be found in (Giuntoli et al., 2020; Robert et al., 2020).

The role of the conceptual framework in the BMS is crucial for several reasons (Bogdanski et al., 2021):

- To build a concrete vision of a sustainable and circular bioeconomy that can be easily shared, discussed, and interpreted among different stakeholders;
- To ensure that the holistic nature of the bioeconomy is captured in as comprehensive manner as possible;
- To enable the disaggregation of various aspects of the bioeconomy, which are often interlinked, and highlight the trade-offs and synergies that have been identified through the selected indicators.

Figure 9: Visualization of the conceptual framework developed for the EU BMS.



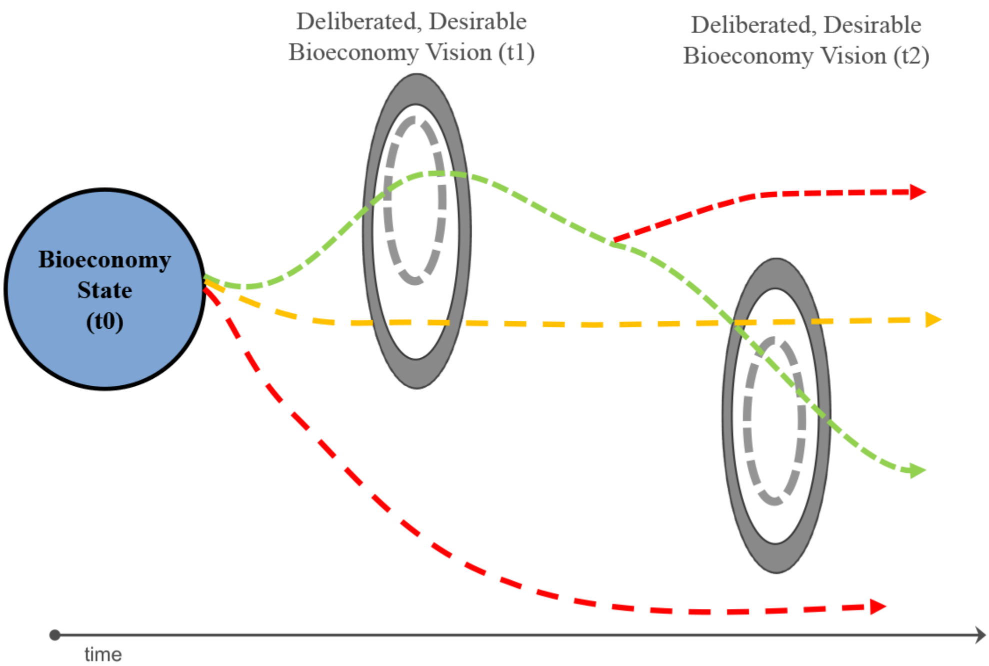
Source: Own representation

As discussed in detail in (Giuntoli et al., 2023) the current framework reflects the political priorities expressed in the 2018 EU Bioeconomy Strategy (European Commission, 2018). In practice, this conceptual framework acts as a 'compass' in which the North is constituted by the normative and deliberated vision of a sustainable bioeconomy (Hebinck et al., 2021), and thus it actually gives meaning to the indicators and interprets their trends as 'positive' or 'negative' progress.

Nonetheless, this framework cannot be considered itself to be a static and final element, but rather this compass will need to be calibrated often as priorities, concerns and imaginaries are context-dependent and are likely to change in time. We argue that this compass can only be effective if: 1) the 'North' is well-defined, and 2) if the compass is well calibrated. Figure 10 illustrates this concept. Starting from an initial bioeconomy state at time t0, the Deliberated and Desirable Vision, captured in the framework, works as a constraint telling us which pathways are considered desirable (green dashed line) and which ones are not (red dashed line). This vision might change in time (t2) as priorities, concerns and imaginaries are context-dependent and are likely to change (Oliver et al., 2021). The second argument is that the compass must be well-calibrated, that is there should not be significant blind spots. Epistemic boxing and framing of the issues at hand is unavoidable when dealing with complex systems, and thus some concerns or knowledge claims will be unavoidably left out of the deliberated vision (the 'North'). However, if this 'uncomfortable knowledge', once included, were to restrict our desirable pathway (the grey dashed circle), then we would be suffering from hypocognition, i.e. following the orange pathway. Although it may be that not everything needs to be recalibrated if the normative criteria already set represents the normative structure in our society (in which case it is sufficient to change indicators or weighting of these), we must be agile enough to incorporate a complete change in paradigm.

For both issues described above, frequent and inclusive discussions and deliberations about a desirable bioeconomy are essential to make sure that this vision is suited to each context and time period (point 1) as well as to fight hypo-cognition (point 2). (Giuntoli et al., 2023) present an initial discussion around this theme.

Figure 10: Illustration of possible trajectories of the EU Bioeconomy State across time and how visions can act as compass to evaluate the Bioeconomy sustainability and desirability.



Source: Own representation

3.4 Bioeconomy monitoring at JRC

It is at this point appropriate to define the Bioeconomy Monitoring activities at the JRC. The BMS has an important role, but other on-going activities also contribute to a better understanding of the Bioeconomy and its trends (Figure 11).

1. Monitoring component (the actual BMS):

This includes the conceptual framework from section 3.3, as well as the whole set of indicators and their metadata, including the gaps and placeholders (known unknowns). This component is summarized in an online dashboard[42] where all indicators and their trends are provided for a detailed and real-time evaluation of the multiple aspects of a sustainable bioeconomy.

2. Assessment and communication component:

This is a periodical evaluation and interpretation of the progress of the EU bioeconomy condensed into an assessment report. This report, especially in Chapter 4, constitutes the first such assessment. As a side note, the aim would be to have the assessment as an integral part of the monitoring system. Assessments could follow a template and be repeated periodically. To get to this stage however, a participatory approach should be adopted to decide on how to present results on a regular basis. At this time, the BMS is still not fully established, thus the assessments remain ad hoc and separate from the monitoring system itself.

3. Research component:

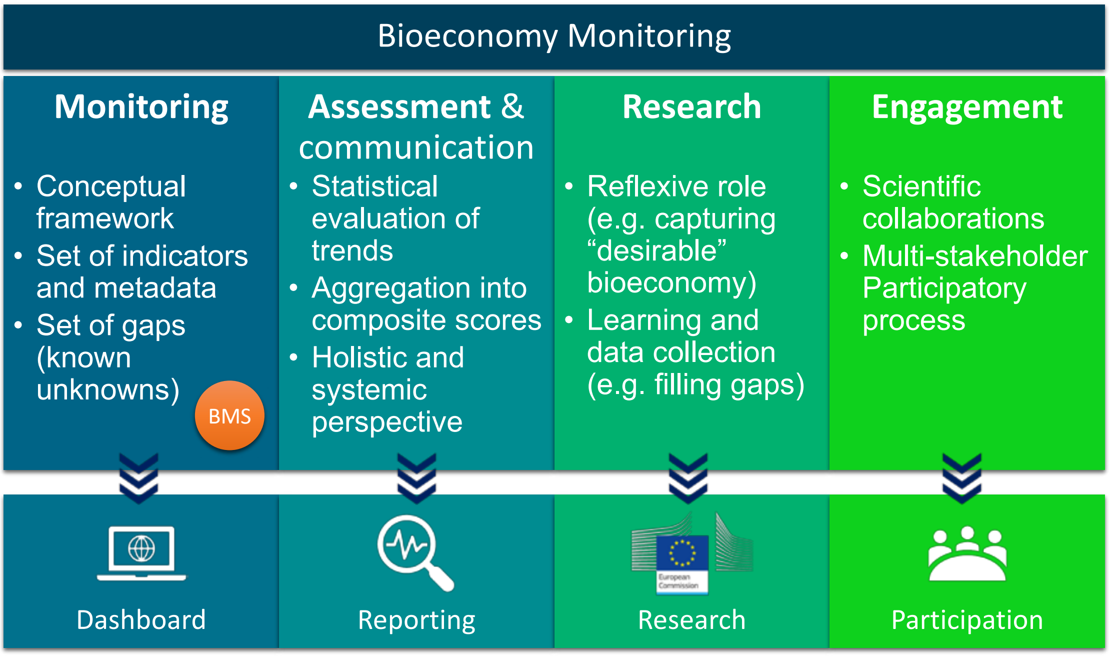
This is an on-going set of research activities carried out at JRC which can be summarized as focusing on: understanding the social-ecological outcomes of the EU Bioeconomy, and reflecting on the normative basis for the Bioeconomy. Activities which contribute to data collection, filling of gaps in indicators, and progressing the understanding of the bioeconomy as a system fit in the former category, while the latter activities focus on capturing aspects of a 'desirable' bioeconomy emerging from the broader societal context and translating them into the conceptual framework (Giuntoli et al., 2023). Chapter 5 of this report presents relevant research activities at JRC that contribute to further the understanding of the bioeconomy and its sustainability.

4. Engagement component:

This is a set of activities which aims at fostering scientific collaborations with other institutions and scientists, for instance by collaborating in defining new indicators (Melin-McCleod et al., 2022; Sanchez-Jerez, Raftoyannis, and Rihimaki, 2023) or new approaches for the assessment of the bioeconomy (as in Chapter 5.2). So far, the JRC has leveraged the expertise of a broad scientific community at the beginning of the BMS project (Joint Research Centre, 2020; Joint Research Centre, 2019; Robert et al., 2020) and has actively engaged with Member States.

([42]) *https://knowledge4policy.ec.europa.eu/visualisation/eu-bioeconomy-monitoring-system-dashboards_en*

Figure 11: Activities for Bioeconomy monitoring.



Source: Own representation

4 Current state of the EU bioeconomy and historical trends

This Chapter presents a quantitative analysis of the indicators currently published in the EU BMS dashboard[43]. The dashboards are continuously evolving as new data becomes available and the status is reported annually (Kilsedar et al., 2023; Kilsedar et al., 2022; Kilsedar et al., 2021). The reason for this continuous evolution lies in the philosophy behind the BMS. Instead of favoring a data-driven approach, whereby the monitoring system would have been based on the ready availability of indicators, or at least the data to produce them, we favored an approach based on a conceptual framework. This has the advantage of portraying a holistic picture of bioeconomy by allowing for meaningful aggregation through its nested approach (assuming the framework is fully filled), however it has the disadvantage of there being room for "wishful" indicators, which in practical terms, mean gaps. Thus, in this section, we present a partial view of what we would consider the whole system, simply because not all the indicators we would need to understand the full system are available.

We also present trends in the individual indicators. While they may not provide a holistic view, they provide insights on the different facets of bioeconomy, particularly when presented as a set of scoreboards grouped by Strategy Objectives, as we do in the following sub sections. The scoreboards presented here are meant to provide the readers with an overview of the main trends for many individual aspects of the bioeconomy. However, no matter how complete and comprehensive the dashboards might be, the indicators are still single pieces of a much bigger puzzle. For instance, the trends presented in this chapter focus only on recent tendencies, but they are not necessarily contextualized, e.g. even if recent trends are positive, are they fast enough to achieve the socio-ecological desired targets? How far is the current state of the bioeconomy from social and ecological tipping points? These are questions that the current analysis cannot answer yet. Chapter 5.2 presents an approach which can potentially analyse the bioeconomy as an integrated social-ecological system.

FOCUS BOX nr. 2:
JRC Biomass Mandate

An important source of data for the BMS in this, and other biomass-related indicators, is the JRC Biomass Mandate. The JRC Biomass Mandate *https://knowledge4policy.ec.europa.eu/projects-activities/jrc-biomass-mandate_en* is a long-term mandate that has been undertaken in order to provide data, knowledge, models and assessments, covering all sources of biomass, agricultural, forest, marine and freshwater, and waste. It includes an assessment of the impacts of the production and use of biomass, and the competition and the synergies between sectors for biomass resources.

Nonetheless, the scoreboards presented here provide the readers with a comprehensive overview of the state and past trajectories of many areas of the bioeconomy and will highlight areas that might be more in need of direct political interventions or of additional research.

4.1 Methods

The next sections introduce Scoreboards that summarize all indicators currently available in the dashboard. The Scoreboards are presented as disaggregated per Objective and focus on data for the EU-27[44]. The Scoreboards in this

([43]) *https://knowledge4policy.ec.europa.eu/visualisation/eu-bioeconomy-monitoring-system-dashboards_en*
([44]) EU27 composition after 2020.
([45]) *https://knowledge4policy.ec.europa.eu/composite-indicators/coinr_en*

chapter summarize only the main trends of each indicator, a more exhaustive summary of the trends and available datasets can be found in the attached Excel file. From left to right, the Scoreboards capture:

- **The Conceptual framework structure** (see section 3.3 for details): Normative criterion, Key Component, Indicator ID, Indicator Name, Indicator Unit.
    - Notice that all indicators are presented in the Scoreboards. Indicators highlighted in green are fully implemented in the BMS; indicators in grey are either not yet implemented or place-holders; indicators in orange are implemented in the BMS but are either not defined at EU27 level (i.e. only at MS level), or are 'descriptive' and thus their trends cannot be assessed as positive or negative.
- **Trend analysis results:** in these 4 columns the short-term (latest available 5-years) and longer-term (latest available 10-years) trends are assessed. Trends with a change of above +1%/year or less than -1%/year are assessed as Positive or Negative, respectively (according to the normative interpretation). Changes with intermediate intensity are assessed as 'No change'.
    - The trend analysis approach is designed to resemble the analysis in (Maes et al., 2020).
    - For short-term trends the latest 5 years available are considered, starting from the most recent available data point. E.g. if the most recent known data point is 2018, data points from 2014-2018 inclusive are analysed. Similarly, for long-term trends the latest 10 years are considered.
    - If the latest five/ten years series has missing values, then data are interpolated using linear interpolation, with the following rules:
        - Only interpolate, not extrapolate. Missing values are not estimated outside the time range of observed values.
        - The entire time series is interpolated before sub-setting to the latest 5 or 10 years. This means that missing values inside the 5- or 10-year ranges can be interpolated using known data points outside of that range, if they are available.
    - A linear regression is then calculated over the last 5 or 10 data points available. The percent-age change is estimated by an equation which is a simple function of the slope and intercept, specifically:

$$\frac{\%\ change}{year} = \frac{slope \cdot 1}{intercept + slope \cdot \text{first year of the interval}}$$

- **Indicator overview:** the last column presents a sparkline including all available data points for the indicator to give the reader a broader view of the historical trend.
- **Data quality (in Annex):** the Annex presents additional three columns to offer the reader with information to assess the quality of the data and thus of the trend analysis. The overall time series available is reported, and data quality is assessed based on data availability and latest data point available:
    - **GOOD:** Indicates that the data availability for both trend analysis (short and long term) is >80% .
    - **MEDIUM:** Indicates that the data availability for one or both trend analysis is lower than 80% but higher than 50%.
    - **POOR:** Indicates that the data availability for one or both of the two trend analysis is lower than 50%.
    - **TIMELY:** Indicates that the last available data point is from, or more recent than, 2020.
    - **ADEQUATE:** Indicates that the last available data point is between 2017 and 2019.
    - **DATED:** Indicates that the last available data point is earlier than 2017.

In each section below, special Focus Boxes are included to highlight indicators which have specifically designed and calculated for the EU BMS.

Finally, section 0 presents a preliminary aggregation of the available indicators into composite scores at Key Component level. A similar exercise was presented in the 2022 Bioeconomy Progress Report (European Commission, 2022). The normalization, aggregation and trend analysis for the scores available was carried out through the COINr package developed by the JRC[45].

For this preliminary analysis, the scores were calculated only for Key Components where more than 50% of indicators were available compared to the ideal framework (i.e. green indicators vs. green&grey indicators in the Scoreboards). However, in certain cases, even with less than 50% of indicators available, it was judged that the available indicators would be able to provide important and useful information. This resulted in the production of 15 scores, out of the 49 KC present in the current framework.
Ideally, as the BMS is further populated with individual indicators in the future, more aggregated scores will become available as well as possible aggregations at higher hierarchical levels, i.e. at Normative criteria and Objective levels. These will be duly reported in future years.

All data are available in the EU BMS dashboard, and all trend analyses presented below are available in the Excel file in annex to this report.

4.2 Objective 1: Ensuring food and nutrition security

EU Strategy Objective 1 focuses on an essential and core objective of the Bioeconomy: Ensuring food and nutrition security. The Objective structure is divided into two normative criteria:

1.1 Food security and nutrition are supported.

1.2 Local economies, societies and environmental conditions of countries exporting food to the EU are not hampered but rather harnessed by the trade of raw and processed biomass and related technologies

The first criterion mirrors the definition of food security by FAO (FAO et al., 2022) with its four dimensions: Availability, Access, Utilization, and Stability. The second criterion aims to capture instead the social, economic, and environmental impacts of trade of food and feed in third countries.

Figure 12: Scoreboard of indicators for Objective 1.

Normative criteria	Key components	Indicator name	Unit	Short-term period	Short-term trend change (% / year)	Long-term period	Long-term trend change (% / year)	Indicator overview
Food security and nutrition are supported	Availability	Agricultural factor income per annual work unit (AWU)	Index (2010 = 100)	2017-2021	0.76	2012-2021	2.43	
		New food products (by sector)						
		New food value chains (by sector)						
		Total biomass supply for food purposes, including inputs	1000 t of dry matter	2014-2018	0.4	2009-2018	0.09	
		Biomass directly consumed by EU citizens as food	1000 t of dry matter	2014-2018	-0.22	2009-2018	-0.07	
	Access	Prevalence of moderate or severe food insecurity in the total population, yearly estimates	%	2015-2019	4.72	2010-2019	4.72	
		Average dietary energy supply adequacy						
		Food purchasing power	% of GDP	2016-2020	-1.32	2011-2020	0.11	
	Stability	Daily calorie supply per capita by source	kcal/cap/d	2014-2018	0.51	2009-2018	0.12	
		Indicator concerning food quality, or food safety						
		Animal welfare						
	Utilisation	Government support to agricultural research and development (by sector)	€/cap	2016-2020	4.73	2011-2020	1.90	
		EU's self-sufficiency rate on protein for feed						
		Import dependency ratio of food (import/domestic production)						
		Value of food imports over total merchandise exports						
Sustainable trade of food is fostered	Economic impact of trade	Economic impact of trade in exporting countries of food (to EU)						
	Environmental footprints of trade	Social condition in exporting countries of food (to EU)						
	Social impact of trade	Environmental footprints in exporting countries of food (to EU)						

While the coverage of the indicators contributing to understand the trends towards Objective 1 is adequate for an overview of the availability, accessibility and utilisation key components, there are several gaps related to stability and the impacts of trade of food and feed on countries exporting to the EU. Nevertheless, the following interpretations may be made based on the available data:

- Food availability indicators are generally stable in line with the latest food security documents released by the European Commission[46].

- There are variations from year to year in food availability, due to extreme weather events. The total biomass supply for food purposes (see focus box nr. 3), for instance, was fairly stable between 2009 (487.4 million tonnes of dry matter, Mtdm) and 2013 (486.1 Mtdm), before dipping in 2014 (483.2 Mtdm) and growing again to 490.9 Mtdm in 2016. After another dip in 2017 (488.7 Mtdm), this indicator grew again to a peak value of 492.9 Mtdm in 2018, the latest data point currently available. The maximum spread in this indicator, between the minimum in 2014 and the maximum value in 2018 is equal to a 2% change in 5 years, which is why this trend is considered to be largely stable.

- The trend of biomass directly consumed as food is even more stable across the period 2008-2018, albeit with annual fluctuations. This amount was equal to 99.9 Mtdm dry in 2008, growing to a maximum of 101.1 Mtdm in 2016, to a value of 99.3 Mtdm in 2018. This indicator only accounts for the food directly consumed by citizens (see focus box nr. 3), thus excluding food waste and feed for animal farming.

- The indicators within the key component on accessibility to food are showing that the moderate or severe food insecurity decreased in EU27 from 8% in 2015 to 6.5% in 2019. Even though the recent trend for this indicator is clearly positive, almost 30 million European citizens still live under conditions of moderate or severe food insecurity. The effects of the 2020 COVID-19 pandemic as well as the impacts of the 2022 Russian invasion of Ukraine will be visible in the next years due to the lag in reporting.

- The impact of the 2020 COVID-19 pandemic is indeed well visible in the indicator for food purchasing power which includes data for 2020. This indicator captures the nominal expenditure of food and non-alcoholic beverages as % of GDP . While the value of this indicator declined from 2009 to 2019 (positive trend), it rose from a value of 6.8% in 2019 to a value of 7.5% in 2020. This trend is likely the result of the COVID-19 pandemic lockdowns.

- The daily supply of calories in the EU27 has been fairly stable from 2003 to 2013, before decreasing to 3387 kcal/capita/d in 2014. Since then, this value has grown to 3 456 kcal/capita/d in 2018 (+2%). While this overall trend is positive, it is interesting to also assess how this caloric intake is divided between animal and vegetal products. The share of calories from animal products decreased constantly from 2003 (29.9%) to 2013 (28.7%), before growing again to 29.3% in 2018.

- There is an increasing trend in government support to agricultural research in EU MS, both in the short and in the long term.

- While the trends presented in Figure 12 and commented here refer to data aggregated at EU27, there are discrepancies in food and nutrition security between countries within the EU, which are visible in the BMS dashboards where data is presented at MS-level.

- Finally, the trade-related indicators are currently under development in the system. Details on how these indicators will be address is documented in the latest progress report (Kilsedar et al., 2023).

([46]) COM(2022) 133, Safeguarding food security and reinforcing the resilience of food systems: *https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2022:133:FIN* ; SWD(2023) 4, Drivers of food security: *https://commission.europa.eu/system/files/2023-01/SWD_2023_4_1_EN_document_travail_service_part1_v2.pdf*

([47]) It would be more accurate to measure food purchasing power as a share of household disposable income rather than GDP. Especially in 2020, the share over GDP could not be very representative, since household income fell less than GDP, due to government transfers to households.

FOCUS BOX nr. 3:
Total biomass supply for food purposes

This indicator is calculated by estimating food demand in all Member States and the European Union and converting this food demand into raw biomass dry matter equivalents. It includes all types of biomass (agricultural or aquatic) that is used to satisfy food requirements of the citizens of the EU. Food produced to be exported is excluded, as well as all waste that takes place before the food is available to consumers. Consumption waste is included in the estimated quantity; that is, some of this biomass will be wasted in the consumption phase. The source data for this indicator is extracted from the EU Biomass Flows (Gurría et al., 2022), produced by the JRC in the context of the Biomass mandate.

Data for this indicator can be navigated and downloaded from
https://knowledge4policy.ec.europa.eu/visualisation/eu-bioeconomy-monitoring-system-dashboards_en?indicatorId=1.1.a.4

The full data can be navigated and downloaded from
https://knowledge4policy.ec.europa.eu/visualisation/biomass-flows_en

FOCUS BOX nr. 4:
Biomass directly consumed by EU citizens by source (animal, fish, plant-based, algae)

This indicator estimates the quantity of food, in raw biomass dry matter equivalents, that is consumed by the citizens of the EU. Consumption waste is excluded from the total quantity. This indicator is calculated by estimating food demand in all Member States and the European Union and converting this food demand into raw biomass dry matter equivalents, excluding food waste. In this case, the consumed food is differentiated by source (agricultural or aquatic). The source data for this indicator is extracted from the EU Biomass Flows (Gurría et al., 2022), produced by the JRC in the context of the Biomass mandate.

Data can be navigated and downloaded from
https://knowledge4policy.ec.europa.eu/visualisation/eu-bioeconomy-monitoring-system-dashboards_en?indicatorId=1.1.a.5

The full data can be navigated and downloaded from
https://knowledge4policy.ec.europa.eu/visualisation/biomass-flows_en

4.3 Objective 2: Managing natural resources sustainably

Bioeconomy sectors depend directly on healthy and resilient ecosystems to supply biomass resources and the other services they depend on. The awareness that human societies and the biosphere are uniquely linked into complex systems and that human societies rely on healthy ecosystems to survive (Folke et al., 2016) has been one of the main drivers for the current sustainability transition embedded in the European Green Deal. Despite substantial benefits delivered by EU environment and climate policies over recent decades, Europe is facing persistent environmental challenges. The recent MAES assessment (Maes et al., 2020) has revealed that terrestrial and marine ecosystems in Europe are under strain mainly due to direct or indirect anthropogenic stressors, such as pollution, persistent human interventions, and climate change.

In response to this, the EU Bioeconomy Strategy presents Objective 2, which aims to lower the pressures on natural ecosystems, increase protection for ecosystems and species, and enhance ecosystems' functions and biodiversity.

The structure of Objective 2 borrows strongly from the exercise carried out in the MAES assessment (Maes et al., 2020). Therefore, the objective is divided into three main criteria:

- **2.1** Ecosystem capacity to produce services is maintained or enhanced
- **2.2** Primary production sectors are managed sustainably
- **2.3** Ecosystem services contribution to human well-being is maintained or enhanced

These criteria reflect a cause-effect chain where pressures, captured in criterion 2.2, affect the conditions of ecosystems, captured in criterion 2.1, which in turn influence the quantity and quality of ecosystem services delivered (captured in criterion 2.3).

Normative criteria	Key components	Indicator name	Unit	Short-term period	Short-term trend change (% / year)	Long-term period	Long-term trend change (% / year)	Indicator overview
Ecosystem capacity to produce services is maintained or enhanced	Environmental Quality	Biochemical oxygen demand in rivers	mgO2 / l	2014-2018	0.29	2009-2018	2.06	
		Phosphate in rivers	mgPO4 / l	2014-2018	-1.81	2009-2018	1.07	
		Phosphorus in lakes						
		Nitrate in groundwater	mgNO3 / l	2014-2018	-0.74	2009-2018	-0.58	
		Nitrate in rivers						
		Nutrients in transitional, coastal and marine waters						
		Exposure of forest area to ozone						
		Exceedance of air quality standards in urban areas						
		Percentage area of urban green space (or percentage of natural area within the city boundaries)						
	Structural and functional ecosystem attributes	Landscape fragmentation Index						
		Share of High Nature Value farmland in agricultural area						
		Share of organic farming in utilised agricultural area	%	2016-2020	7.06	2011-2020	7.69	
		Livestock density index	unit per ha					
		Forest fragmentation and connectivity index						
		Deadwood						
		Share of forest area						
		Forest and other wooded land growing stock	1000 m³	2016-2020	0.61	2011-2020	0.99	
		Ecological status of European waters						
		Fish stock biomass in NE Atlantic & Mediterranean						
	Species diversity and abundance	Common Farmland bird Index	Index, 2000 = 100	2014-2018	-0.30	2009-2018	-0.54	
		Common Forest bird Index	Index, 2000 = 100	2014-2018	1.28	2009-2018	1.01	
		Grassland butterflies Index	Index, 2000 = 100	2013-2017	0.89	2008-2017	-0.68	
		Age and size distribution of commercially-exploited fish species						
	Conservation status of habitats and species	Surface of marine sites designated under NATURA 2000	km^2	2016-2020	9.51	2011-2020	20.20	
		Surface of terrestrial sites designated under NATURA 2000	km^2	2016-2020	0.08	2011-2020	0.08	
		Conservation Status of European Habitats						
		Conservation status of grassland						
		Threatened tree species in forests						

Normative criteria	Key components	Indicator name	Unit	Short-term period	Short-term trend change (% / year)	Long-term period	Long-term trend change (% / year)	Indicator overview
Primary production sectors are managed sustainably	Pressures from forest management	Ratio of annual fellings (m³/ha/year) to net annual increment (m³/ha/year)	-	2011-2015	-2.59	2006-2015	-1.15	
		Fraction of primary residues remaining in forest						
		Change in ecosystems extent: Forest and woodland						
		Land use / land cover type taken over by forest						
		Number of annual introductions of invasive alien species in forests						
		Certified forests						
	Pressures from Marine fisheries & aquaculture management	Nutrient discharge from fisheries aquaculture						
		Fishing mortality of commercially exploited fish and shellfish exceeding fishing mortality at maximum sustainable yield - North-East Atlantic	F/F_MSY	2014-2018	3.43	2009-2017	2.30	
		Fishing mortality of commercially exploited fish and shellfish exceeding fishing mortality at maximum sustainable yield - Mediterranean & Black Sea	F/F_MSY	2013-2017	1.55	2008-2017	0.27	
		Number of annual introductions of invasive alien species in marine waters						
	Pressures from Freshwater fisheries & aquaculture management	Number of annual introductions of invasive alien species in freshwater						
		Size of aquaculture production units						
		Number of integrated multi-trophic aquaculture production units						
	Pressures on agroecosystems	Ammonia emissions from agriculture						
		Land use / land cover type taken over by agricultural land						
		Change in ecosystems extent: cropland & grassland						
		Number of annual introductions of invasive alien species in agroecosystems						
		Intensification of farming (share of low input farms in UAA)	%	2013-2017	-2.97	2008-2017	-2.55	
		Sales of pesticides						
Ecosystem services contribution to human well-being is maintained or enhanced	Provisioning services	Biomass production in EU from primary production sectors: Agriculture	tonnes of dry matter	2013-2017	1.08	2008-2017	1.50	
		Biomass production in EU from primary production sectors: Fisheries	tonnes of dry matter	2012-2016	2.77	2007-2016	-0.30	
		Biomass production in EU from primary production sectors: Forestry	tonnes of dry matter	2013-2017	1.35	2008-2017	1.61	
		Roundwood removals	m³ solid volume over bark	2016-2020	1.96	2011-2020	1.70	
	Regulating services	Flood regulation (flood control, flow, demand, potential, unment demand, monetary values)						
		Air quality						
		Net ecosystem productivity						
	Cultural services	Aesthetics considerations of nature						
		Recreational services (recreation, flow, demand, potential)						

Figure 13: Scoreboard of indicators for Objective 2

The indicators in this Objective are meant to provide a meaningful overview of the state of ecosystems, and especially of the Pressures associated to primary production sectors closely associated to the Bioeconomy. However, they are not meant to substitute the in-depth assessment and monitoring carried out by other exercises and we refer the reader to the MAES assessments to have a full picture of the state of European ecosystems.

Among the key findings from the indicators in Figure 13, we point out that:

- Indicators for provisioning services show a clear positive trend. Overall biomass production from agriculture, fisheries, and forestry has increased. These trends are not surprising given the expansion of the bioeconomy and the subsequent increase in demand for raw biomass from ecosystems.

- Biomass production from agriculture increased from 634 Mtdm in 2009 to 704 Mtdm in 2017 (+11%). Biomass production from forestry increased from 208 Mtdm in 2009 to 248 Mtdm in 2017 (+19%). While biomass production from fisheries decreased from 1.46 Mtdm in 2009 to 1.42 Mtdm in 2017 (-2.9%).

- Looking at the pressures placed by primary production sectors over ecosystems, the limited amount of indicators currently available are focused on pressures from forest management (i.e. Ratio of annual fellings to net annual increment) and from agriculture (i.e. Share of low input farms in UAA). Both indicators show continued negative trends. For instance, the share of low input farms in the overall UAA has decreased from a maximum of 34.5% in 2009 down to a share of 27% in 2017. This trend is accompanied by a smaller increase in high-input farms (33.9% in 2009 to 36.3% in 2017) and a larger increase in medium-input farms (31.6% in 2009 to 36.7% in 2017).

  The ratio of fellings to NAI has been stable around 70% from 2003 to 2008, before dipping in 2009 to 64% after the economic crisis. The value recovered to 68% already in 2010, before growing steadily to 75% in 2014. The overall fellings rate at EU level has been increasing within the last decade. The increasing impact of natural disturbances and the recent increase of the harvest demand may further reduce the marginal share of increment available for wood supply. The overall removals estimated at EU level are still partially underestimated, this is discussed in detail in Avitabile et al (2023).

- On the other hand, indicators on exploitation levels of fisheries show positive trends, more markedly for the North-East Atlantic area where exploitation levels of fish stocks have been decreasing for all the recorded period (2003-2018), from a value of 1.7 down to 1.0. For the Mediterranean & Black sea areas, exploitation levels have been fluctuating in the same period, starting from a value of 2.4 in 2003, raising to a peak of 2.7 in 2011, then decreasing again to 2.4 in 2017.

- Biodiversity indices show stable conditions for farmland birds and grassland butterflies, but their values are unfortunately stable on a much-degraded state compared to the past. Indeed (Maes et al., 2020) indicate both short and long term trends of these indicators as degrading. For instance, common farmland birds abundance in 2018 is almost 17% lower compared to the year 2000, and almost 30% lower compared to 1990. Grassland butterflies abundance in 2018 is almost 26% lower compared to the year 2000 and a staggering 39% lower compared to 1990. On the contrary, the index for common forest birds shows a promising positive trend that continues from a minimum value recorded in 2006, to a value in 2018 which is the highest over the whole recorded period (1990 – 2018), almost 4% higher than the value for the year 1990.

- Marine protected areas continue to increase markedly, increasing by 2.5 times from 177 468 km2 in 2013 up to 450 752 km2 in 2020. Terrestrial protected areas also continue to increase, but at a very low rate, from a surface of 760 542 km2 in 2013 to a value of 764 222 km2 in 2020 (+0.5%), now accounting for 18.5% of Europe's area. While these trends are positive developments, it must be noted that the extent of protected areas is not necessarily correlated to lower pressures or improved condition (see point 5.112 of United Nations, 2021)

4.4 Objective 3: Reducing dependence on non-renewable, unsustainable resources

This Objective reflects the goal for an EU Bioeconomy that follows sustainable production and consumption principles along the value chain as well as circular economy principles. Objective 3 includes six main criteria:

- **3.1** Resource efficiency, waste prevention and waste-re-use along the whole bioeconomy value chain is improved.
- **3.2** Food loss and waste is minimised and, when unavoidable, its biomass is reused or recycled.
- **3.3** Bioeconomy should promote sustainable production and consumption of biomass and bio-based products (within EU).
- **3.4** Consumption patterns of bioeconomy goods match sustainable supply levels of biomass.
- **3.5** Local economies of countries exporting non-food commodities to the EU are not hampered but rather harnessed by the trade of raw and processed biomass and related technologies.
- **3.6** The sustainability of urban centres is enhanced.

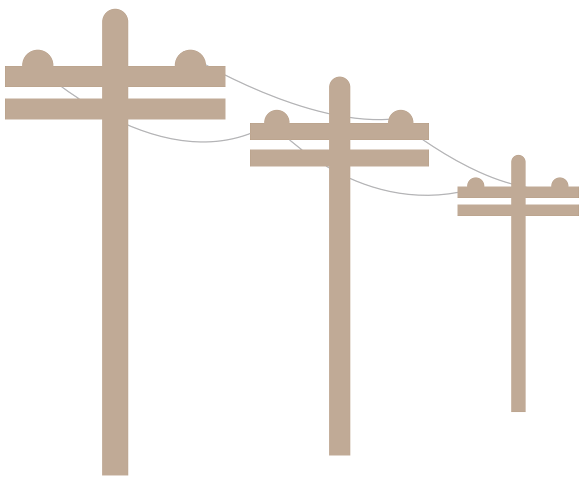
Objective 3 is very heterogeneous in its composition. The first criterion covers issues related to the efficiency of use of biomass resources across the EU economy by looking into material footprint and domestic material consumption of biomass materials. Additionally, the first criterion focuses on biogenic waste management, and circular use of resources, including cascading use of woody materials.

The second criterion illustrates food waste generation along the supply chain and disaggregated by specific food categories.

The third criterion is still work in progress, but once defined, it will detail the environmental impacts of the total EU consumption of bio-based products.

The fourth criterion is a more descriptive one, where trends in supply and use of different biomass types are detailed.

The fifth and sixth criteria are still work in progress: they aim to capture impacts of trade of non-food biomass in third countries (3.5) and the contribution of biomass, e.g. through urban trees and green areas, to the well-being of urban citizens.



Normative criteria	Key components	Indicator name	Unit	Short-term period	Short-term trend change (% / year)	Long-term period	Long-term trend change (% / year)	Indicator overview
Resource efficiency, waste prevention and waste-re-use along the whole bioeconomy value chain is improved	Resource efficiency (Material footprint)	Domestic Material Consumption (Biomass)	% of total Domestic Material Consumption	2017-2021	-0.96	2012-2021	-0.37	
		Material Footprint (Biomass)	kg/$ of GDP	2015-2019	1.23	2010-2019	1.69	
		Land footprint in EU of EU consumption (for non-food&feed)						
	Energy Efficiency	Energy productivity	€ per kg of oil equivalent	2016-2020	2.52	2011-2020	2.16	
		Share of renewable energy in gross final energy consumption	%	2016-2020	5.52	2011-2020	4.47	
		Share of renewable energy in gross final energy consumption of bio based industries or bioenergy industries						
	Biogenic waste prevention, re-use/ recycling, and recovery	Cascading factor of wood resources - Share of secondary woody biomass used in material industry	% of woody biomass used in material industry	2013-2017	0.11	2008-2017	-0.88	
		Circular material rate	%	2016-2020	2.75	2011-2020	1.82	
		Total energy supply from municipal waste						
		Recycling rate of municipal waste	%	2015-2019	1.39	2010-2019	3.03	
		Biowaste generated by source: Households	kg dry	2014-2018	-1.18	2009-2018	-0.56	
		Biowaste generated by source: Industrial and Agricultural	kg dry	2014-2018	-1.33	2009-2018	-0.32	
		Biowaste generated by source: Total	kg dry	2014-2018	-1.27	2009-2018	-0.42	
		Biowaste recovered by source: Households	kg dry	2014-2018	4.17	2009-2018	4.35	
		Biowaste recovered by source: Industrial and Agricultural	kg dry	2014-2018	1.91	2009-2018	0.90	
		Biowaste recovered by source: Total	kg dry	2014-2018	2.70	2009-2018	2.04	
Food loss and waste is minimised and, when unavoidable, its biomass is reused or recycled	Food loss and waste minimization	Food waste along supply chain: Total	tonnes	2015-2019	-0.24	2010-2019	-0.24	
		Food waste along supply chain: Primary Production	tonnes	2015-2019	0.58	2010-2019	-0.38	
		Food waste along supply chain: Processing and Manufacturing	tonnes	2015-2019	-0.60	2010-2019	-0.34	
		Food waste along supply chain: Retail and Distribution	tonnes	2015-2019	-0.52	2010-2019	-0.30	
		Food waste along supply chain: Consumption	tonnes	2015-2019	-0.28	2010-2019	-0.18	
		Food waste by food category: Cereals	tonnes	2015-2019	-1.14	2010-2019	-0.84	
		Food waste by food category: Dairy	tonnes	2015-2019	0.00	2010-2019	-0.25	
		Food waste by food category: Eggs	tonnes	2015-2019	0.53	2010-2019	-0.08	
		Food waste by food category: Fish	tonnes	2015-2019	-1.09	2010-2019	-0.08	
		Food waste by food category: Fruits	tonnes	2015-2019	-0.81	2010-2019	-0.48	
		Food waste by food category: Meat	tonnes	2015-2019	-0.26	2010-2019	-0.21	
		Food waste by food category: Oilcrops	tonnes	2015-2019	-3.39	2010-2019	-1.95	
		Food waste by food category: Potatoes	tonnes	2015-2019	0.92	2010-2019	0.66	
		Food waste by food category: Sugarbeets	tonnes	2015-2019	0.93	2010-2019	0.19	
		Food waste by food category: Vegetables	tonnes	2015-2019	0.73	2010-2019	-0.10	

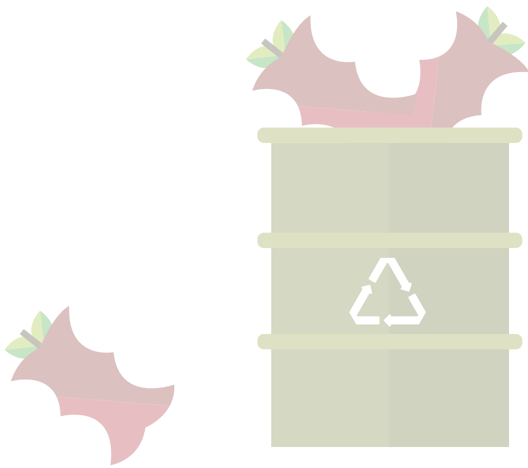


Figure 14: Scoreboard of indicators for Objective 3

Normative criteria	Key components	Indicator name	Unit	Short-term period	Short-term trend change (% / year)	Long-term period	Long-term trend change (% / year)	Indicator overview
Sustainable production and consumption is promoted	Bio-based products environmental impacts	Environmental impacts based on product-based LCA and basket of representative products of the bioeconomy						
Consumption patterns of bioeconomy goods match sustainable supply levels of biomass	Consumption and demand for biomass and bio-based products	Import dependencies for energy (wood, biofuels, bioenergy)						
		Total biomass consumed for energy						
		Total biomass consumed for materials						
		Share of woody biomass used for energy	%	2013-2017	0.36	2008-2017	-0.59	
	Production of bio-based products	Liquid biofuels production (bioethanol, pure biogasoline, biodiesel, bio jet kerosene and other liquid biofuels)						
		Biogasses (indigenous) production						
		Production of bio-based materials (plastics, textiles, chemicals)						
		Advanced biofuels production						
	Reduced dependence on non-renewable resources	Share of renewables for transport, electricity and heating & cooling	%	2015-2019	2.64	2010-2019	3.93	
		Total consumption of energy, including fossil-based						
		Share of wood-based constructions						
		Share of consumption of bio-based plastics, textiles and chemicals						
Sustainable trade of non-food biomass is fostered	Economic impact of trade in exporting countries of non-food (to EU)							
		Economic impact of trade in exporting countries of non-food (to EU)						
	Environmental footprints in exporting countries of non-food (to EU)							
		Environmental footprints in exporting countries of non-food (to EU)						
	Social impact of trade in exporting countries of non-food (to EU)							
		Social condition in exporting countries of non-food to EU						
The sustainability of urban centres is enhanced	Enhanced well-being and health of urban dwellers	Self-assessed satisfaction with recreational and green areas						
		Self-assessed satisfaction with living environment						
		Self-assessed overall life satisfaction						

- Trends for resource and energy efficiency are largely positive. For instance, the mass of biomass consumed to generate GDP has decreased in the short and medium term, from 0.19 kg biomass/USD of GDP in 2009 down to 0.15 kg biomass/USD of GDP, although the overall domestic material consumption of biomass in Europe has remained rather constant and so has the share of biomass over the total material throughput of the European economy (22.3% in 2009 to 22.9% in 2019). Similarly, energy productivity and renewable energy use across the whole economy have greatly increased. Even though these indicators are taken as proxies to reflect trends also in bioeconomy sectors, the values specific to bioeconomy industries are not yet available; JRC is working to produce a dedicated indicator to account for the share of renewable energy used in bio-based sectors (Melim-Mcleod et al., 2022)

- Biowaste generation has been increasing in the last 5 years, from a value of 145.4 Mtdm in 2012 to 147.1 Mtdm in 2018, although so has the fraction of biowaste recovered, growing from 83% in 2012 to 90.4% in 2018.

- The generation of food waste does not show any significant change in time in any specific step of the supply chain, amounting to a total value of 84 Mt in 2009 and to 82.6 Mt in 2019.
  For the latest data available (2019), the large majority of food waste was generated in the final consumption step (63.3%), followed by processing and manufacturing sectors (17.5%), primary production (12.1%), and retail and distribution (7.1%).
  Among food categories, in 2019, the majority of food waste consisted in fruits (26.6%), vegetables (20.1%), cereals (12.8%), meat (10%), potatoes (9.8%), dairy (8.8%), and others (11.9%).

- The total consumption of biomass for energy and materials has been increasing constantly between 2009 – 2017. Biomass consumption for energy increased from 154.9 Mtdm in 2009 to 207.3 Mtdm in 2017 (+33.8%). Biomass consumed for materials expanded from 95.4 Mtdm in 2009 to 109 Mtdm in 2017 (+14.2%).
  It is difficult to interpret these indicators because of their ambiguous directionality (see Box 6, *Total biomass consumed for energy and materials*).

FOCUS BOX nr. 5:
Biowaste and food waste

Data on waste generation is collected from EU member states in a framework set up by the Waste Statistics Regulation and published by Eurostat (European Commission, 2012). This data includes a mix of organic and inorganic wastes generated from various economic activities (including households). Nevertheless, it does not distinguish the biodegradable component in the different waste categories. For example, certain waste categories such as textile or rubber waste contain a mix of biodegradable and synthetic wastes, and the two components are not reported separately. Similarly, the biodegradable fraction in generic categories such as "household and similar waste" is not estimated. These figures are the result of a harmonised approach to processing the data. The resulting amounts of biowaste estimated for the EU-27 at household and agricultural and industrial levels are shown in the indicators in Figure 14. The same values can be obtained for each EU MS in terms of wet and dry mass. For food waste, JRC developed a model to perform the estimation of food waste generated by EU MS across the supply chain (primary production, processing and manufacturing, retail and distribution, food services, and household consumption), at food group level (sugar beet, cereals, fruit, vegetables, potatoes, oilseeds, meat, fish, eggs, and dairy). The model provides results for the years 2000 – 2017 for EU-27 and at Member State level (Caldeira et al., 2021).
Data can be navigated and downloaded:

Biowaste generated by source data
https://knowledge4policy.ec.europa.eu/visualisation/eu-bioeconomy-monitoring-system-dashboards_en?indicatorId=3.1.c.5

Biowaste recovered by source data
https://knowledge4policy.ec.europa.eu/visualisation/eu-bioeconomy-monitoring-system-dashboards_en?indicatorId=3.1.c.6

Food waste along the supply chain (mass balance approach)
https://knowledge4policy.ec.europa.eu/visualisation/eu-bioeconomy-monitoring-system-dashboards_en?indicatorId=3.2.a.1

Food waste by food category (mass balance approach)
https://knowledge4policy.ec.europa.eu/visualisation/eu-bioeconomy-monitoring-system-dashboards_en?indicatorId=3.2.a.2

FOCUS BOX nr. 6:
Total biomass consumed for energy and materials

The total biomass consumed for energy and the total biomass consumed for materials are two separate indicators derived from the JRC Biomass Mandate. The values represent both primary and secondary sources of biomass (thus also by-products and waste), converted to a common unit: tonnes of dry matter (see (Gurria et al., 2022)). These indicators complement the indicators on total biomass used for food purposes and total biomass consumed directly by humans (see boxes 3 & 4). It is difficult to interpret these indicators because of their ambiguous directionality. In theory, the directionality should be positive because of where these indicators are placed in the BMS conceptual framework. This means that more biomass used for material and energy should be considered better but it is not necessarily correct if overall consumption is increasing (among other reasons). However, there is no benchmark on total consumption for material and energy use.

Data can be navigated and downloaded:

Total biomass consumed for energy

https://knowledge4policy.ec.europa.eu/visualisation/eu-bioeconomy-monitoring-system-dashboards_en?indicatorId=3.4.a.2

Total biomass consumed for materials

https://knowledge4policy.ec.europa.eu/visualisation/eu-bioeconomy-monitoring-system-dashboards_en?indicatorId=3.4.a.3

Share of woody biomass used for energy

https://knowledge4policy.ec.europa.eu/visualisation/eu-bioeconomy-monitoring-system-dashboards_en?indicatorId=3.4.a.4

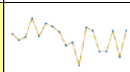
4.5 Objective 4: Mitigating and adapting to climate change

Objective 4 covers aspects related to the role of the Bioeconomy in Climate Change Mitigation and adaptation. The Objective has two main criteria:

4.1 Climate change mitigation and adaptation are pursued.
4.2 The sustainability of urban centres is enhanced.

Criterion 4.2 is complementary to criterion 3.6 in covering the role of biomass in contributing to sustainable urban areas and well-being of citizens.

Figure 15: Scoreboard for Objective 4

Normative criteria	Key components	Indicator name	Unit	Short-term period	Short-term trend change (% / year)	Long-term period	Long-term trend change (% / year)	Indicator overview
Climate change mitigation and adaptation are pursued	Climate change mitigation	net GHG emissions (emissions and removals) from bioenergy (absolute and relative vs. total sector emissions)						
		net GHG emissions (emissions and removals) from BBI (absolute and relative vs. total industrial emissions)						
		net GHG emissions (emissions and removals) from agriculture	Million tonnes of CO2 equivalent	2014-2018	-0.13	2009-2018	-0.38	
		net GHG emissions (emissions and removals) from bio-waste (absolute and relative vs. total waste emissions)						
		GHG emissions from fishing and aquaculture						
		net GHG emissions (emissions and removals) from LULUCF	Million tonnes of CO2 equivalent	2014-2018	-4.00	2009-2018	-2.48	
		Financial support to bio-based sectors (climate action)						
	Climate change adaptation	Annual heating and cooling degree days						
		Crop yield (Winter wheat, Spring wheat, Grain maize and corn-cob)	tonne/ha					
		Water exploitation index (WEI)	Pressure on renewable freshwater resources (%)	2013-2017	-3.08	2008-2017	-0.55	
		Soil moisture (seasonal average)						
		Soil erosion / desertification						
		Soil organic carbon content						
		Adaptation in agriculture, share of farmers with CAP risk management tools (insurance)						
		Adaptation in agriculture, share of agricultural land under commitments to improve adaptation (ha)						
		Adaptation in agriculture, unsustain-able water use: share of irrigated land under commitments to improve water balance						
		Adaptation in forest, # fire instances						
		Adaptation in forest, Burnt area						
		Adaptation in forest, natural disturbance events						
		Adaptation in fisheries, potential catch						
		MS Preparedeness - Year of adoption of the National Adaptation strategy/Plan (NAS/NAP)						
		Adaptation, International Transboundaries effects - loss in GDP						
The sustainability of urban centres is enhanced	Enhanced resilience/ adaptation to climate change for urban areas	City preparedness - # cities signatories of COM - Adaptation						
		Investments in urban adaptation through nature-based infrastructures or EBA						

This objective still presents several indicators gaps, in particular on the full set of climate change adaptation indicators (see Box 7, Climate change adaptation in Forestry and Fisheries). Nevertheless, the indicators in two major bioeconomy-related sectors, Agriculture and Land use, land use change and forestry, do not show promising trends. There is a slight worsening in the emissions from agriculture. The sector is still reporting a large amount of GHG emissions, with an increase from 2012 levels, 383.9 Mt $CO_{2eq.}$, to a value of 394.4 Mt $CO_{2eq.}$ in 2018. The trend in the LULUCF sector is more worrisome, as this sink has been shrinking since 2013, when it was -323.9 Mt $CO_{2eq.}$, to a value of -262.7 Mt $CO_{2eq.}$ in 2018. While LULUCF includes cropland and grassland, these are relatively stable throughout time and the fluctuations in the indicator are due to the forests (and to a certain extent, to the harvested wood products). The forest carbon sink is mainly driven by the difference between increment and harvests, and natural disturbances.

FOCUS BOX nr. 7:
Climate change adaptation in forestry and fisheries

Climate change adaptation is considered an important set of indicators to monitor. Because of the low number of climate change adaptation indicators for the different primary production sectors at the EU scale, the JRC is asking experts to support us in the definition of useful indicators for this purpose. A recent report details the suggested indicators for climate change adaptation in the fisheries and forestry sectors, these are published in a recent report by (Sanchez-Jerez, Raftoyannis, and Rihimaki, 2023), to be implemented in the current year in the BMS to enrich the Objective 4 series.

Climate change is modifying marine and coastal environments in the oceans. Observed changes include sea temperature rise, mixing of layers, changing ocean currents, rising sea levels, salinity, acidification, changes in rainfall, and increased severity and frequency of extreme events. The economic sectors that depend on the oceans, such as fisheries and marine aquaculture, are impacted by these changes, which are affecting fish growth, distribution, species composition and an overall reduction in production and yield, partially due to diseases.

The EU Forest Strategy integrates climate action in the wider coherent approach towards sustainable forest management. One of its priority areas is "Forests in a changing climate", where the strategic objective is to enhance the forests adaptive capacity and resilience. Climate change has already caused many changes in forest ecosystems and negative effects prevail, including warming-induced shifts in species distribution, and drought-related increases in tree mortality. Impacts of climate change magnify local disturbances, such as environmental pollution, nitrogen deposition, habitat fragmentation, forest fire, pest outbreak, and alien species, altering forest development trajectories and decreasing capacity for resistance.

The Water Exploitation Index is another critical indicator showing the balance between water demand and abstractions vs. water availability. This indicator is particularly critical for water-stressed regions such as the Mediterranean (De Roo et al., 2021). In present climate, the Mediterranean regions already face water stress conditions, with the annual average WEI varying between 12.7% in Portugal up to 70.3% in Cyprus. During up to 4 summer months per year the WEI values are higher than 20% in the most southern parts of Europe, which indicate medium to high water stress. For future climate it is projected that the WEI values are exacerbating in already existing water scarce areas and moreover new water scarce areas are created in countries further north like Germany, Bulgaria, Romania and France (Bisselink et al., 2020).

FOCUS BOX nr. 8:
Water exploitation index

Global withdrawals of water to satisfy demands have grown dramatically since the last century. The Water Exploitation Index (WEI) is widely regarded as an important measure of water stress, and the United Nations (1997) have used it in the past to classify countries as having:

- Low water stress (WEI<10%),
- Moderate water stress (10%≤WEI<20%),
- Medium-high water stress (20%≤WEI<40%), and,
- High water stress (WEI≥40%).

The WEI is the ratio of the total volume of water abstraction over the total volume of available water and ranges between 0 and 100%. It shows the effect of the amount of water abstracted from lakes, rivers and groundwater for the several uses (domestic, agricultural, industrial, etc.) to the total available water in the same area. Thus, the WEI indicator provides an indication of the pressure on the water resources of a certain territory as a consequence of water withdrawals. Hence, it also identifies areas most prone to suffer recurrent or permanent situations of water scarcity (Water Scarcity and Droughts Expert Group, 2012).
Data can be navigated and downloaded:

Water exploitation index
https://knowledge4policy.ec.europa.eu/visualisation/eu-bioeconomy-monitoring-system-dashboards_en?indicatorId=4.1.b.3

4.6 Objective 5: Strengthening European competitiveness and creating jobs

Objective 5 of the EU's Bioeconomy Strategy, Strengthening European Competitiveness and Creating Jobs, has as a purpose the promotion of opportunities for growth and economic development derived from fostering the bioeconomy. This objective is divided into six criteria:

5.1 Economic development is fostered.
5.2 Inclusive economic growth is strengthened.
5.3 Resilience of the rural, coastal and urban economy is enhanced.
5.4 Existing knowledge is adequately valued and proven sound technologies are fostered.
5.5 Knowledge generation and innovation are promoted.
5.6 Demand and supply-side market mechanisms and policy coherence between supply and demand of food and non-food goods are enhanced.

Normative criteria	Key components	Indicator name	Unit	Short-term period	Short-term trend change (% / year)	Long-term period	Long-term trend change (% / year)	Indicator overview
Economic development is fostered	Contribution of bioeconomy to economic development	Contribution of the Bioeconomy to GDP						
		Value Added per sector: Agriculture	%	2015-2019	-0.69	2010-2019	-0.75	
		Value Added per sector: Forestry	%	2015-2019	-4.01	2010-2019	-0.32	
		Value Added per sector: Fishing and Aquaculture	%	2015-2019	-4.65	2010-2019	-1.68	
		Value Added per sector: Manufacturing of bio-based textiles	%	2015-2019	-1.36	2010-2019	-1.74	
		Value Added per sector: Manufacturing of bio-based wearing apparel	%	2015-2019	2.32	2010-2019	-2.22	
		Value Added per sector: Manufacturing of leather	%	2015-2019	-1.45	2010-2019	0.60	
		Value Added per sector: Manufacturing of wood products	%	2015-2019	0.84	2010-2019	-0.44	
		Value Added per sector: Manufacturing of paper and paper products	%	2015-2019	0.90	2010-2019	0.29	
		Value Added per sector: Manufacturing of bio-based pharmaceuticals	%	2015-2019	3.29	2010-2019	2.78	
		Value Added per sector: Manufacturing of bio-based plastics and rubber	%	2015-2019	4.44	2010-2019	0.96	
		Value Added per sector: Manufacturing of wooden furniture	%	2015-2019	-0.49	2010-2019	0.19	
		Value Added per sector: Manufacturing of bio-based chemicals	%	2015-2019	-0.41	2010-2019	-0.05	
		Value Added per sector: Generation of bio-based electricity	%	2015-2019	1.04	2010-2019	1.01	
		Value Added per sector: Production of bio-diesel	%	2015-2019	0.83	2010-2019	4.28	
		Value Added per sector: Production of bio-ethanol	%	2015-2019	-1.41	2010-2019	3.57	
		Value Added per sector: Manufacturing of food	%	2015-2019	-0.26	2010-2019	0.22	
		Value Added per sector: Manufacturing of beverages	%	2015-2019	1.82	2010-2019	0.71	
		Value Added per sector: Manufacturing of tobacco	%	2015-2019	7.75	2010-2019	1.03	
		GVA to turnover ratio						
		Economic productivity (GVA/unit of biomass)						
		Gross value added per person employed in bioeconomy	Apparent labour productivity [1000 EUR per person]	2015-2019	5.02	2010-2019	4.65	
	Value of raw and processed biomass, value added in bioeconomy sectors	Turnover in bioeconomy per sector	Million EUR	2015-2019	3.81	2010-2019	2.63	
		Value-added per sector	Value added at factor cost in million euro	2015-2019	4.83	2010-2019	3.28	
	Exports of EU food and non-food biomass, processed goods and/or related technologies							
		Export value						
		Trade balance (net export)						
	Comparative advantage							
		Terms-of-Trade of biomass (export/import)						
		Revealed comparative advantage of biomass (Balassa index)						
		Number of enterprises in bioeconomy						
		Bioeconomy SME birth & death rates						

Figure 16: Scoreboard of indicators for Objective 5

Normative criteria	Key components	Indicator name	Unit	Short-term period	Short-term trend change (% / year)	Long-term period	Long-term trend change (% / year)	Indicator overview
Inclusive economic growth is strengthened	Employment in bioeconomy							
		Persons employed per bioeconomy sectors	number of people	2015-2019	-0.17	2010-2019	-0.97	
	Working conditions related to bioeconomy							
		Occupation health and safety in bioeconomy sectors						
	Equality & inclusiveness in bioeconomy sectors	Employment by age in bioeconomy sectors						
		Employment by educational level in bioeconomy sectors						
		Employment by gender in bioeconomy sectors						
		Income by gender by sector						
		Income distribution along bioeconomy value chains						
Resilience of the rural, coastal and urban economy is enhanced	Existing knowledge on bioeconomy technologies	Adoption of new bioeconomy technology by primary producers for both production and transformation levels						
		Rolling-out of pilot projects						
		Investment in TRL8-9 bio-based products						
Knowledge generation and innovation are promoted	Knowledge generation/ (high level) education	% persons employed with 3º education in bioeconomy sectors						
		Changes in University curricula (number)						
		Investment in higher education related to bioeconomy						
	Research and innovation	Number of patents by bioeconomy sectors						
		Investment in research and innovation (1000 eur)						
		Open innovation						
		New non-food products produced from primary sources						
		Number of research outputs in the field of bioeconomy						
Demand and supply-side market mechanisms and policy coherence between supply and demand of food and non-food goods are enhanced								
	Market mechanisms (e.g. prices, consumer awareness)							
		Market or consumers acceptance						
		Number of labelled or certified bio-based products						
	Resource competition among sectors of the bioeconomy and Biomass demand for new value chains							
		Share biomass used by primary sector						
		Producer prices per primary production sector						

The following findings may be extracted from the analysis of the available information:

- The dynamics regarding the share of value added over GDP of the bioeconomy sector are heterogeneous:
  - In general, biomass-producing activities (agriculture, forestry and fishing) registered stable ("no changes") or slightly negative trends in their share of GDP. In fact, the share over GDP of these activities decreased from 1.65% in 2010 to 1.59% in 2019.
  - The share of manufacture of food and beverages activities also registered stable trends in the analysed periods. The share over GDP from these activities was 1.86% in 2010 and 1.80% in 2019.
  - More traditional non-food biomass-processing activities also show a stable evolution (e.g. wood products and paper, whose share was around 0.71% during the analysed period) or, in the case of textiles, a structural decline (from 0.21% of GDP in 2010 to 0.18% in 2019).
  - Most positive and dynamic trends can be observed for more recent bio-based industrial activities related to chemicals, pharmaceuticals, plastics and the energy-oriented bio-based sectors. Their share over GDP grew from 0.48% in 2010 to 0.52% in 2019.

- Despite the heterogeneous trends of bio-based activities, the gross value added per person employed in the bioeconomy showed a strong increasing trend in the considered periods. Thus, this variable grew from 26,842€ in 2010 to 38,689€ in 2019, which represents an accumulated increase around 40% during this period. This reflects an improvement in the labour productivity on the overall bioeconomy.

- The above finding relates to the increasing trends in both turnover and value added in the total bioeconomy, but also by a slightly decreasing trend in the number of people employed in the bioeconomy sectors (from 19.1 million persons employed in 2011 to 17.4 million in 2019). This fall can be explained by the reduction in the agricultural labour force in the analysed period, which was only partially offset by an increase in the number of employed persons in other bio-based sectors.

FOCUS BOX nr. 9:
Quantifying socio-economic indicators of the European bioeconomy

The quantification of jobs, turnover and value added created in the different bioeconomy sectors and in the Member States of the European Union is carried out following the method proposed by Ronzon and M'barek (2018). This method consists of a systematic combination of Eurostat statistics (National Accounts, Structural Business Statistics and the results from Europrom survey) with output bio-based shares elaborated by Nova Institute.

According to these indicators, the EU bioeconomy provided 17.42 million jobs in 2019 (8.3% of total employment), and its value added reached 657 billion euro (4.7% of total value added).

It should be noted that the method from Ronzon and M'barek (2018) does not provide estimates for bioeconomy services, given the limitations of the employed data sources. However, the JRC has already developed a methodology to quantify the contribution of services to the bioeconomy (see Ronzon et al., 2022). The results are expected to be published in the next months (see Section 5.1 for further information). Simultaneously, the JRC is also working on a method to regionalize employment and value added in the EU bioeconomy at the NUTS2 level (see Lasarte-López et al. 2022).

Detailed estimates by country and sector are available here:
https://datam.jrc.ec.europa.eu/datam/mashup/BIOECONOMICS/index.html

Data can also be navigated and downloaded:

Value added per sector/bioeconomy value added
https://knowledge4policy.ec.europa.eu/visualisation/eu-bioeconomy-monitoring-system-dashboards_en?indicatorId=5.1.a.2
Gross added value per person employed in bioeconomy
https://knowledge4policy.ec.europa.eu/visualisation/eu-bioeconomy-monitoring-system-dashboards_en?indicatorId=5.1.a.5
Turnover in bioeconomy per sector
https://knowledge4policy.ec.europa.eu/visualisation/eu-bioeconomy-monitoring-system-dashboards_en?indicatorId=5.1.b.1
Value added per bioeconomy sector
https://knowledge4policy.ec.europa.eu/visualisation/eu-bioeconomy-monitoring-system-dashboards_en?indicatorId=5.1.b.2
Persons employed per bioeconomy sector
https://knowledge4policy.ec.europa.eu/visualisation/eu-bioeconomy-monitoring-system-dashboards_en?indicatorId=5.2.a.1

FOCUS BOX nr. 10:
Research & innovation indicators of the bioeconomy

Innovation is considered as a key enabler for the transition towards a carbon-neutral economy. Currently, the JRC is developing methods to monitor research and innovation efforts and outcomes in the bioeconomy sectors (Normative criteria 5.4, Existing knowledge is adequately valued and proven sounded technologies are fostered, and 5.5, Knowledge generation and innovation is promoted. In addition, an expert consultation has been launched to assess whether the indicators foreseen in the aforementioned Normative criteria of the EU-BMS were plausible and whether the required time series and reproducibility criteria can be met.

4.7 Composite scores

While valuable insights are provided by the trends of the individual indicators shown in the Scoreboards above, aggregate scores of multiple indicators offer the reader a more immediate overview of potential areas of concern in the state of the bioeconomy. As indicated in section 3.3, the design of the conceptual framework allows to identify a meaningful structure and hierarchy of indicators which can be used as the basis for aggregation.

In this section, we report the trend analysis calculated for the composite scores aggregated at the key component level, the third hierarchical level of the BMS conceptual framework. This is the same level used for the assessment in the 2022 progress report of the EU Bioeconomy (EC, 2022). At this stage of development of the BMS we argue that the key component level is the most appropriate for aggregation because it combines the very specific measures of the indicators (e.g. employment in specific bioeconomy sectors, or levels of a single pollutant in rivers) to a more comprehensive level that can be recognized and understood as a family of indicators (e.g. employment in all bioeconomy sectors or environmental quality). By assessing this level of the framework, the pathways for Europe's trajectory towards a desired bioeconomy can be better understood by taking a step back and looking at the overarching and collective trends within the framework.

Following the approach taken above for the assessment of trends of the individual indicators, this more aggregate analysis is also based on both short- and longer-term trends (5 and 10 years)[48]. When visualizing the groupings of indicators in terms of "progress", which is interpreted by the overall trends in the indicators once their directionality is normalized, the main trends show that the EU bioeconomy appears to be making progress in several areas. The hints that point to this conclusion are: the circularity and resource efficiency aspects are improving, we are obtaining increasing amounts of biomass from ecosystems through provisional services, and we are adding more economic value to biomass and bio-based products. There has been however, a reduction in employment, which may or may not be the result of technological progress. On the other hand, data show that pressures from the primary production systems are high, as described in section 4.3; for instance, pressures from forest management on forest ecosystems have increased, as also supported by the evidence in the declining LULUCF sink (section 4.5). The abundance of common forest birds seems to have improved in the last 5 and 10 years with respect to 2000 values, while the indices for grassland butterflies and farmland birds have continued a steady decline. In the aggregation of these three indicators the steep positive trend of the forest bird index dominates over the slow decay of the other two indicators, so that the overall score appears to be largely positive. Despite this mathematical result, we we warn caution in interpreting this result and we refer to the in-depth analysis of (Maes et al., 2020).

([48]) This approach differs from the Bioeconomy Strategy Progress Report, where the fixed time series from 2012-2017 was used, a different statistical approach was applied that was suitable for the long time series to be assessed, and we did not apply a threshold for a minimum number of indicators to represent their respective key components.

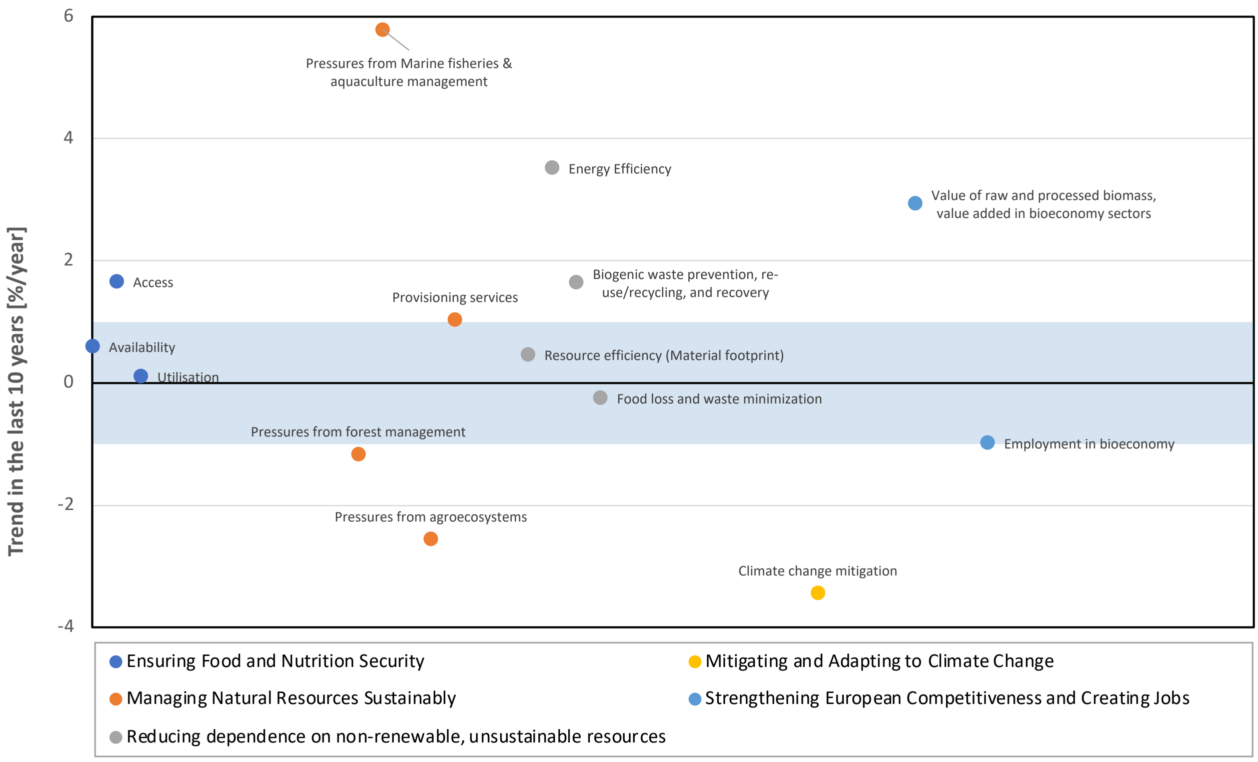
Figure 17 shows the aggregate assessment by key component for the short-term, 5-year period. The color coding refers to the EU Bioeconomy Strategy objectives. Of the 15 key components with sufficient data to assess, 7 are showing an improvement in the short term (including the score for 'species diversity and abundance' which is outside of the scale represented), while 3 are showing a decline (as defined in section 4.1 Methods). A further 5 key components are considered to have no clear trend.

Figure 17. Summary of trend analysis for the last 5 years, of the key components contributing to a sustainable bioeconomy. Long names of key components are: Food availability, Food accessibility, Food utilisation, Species Diversity and abundance (not shown, outside of the scale represented), Pressures from forests, Pressures from Marine fisheries & aquaculture management, Pressures from agroecosystems, Provisioning services, Material Resource efficiency, Biogenic waste prevention, re-use,recycling, and recovery Biogenic waste prevention, re-use, recycling, and recovery, Food loss and waste minimization, Climate change mitigation, Value of raw and processed biomass, Employment in bioeconomy.

Source: Own representation

Figure 18 shows the aggregate assessment by key component for the long-term, 10-year period. Of the15 key components with sufficient data to assess, 7 are showing an improvement in the short term (including the score for 'species diversity and abundance' which is outside of the scale represented). One of these 7 indicators is “provisioning services”. Its positive trend is clearly more pronounced in the short-term assessment because of the increase in removals of woody biomass from forests in the last five years of measure. Four indicators are showing a decline, which differs from the three we see in the short-term assessment. This is due to the employment in bioeconomy key component, whose trend is overall negative in the long term but seemed to have stabilised in the last five years. A further 4 key components are considered to have no clear trend on the long term. The key components Food availability, food utilisation, material footprint and food loss and waste miminisation are all showing stable trends for both the short and the long term.

Figure 18. Summary of trend analysis for the last 10 years, of the key components contributing to a sustainable bioeconomy. Long names of key components are listed in the caption of the above figure.



Source: Own representation

Europe is generally moving towards the objectives of the EU Bioeconomy Strategy, but environmental challenges persist, pointing to a need for policy coordination. There are multiple pressures on land, and while the drivers are not associated here in this context, they are associated in others[49], the increasing demand for material and energy is largely accountable and a lower overall consumption may alleviate some of these pressures, as could a transformation in work-force and innovation to be more resource efficient.

([49]) ex. JRC Biomass Mandate *https://knowledge4policy.ec.europa.eu/projects-activities/jrc-biomass-mandate_en*

5 Exploring new lenses to analyse the bioeconomy

Chapter 4 describes the main trends emerging from the indicators currently included in the BMS. However, other research activities, on-going or planned at the JRC, contribute to further our understanding of the bioeconomy. This chapter describes two such activities: section 5.1 describes the method to include bioeconomy-related services into the scope of the BMS, and thus deepening our understanding of the socio-economic relevance of the EU Bioeconomy; section 5.2 proposes an approach, based on socio-metabolic principles, that can be used to structure the data provided in individual indicators, and assess the sustainability of the EU bioeconomy through a systemic lens accounting simultaneously for environmental, social and economic conditions.

5.1 Services in the bioeconomy: definition, quantification and implications for the BMS

To the best of our knowledge, there is no universally accepted definition of a 'bioeconomy service'. From a policy perspective, eleven countries[50] in the world, plus the Nordic Council of Ministers and the European Union, mention the provision of services in their bioeconomy strategic documents (German Bioeconomy Council, 2018; International Advisory Council on Global Bioeconomy, 2020). A cursory examination reveals references to (inter alia) nature tourism (Finland, Thailand and the Spanish region of Extremadura), catering and accommodation (Latvia), recreation (Finland, Norway) and ecosystem services (Costa Rica) (Finnish Ministry of Employment and the Economy, 2014; Junta de Extremadura, 2017; Ministry of Agriculture Republic of Latvia, 2018; Ministry of Environment and Energy of Costa Rica, 2020; Norwegian Ministries, 2016; Thailand's Office of National Higher Education Science Research and Innovation Policy Council, 2020).

The 2018 EU Bioeconomy strategy states that the bioeconomy 'includes and interlinks:

- land and marine ecosystems and the **services** they provide;
- all primary production sectors that use and produce biological resources [...];
- and all economic and industrial sectors that use biological resources and processes to produce food, feed, bio-based products, energy and **services**' (European Commission, 2018).

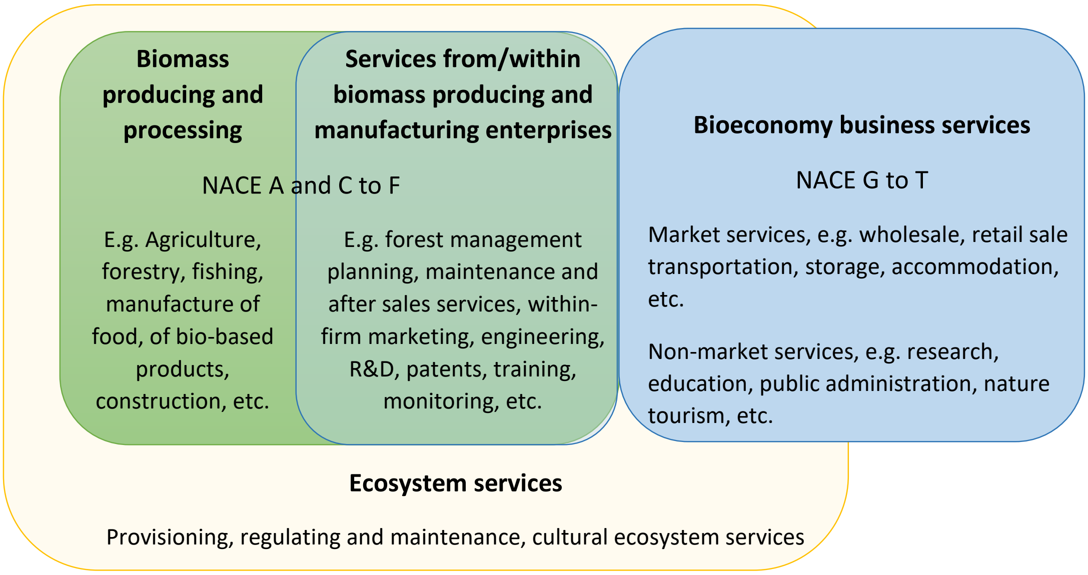
However, the Strategy does not provide a list of economic sectors that match this definition.

Agri-food and blue economy policy documents stress the role of food service operators (e.g. wholesalers and retailers), of research and development (R&D) and advisory services and of the protection of ecosystem services in shaping the agri-food and aquatic systems' sustainability (European Commission, 2020a, 2020b; European Commission, 2019). In sum, the scientific and policy literature identify some agriculture- or aquatic-related services but they do not provide any comprehensive definition of them either.

A more considered framework appears in the forest-related literature which offers several services 'typologies' in the forest-based sector (FOREST EUROPE, 2020; Näyhä, Pelli, & Hetemäki, 2014; Näyhä, Pelli, & Hetemäki, 2015; Pelli, Haapala, & Pykäläinen, 2017; UNECE/FAO, 2014). Typologies differ in the domain of services they cover and show overlaps, as noted in Figure 19. Thus, adopting the NACE classification, different types of services are distributed between forestry (NACE A02) and forestry-related manufacturing enterprises (NACE C to F) (green and blue frames in Figure 19), those business services performed all along bioeconomy value chains (NACE G to T, blue frame Figure 1) and ecosystem services (beyond the scope of NACE, yellow frame Figure 19). In addition, in Pelli et al. (2017), the interaction between producers and consumers also qualifies as a service if it impacts the value creation process (beyond the scope of NACE, not shown).

(50) Argentina, Brazil, Canada, Costa Rica, Finland, Germany, Latvia, Norway, Spain, Thailand and the United Kingdom.

Figure 19. The different types of bioeconomy services mentioned in the literature and their relation to the NACE classification



Source: Ronzon et al. (2022)

5.1.1 The quantification of bioeconomy services

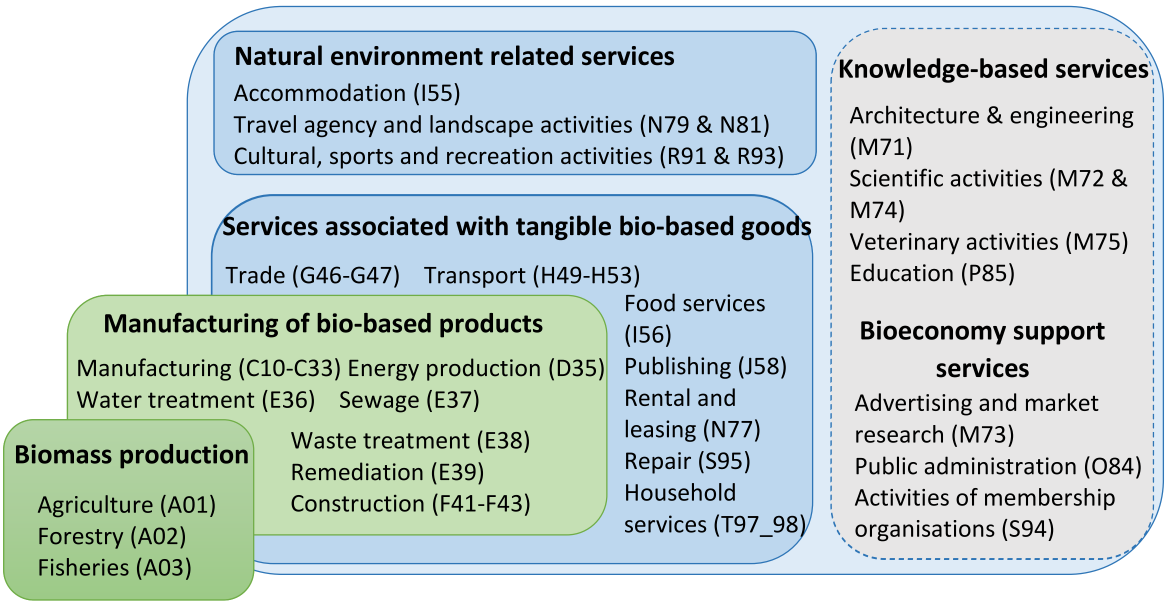
When quantifying bioeconomy services, different aspects can be considered. We can differentiate (i) the quantification of ecosystem services, (ii) the quantification of services embedding a bioeconomy-relevant feature, (iii) the quantification of those services that depend on the use of renewable biological resources, and (iv) the quantification of the services provided to core bioeconomy activities for their development.

Regarding the services provided by land and marine ecosystems, the Knowledge Innovation Project on an Integrated system of Natural Capital and ecosystem services Accounting **(KIP INCA)** aims to develop a set of experimental accounts at the EU level, following the United Nations System of Environmental-Economic Accounting - Experimental Ecosystem Accounts (SEEA-EEA) (Vallecillo et al., 2019; Vallecillo et al., 2018). For each ecosystem service, the quantification of the flow of the service used is based on the spatial relationship between the service potential and the demand that are themselves assessed biophysically using the ESTIMAP toolbox. The results of the biophysical assessment are then translated into monetary units using valuation methods consistent with the System of National Accounts. The rest of the chapter focuses solely on quantifications compatible with the framework for economic activities of the European System of National Accounts (SNA) framework (i.e. the NACE classification of industries).

The three other types of quantifications relate with marketed bioeconomy services accounted within the SNA.

The services embedding a bioeconomy-relevant feature are measured by the so-called 'output-based' approach. They contribute to the bioeconomy proportionally to the bioeconomy nature of the service produced. Following that approach, Ronzon, Iost, and Philippidis (2022) distinguish four types of services (Figure 20). The bioeconomy content of the services related with tangible bio-based goods - like the trade, transport or distribution of bio-based products – is quantified proportionally to the biomass content of these bio-based goods. The other services produce intangible goods. Their contribution to the bioeconomy is quantified according to their link with the natural environment (e.g. night spent in rural areas in the case of the accommodation sector), or according to the knowledge they produce in bioeconomy-relevant fields (e.g. scientific research in natural sciences). The quantification of services in support to the bioeconomy is more difficult and no criteria could be applied considering available statistics in the case of market research and membership organizations. The contribution of the public administration to the bioeconomy is considered of the same proportion than the relative contribution of all other economic sectors to the bioeconomy (i.e. in percentage points of GDP or of total employment).

Figure 20. Categorisation of the bioeconomy activities within the NACE classification following the output-based approach.



Source: Ronzon et al. (2022)

Alternatively, the **"input-based approach"** measures the contribution of services to the bioeconomy according to their own use of biomass resources. Following that approach and using data from input-output tables (IOTs), Kuosmanen et al. (2020) and Cingiz, Gonzalez-Hermoso, Heijman, and Wesseler (2021) propose to quantify the biomass input cost share of every service as the proportion of inputs costs related with the purchase of biomass and bio-based inputs over total input costs. A similar approach has been applied in the literature to more restricted sectors (e.g. bioeconomy publishing activities employing Eurostat Supply and Use tables by Robert, Jonsson, Chudy, and Camia (2020), or geographical areas such as Germany by Efken, Dirksmeyer, Kreins, and Knecht (2016) and Iost et al. (2019)).

Finally, the **upstream component** quantified by Cingiz et al. (2021) measures the size of the services that are provided to core bioeconomy activities (i.e., agriculture, forestry, fisheries, the manufacture of food, beverage, tobacco, paper and wood products). This measure is based on output cost shares calculated from IOTs, that is the proportion of the outputs of an industry that are sold to the core bioeconomy sectors aforementioned.

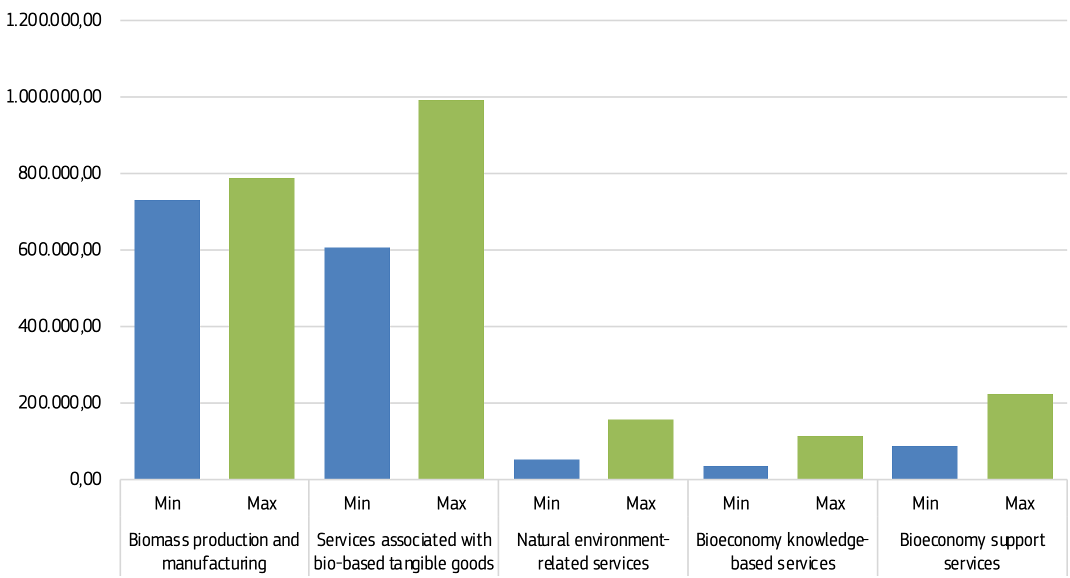
5.1.2 Bioeconomy services in numbers

The different quantitative methodologies as exposed above shed light on different aspects of the bioeconomy that we summarise hereunder. The EU28 and the year 2015 is the only common scope across methodologies. Therefore, the quantifications presented in this section will refer to that scope given the purpose of comparing methodologies.

The output-based approach implemented by Ronzon et al. (2022) concludes that the value added size of services associated with tangible goods (EUR 600 - 1,000 billion) is comparable to the value added generated by the production of biomass and its manufacturing (see Figure 21). The wholesale, retail trade, transport, repairing and rental of bio-based products generates EUR 439-732 billion. Additionally, the value added of food services is worth EUR 167 billion and bio-based publishing activities up to EUR 43 billion. Available statistics do not permit to disentangle the bio-based part of household services, which amounts to EUR 50 billion in total, i.e. their maximum size[51].

Figure 21. Value added at factor cost from the bioeconomy sectors in the EU28 (million euro, 2015).

Source: Own elaboration from Ronzon et al. (2022)



([51]) In the absence of more data, their minimum size is considered null.

According to the same authors, marketed services related with the environment – i.e., rural accommodation and travel agency activities, landscape activities and nature sport and recreation activities – create between EUR 54 billion and EUR 160 billion of value added. Note that available statistics do not permit to estimate a precise quantification of nature sport and recreation's value added. Their maximum size is given by the total value of nature and non-nature sport and recreation activities combined (EUR 75 billion)2. Another EUR 35-112 billion of value added are generated by knowledge-based services in the field of the bioeconomy. Among them, scientific activities are worth EUR 3-61 billion, Education EUR 14-33 billion euros, Veterinary activities EUR 9 billion and bio-based architecture and engineering EUR 8-9 billion. Finally, the value added from support services to the bioeconomy is difficult to estimate with current information. It ranges between EUR 88 billion euros and EUR 225 billion and comprises the activities of advertising and market research, of public administration and of membership organisations.

The input-based approach implemented by Kuosmanen et al. (2020) quantifies that EUR 370 billion of value added are generated from the use of biomass in bioeconomy services. Compared to the output-based approach which excludes some service activities considered non-bioeconomy relevant, the input-based approach clearly shows that biomass or bio-based products source all types of services to some extent. For example, the human health activities that are excluded from the scope of the EU bioeconomy strategy buy 4% of their inputs in the form of biomass or bio-based products. Proportionally to the value added they generate, this represents EUR 30 billion. The aggregate of activities not providing bioeconomy relevant outputs is worth EUR 95.5 billion with human health activities, social work and real estate being the biggest contributors (respectively EUR 30; 23 and 13 billion).

The biomass input cost share of services (input-based approach) is systematically lower than the biomass content or bioeconomy relevance of their outputs (output-based approach), except for the services mentioned above (with no bioeconomy relevant outputs) and for education. Indeed, breakfast can be served in schools, paper is used, wooden desks can be purchased... All in all, 4% of the inputs of the EU education system are made of biomass or bio-based products which compares with less than 2.5% of all teachers that have taught at graduating level to then graduates in bioeconomy-related fields.

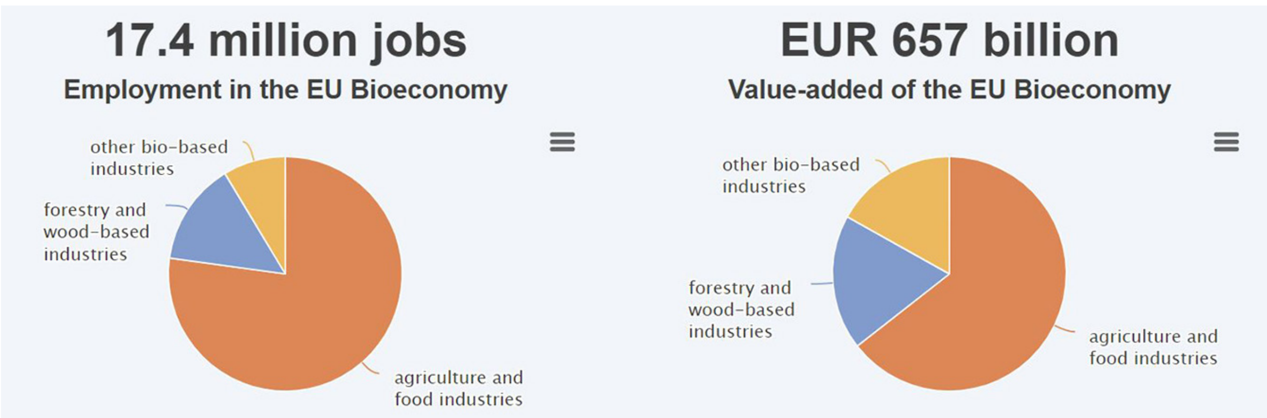
Finally, the upstream component calculated by Cingiz et al. (2021) provides additional information on the value added generated by the provision of services to core bioeconomy sectors, i.e., agriculture, forestry, fishing and aquaculture, the manufacturing of food, beverage, tobacco, wood products, paper and the printing industry. Estimated at around EUR 215 billion, that upstream value added is similar in size to the one produced by biomass producing sectors (i.e., agriculture, forestry and fishing and aquaculture). That finding reaffirms the importance of service activities in support of the bioeconomy. The largest contribution by far comes from wholesale and retail sale services (EUR 113 billion). "Other business sector services" follow with a EUR 35 billion contribution. They embed as diverse activities as business management, architecture, scientific research and engineering. Rental and leasing, employment and travel agencies. Core bioeconomy sectors also rely significantly on transport and storage services, financial and insurance activities as well as human health and social work (respective value-added contribution of EUR 20 billion, EUR 15 billion and EUR 12 billion).

In conclusion, the multiplicity of quantitative measures brings a wealth of information that shed new light on the importance and position of services into the European bioeconomy. From an output perspective, the value added from bioeconomy services is of comparable size to that of primary and industrial bioeconomy. Therefore, the development of bio-based markets promoted by the EU bioeconomy strategy brings economic value beyond the targeted sectors of biomass production and bio-based industries. The input perspective and the upstream effect characterize well the intertwining between the bioeconomy and all other economic activities: all service activities use biomass to some extent (input-based approach) but bioeconomy activities are also strongly dependent on all types of services (upstream effect). Quantification methodologies serve the characterisation of those inter-dependencies.

5.1.3 Potential implications of integrating bioeconomy services into the scope of the BMS

As mentioned in Section 4.6, the BMS adopted the output-based approach to populate indicators on employment and value added in the bioeconomy sectors, following the approach from Ronzon and M'barek (2018). However, no bioeconomy services are considered in the provided numbers (see Figure 22).

Figure 22. Economic indicators in the current version of the EU Bioeconomy Monitoring System (EU27, 2019)

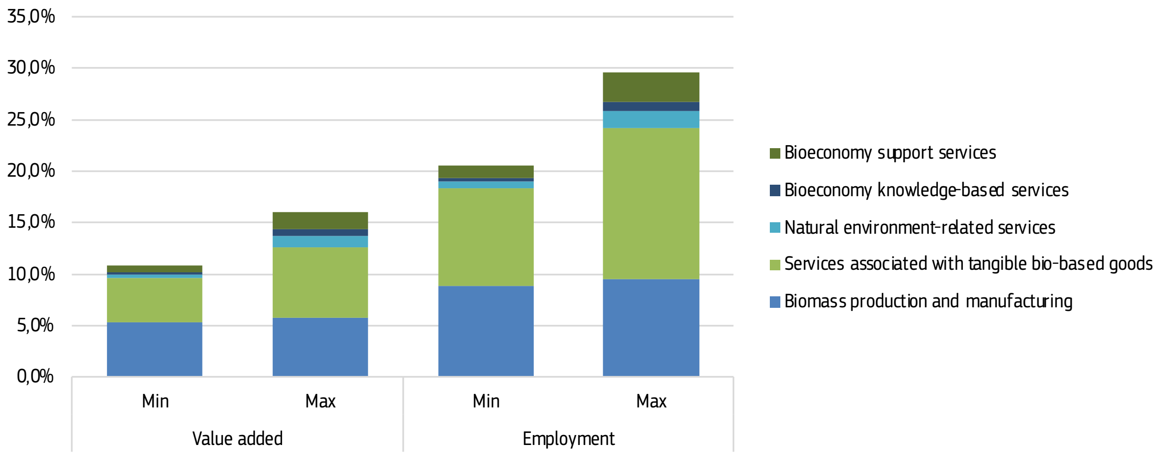


Source: EU Bioeconomy Monitoring System

The purpose of this section is to illustrate the implications of integrating bioeconomy-related services into the scope of the BMS. For this purpose, we conducted an exploratory analysis of the structure and trends in the overall bioeconomy including the services considered in the output-based approach by Ronzon et al. (2022)[52]

The main effect of expanding the scope of the BMS with services would be a substantially increase of the estimated size of the bioeconomy and, subsequently, of its contribution to the total economy. If all the services categories proposed by Ronzon et al. (2022) were included, the value added in the bioeconomy sectors could be between 10.9% and 16.0% of total EU GDP in 2019 (vs. 5-4 – 5.8% from the biomass-producing and transforming sectors currently considered in the BMS). In the same year, the bioeconomy sectors would have provided between 20.5% and 29.6% of total employment, from which the biomass-producing and transforming sectors would contribute with 8.9% - 9.5% of total employment.

Figure 23. Contribution of the bioeconomy (including services) to GDP and employment by sectors. (EU27)

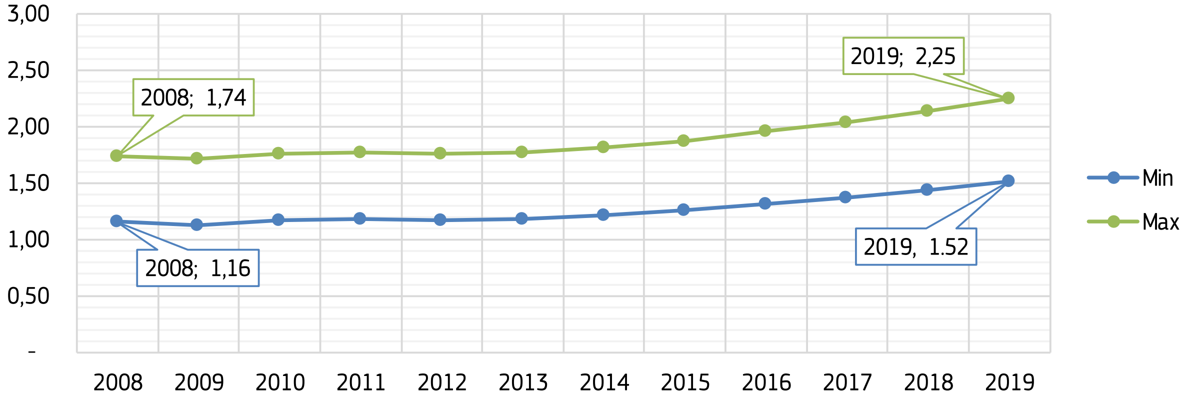


Source: Own elaboration from Ronzon et al. (2022)

In line with the economic trends, both employment and value added in the bioeconomy services would have increased in the last decade (see Figure 24 and Figure 25). The minimum estimate of value added in the bioeconomy services grew from 1.16 billion euro in 2008 to 1.52 in 2019. In the maximum estimate, this value went from 1.74 to 2.25 billion euro in the same period. These changes represent a growth around 30% of the value added in the bioeconomy services in the considered period (31% for the minimum estimated size, 29% in the maximum one). As of employment, the increases would have been more moderate. The minimum estimated number of people employed in bioeconomy services went from 42.4 million persons in 2008 to 43.0 in 2019, while the maximum estimate increased from 60.3 to 62.0 millon in the analysed period.

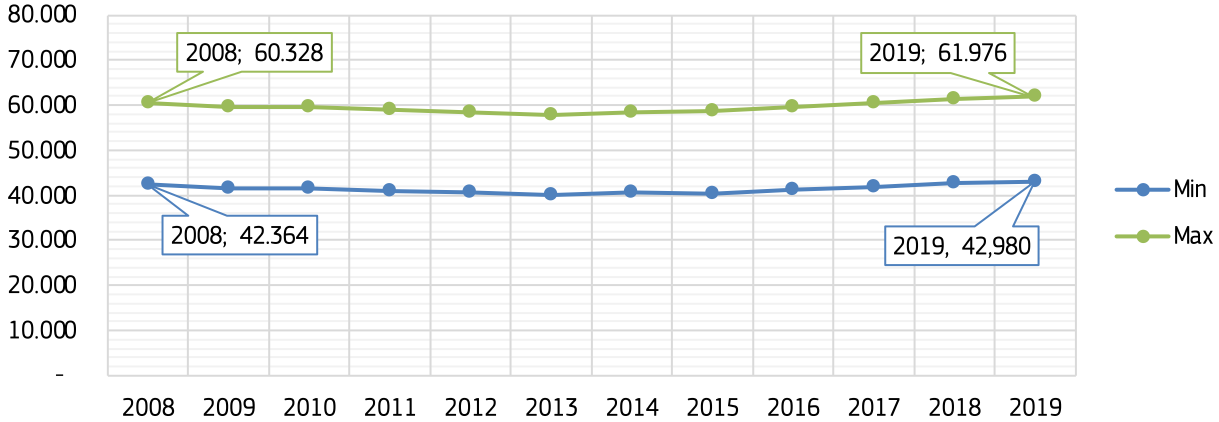
([52]) The authors of this chapter remark that the purpose of this section is not normative, but exploratory. The integration of bioeconomy services into the scope of the BMS (and the specific categories of services to be considered within the system) is still subject to further discussion among stakeholders.

Figure 24. Estimated value added in the bioeconomy services (EU27, million euro).



Source: Own elaboration from Ronzon et al. (2022)

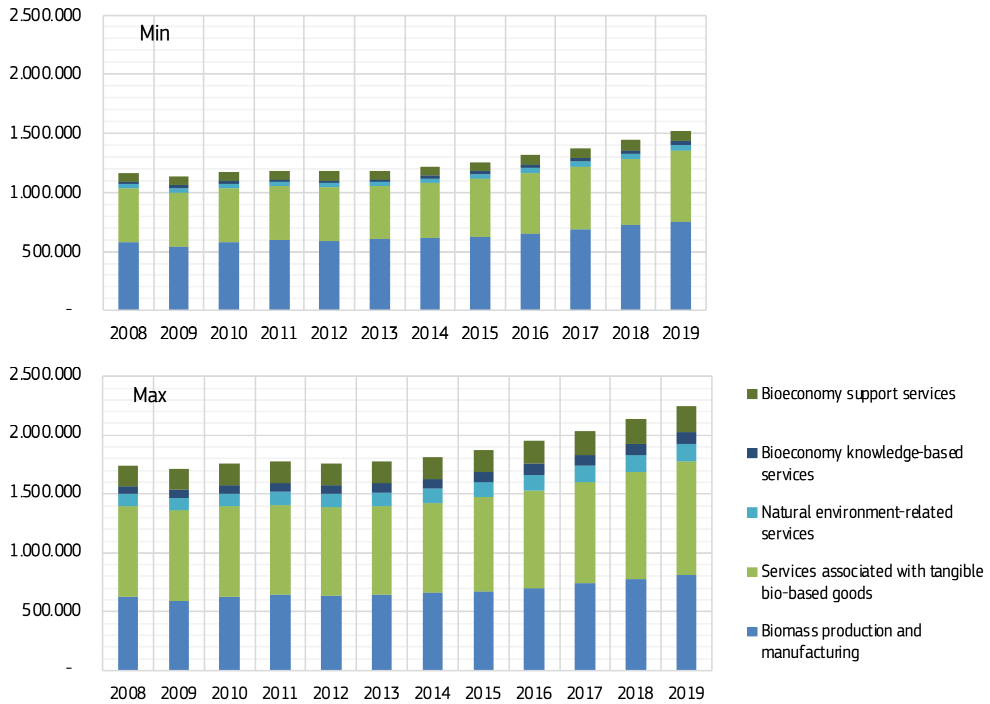
Figure 25. Estimated number of persons employed in the bioeconomy services (EU27, thousand persons).



Source: Own elaboration from Ronzon et al. (2022)

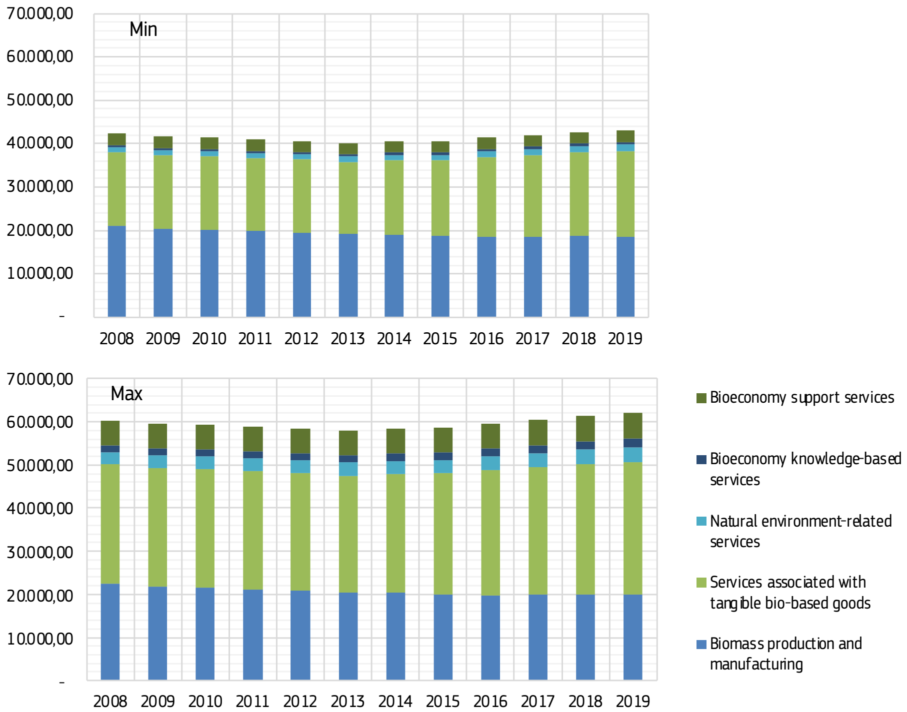
The sectoral composition of the bioeconomy (including services) also reflects changes along this period, as can be observed in Figure 26 and Figure 27. In general, the services would have tended to increase their share over the total bioeconomy in terms of both value added and employment, to the detriment of the biomass-producing and transforming sectors. This is especially important for the total employment in the bioeconomy: while the number of persons employed in the biomass-producing and transforming sectors fell in the period analysed, the total number of persons employed in the bioeconomy would increase if services are considered. This finding can be explained by the possible reallocation of labour from agriculture to the tertiary sectors.

Figure 26. Estimated value added (Min – Max) in the EU27 bioeconomy (million euro).



Source: Own elaboration from Ronzon et al. (2022)

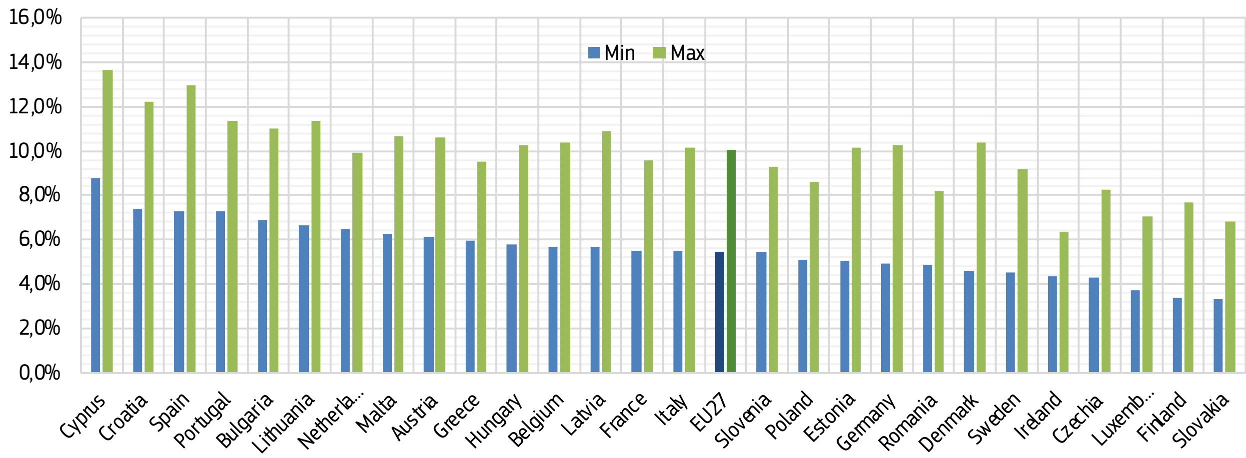
Figure 27. Estimated employment (Min - max) in the EU27 bioeconomy (thousand persons).



Source: Own elaboration from Ronzon et al. (2022)

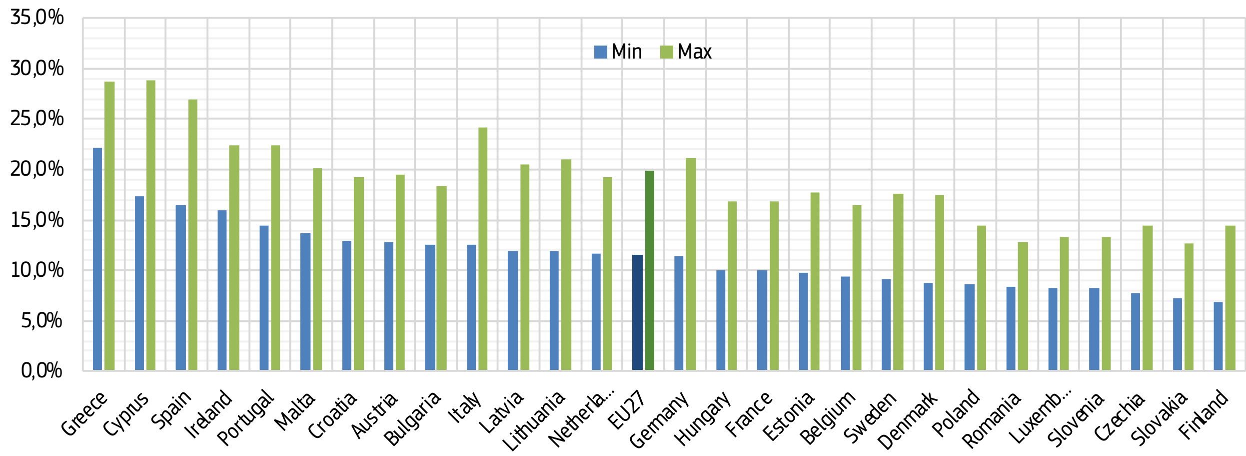
Last, another important finding is the fact that the size and sectoral composition of value added and employment in the bioeconomy services shows substantial differences across Member States. Figure 28 and Figure 29 respectively show the estimated share of value added and employment over the total economy by country, following the output-based approach from Ronzon et al. (2022). Thus, the share of value added in the bioeconomy could vary between the 3.3% from Slovakia to the 8.8% from Cyprus in the minimum estimated size, and between the 6.4% from Ireland and the 13.6% from Cyprus in the maximum estimated size. As for employment, the share would vary from the 6.9% from Finland to the 22.2% from Greece in the minimum estimated sizes, and between the 12.7% from Slovakia and the 28.8% from Cyprus in the maximum estimated size.

Figure 28. Estimated value added in the bioeconomy sectors by country (share over GDP, 2019)



Source: Own elaboration from Ronzon et al. (2022)

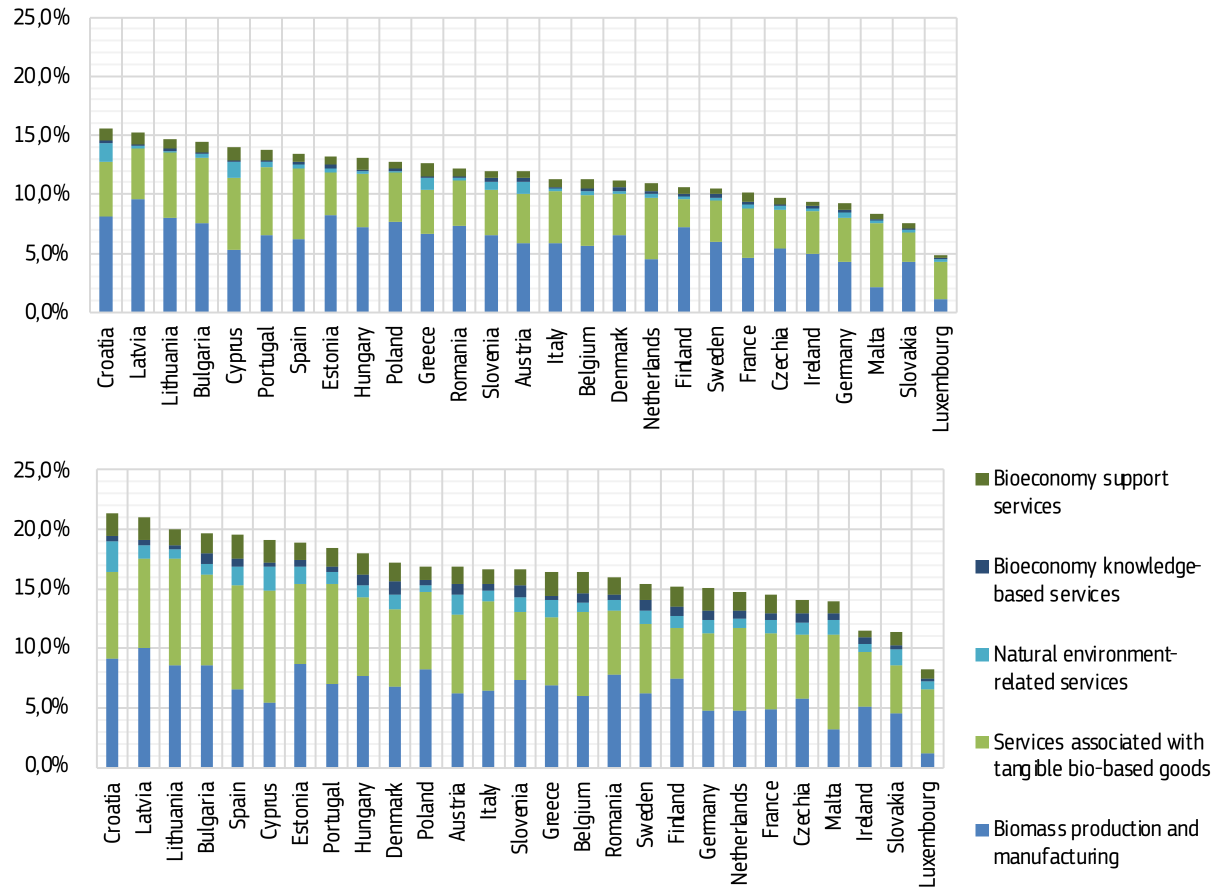
Figure 29. Estimated employment in the bioeconomy sectors (share over total employment, 2019).



Source: Own elaboration from Ronzon et al. (2022)

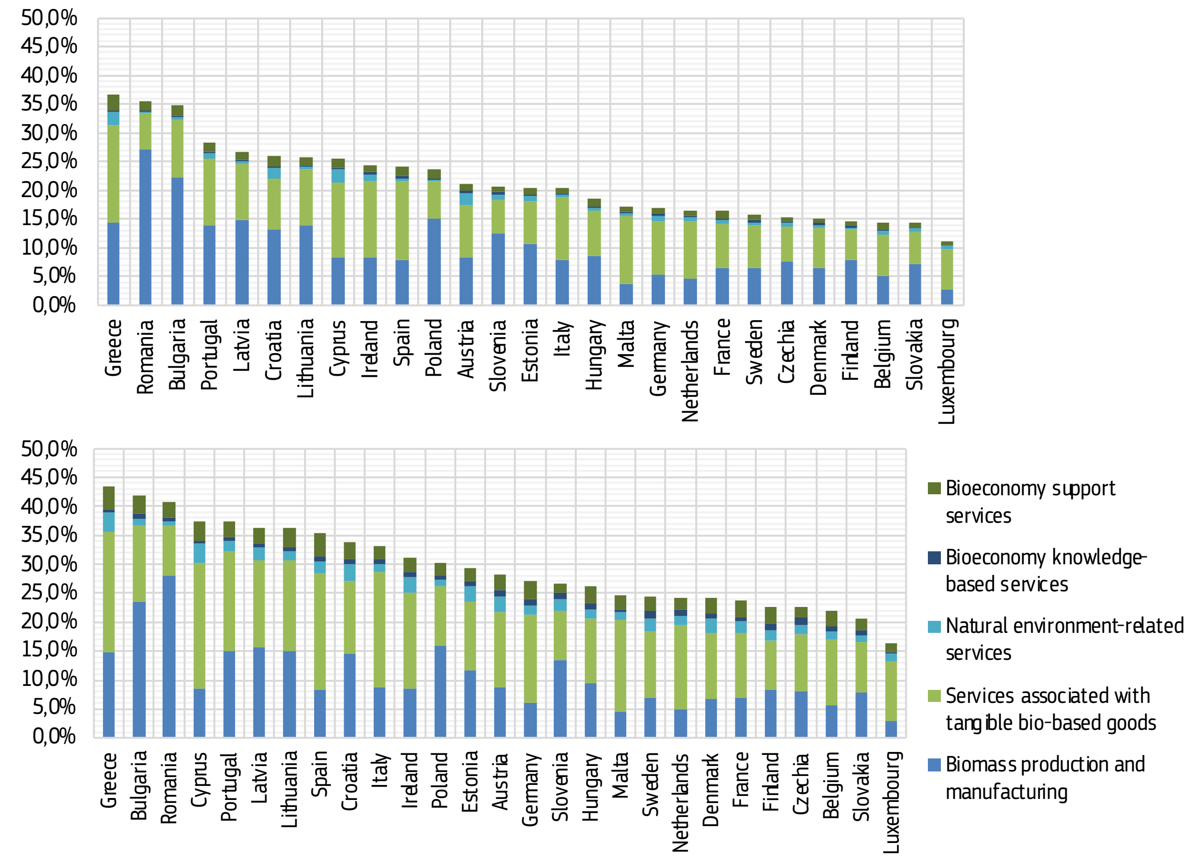
Last, Figure 30 and Figure 31 show the sectoral composition of the bioeconomy by country. From these figures, we can observe that the integration of the bioeconomy services into the analysis would change the picture for the Member States. Thus, some countries, for which the estimated size of the bioeconomy is below the average with the current numbers in the EU-BMS, would see the importance of the total bioeconomy substantially increased due to the integration of services. As a matter of fact, the scope of the service sectors belonging to the bioeconomy, is in the eye of the beholder.

Figure 30. Value added (Min – Max) by country (share over GDP, 2019).



Source: Own elaboration from Ronzon et al. (2022)

Figure 31. Employment (Min – Max) by country (share over total employment, 2019).



Source: Own elaboration from Ronzon et al. (2022)

5.2 Sociometabolic approach for a system's assessment of the EU bioeconomy

This chapter describes how bioeconomy sustainability assessment grounded in the concept of societal metabolism could be used to inform and support the policymaking process. While the BMS aims to be comprehensive, it still follows a reductionist approach where the various relevant aspects are treated separately and represented by siloed indicators. The trends presented in Chapter 4 are independent from the current societal and environmental context. The societal metabolism perspective and the use of the MuSIASEM approach, as described in this section, can complement the perspective emerging from the BMS by integrating several of the indicators and data sets into a holistic picture of the complete bioeconomy system.

The approach can take stock of the broad set of exercises that are currently used to study the sustainability of the bioeconomy. Indeed, the approach can be seen to internalise, contextualise, and synthesise inputs from life-cycle assessment databases, such as the EU Consumption Footprint (Sala et al., 2019), material and energy flow datasets, such as the JRC Biomass Flows (see Focus Box 2 in Chapter 4), as well as socioeconomic databases ((Ronzon et al., 2020) and expanded on in section 5.1).

The next sections introduce the basic concept of societal metabolism as well as its theoretical foundations. Following this theoretical introduction, a series of more practical considerations is presented. An accounting framework for the diagnostic analysis of a metabolic pattern is outlined and, lastly, how a diagnostic analysis can be used to anticipate issues of sustainability and inform policymaking processes is described.

5.2.1 Basic Concept of Societal Metabolism

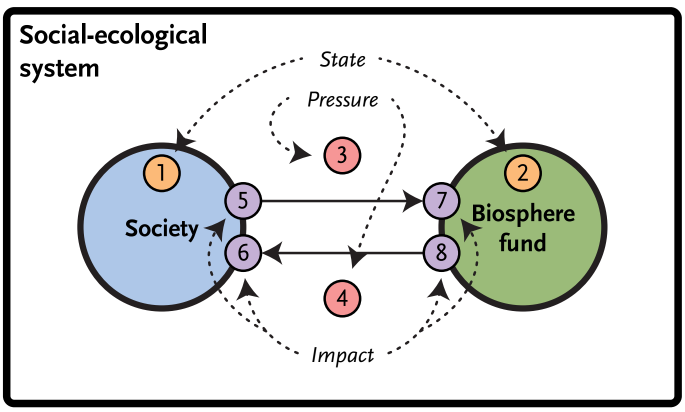
The basic assumption behind the concept of societal metabolism is that societies are organisms. To theoretically justify societies as organisms two basic types of system relation must be understood (1) metabolic relations and (2) repair relations. A metabolic relation refers to a situation whereby a metabolic processor produces a set of output flows from a set of input flows. A herd of dairy cows, for example, generates such flows as milk, manure, and methane, having received as input such flows as water and feedstuff. A repair relation refers to a relation whereby a metabolic processor is itself resynthesized, such as replenishment of the herd of dairy cows, or of power capacity in the economy following a natural disaster.

When a system of metabolic processors reproduces itself, the system can be understood as an organism. Just as the organs in your body reproduce each other (Rosen, 1972), the various institutional sectors of society reproduce each other. When issues of sustainability arise in a society—an organism—sustainability scientists must endeavour to generate a robust understanding of the metabolic pattern of that society. In other words, they must endeavour to understand the complicated set of material and energy exchanges within the society and between the society and its surroundings, as well as the technical characteristics and functions of the metabolic processors associated with those exchanges.

5.2.2 Theoretical Pillars

A theoretical reference for those working to profile societal metabolism is presented in the following. The pillars of the foundation operationalise the drivers, pressures, states, impacts, responses (DPSIR) framework (Smeets and Weterings, 1999) and their presentation is organised accordingly. The pillars emerge from more than two decades of development of the multi-scale integrated analysis of societal and ecological metabolism (MuSIASEM) approach, which is the preeminent framework used by scientists working with the concept of societal metabolism (Giampietro, Mayumi, and Ramos-Martin, 2009; Giampietro and Mayumi, 2000; Giampietro and Mayumi, 2000).

Figure 32: Simple schematic detailing the relation between state, pressure, and impact



Source: Own representation

The state of a society, a system, can be assessed in terms of the internal set of metabolic and repair relations. In relational biology, metabolic relations are also referred to as "material entailments"—a material flow is "entailed" between two processors when we assert that a metabolic relation exists between the two processors. Repair relations are also referred to as "functional entailments" since what is "entailed" is a metabolic processor itself—metabolic processors are functions in mathematical terms. In relying on relational biology (Rosen, 2005), societal metabolism gains not only a universal modelling language but also a theoretical edifice supporting the idea that societies are organisms not in some metaphorical sense but rather in a literal sense (Renner, Louie, and Giampietro, 2021). In Figure 32, Point 1 indicates in representative form the state of a society and Point 2, the state of a biosphere resource. The concept of state is illustrated in more detail later in this section as well as in the following section, but, in initial very general terms, state can be understood to refer to the internal set of causal relations of a system. The two types of causal relation we have been discussing are metabolic relations and repair relations. Scientific models themselves can be understood as explanations of the state of a system. A model of the state of a social-ecological system divides the system into various parts, like various biosphere resources such as a forest and a fishery and institutional sectors of society such as a primary industrial sector and a manufacturing sector, and then proceeds to describe the various causal relations between those parts.

The field of biophysical economics acts to bridge the assessment of state in biology and state in sociology. The work of (Georgescu-Roegen, 1971), so-called father of biophysical economics ("bioeconomics"), is of particular use. Bridging economics in sociology and metabolism in biology may sound a stretch but in fact is not so difficult of a feat. (Polyani, 2001) substantively defines the economy to be the "instituted process of interaction between man and his [natural and social] environment, which results in a continuous supply of want satisfying material means." As the relational biology discussion emphasized, metabolism is about material entailment, hence assessment of societal metabolism involves fundamentally an assessment of economy, plus the for-what of the economy embedded in broader society. Translating the language of relational biology into the language of Georgescu-Roegen's bioeconomics, a metabolic input or output is a flow and metabolic processors, which require repair to remain stable in time, are funds. Funds differ from stocks in that stocks do not metabolise anything, or if they do, they metabolise to a negligent degree. Whereas a dairy cow is commonly given as an example of a fund, a fossil aquifer serves as an example of a stock. Funds are fundamental to the circularisation of resource flows but they come at a price—they must be maintained. In this way, discussion of system state in relation to metabolism and repair, flows and funds, our theoretical foundation can be seen to cast a significantly broader consideration than input-output style approaches such as material and energy flow accounting. To make the point, in material and energy flow accounting, for example, it is typical to sum together in terms of mass broad bundles of resource flows—imported cement plus imported computer chips. In contrast, in flow-fund accounting, emphasis is placed on defining flows in relation to funds (stable elements) and the functions those funds serve. Cement and computers chips serve very different functional roles in society; hence those flows are used by different funds and typically must be individuated in flow-fund accounting. This added consideration becomes invaluable when the society being assessed is faced with a need to undergo substantive change due to a major sustainability predicament—transformation of a society requires a restructuring of the functional relations between flows and funds.

Following the above understanding of system state, a system driver is simple enough to understand. A driver is a change in state that brings about change in a material or functional relation. Population growth in a society can be understood to drive, for example, an increased requirement for nutrient carriers. The population is understood as a metabolic processor or, equivalently, as a bioeconomic fund. Change in the fund drives, in this example, change in the requirement of a material input flow.

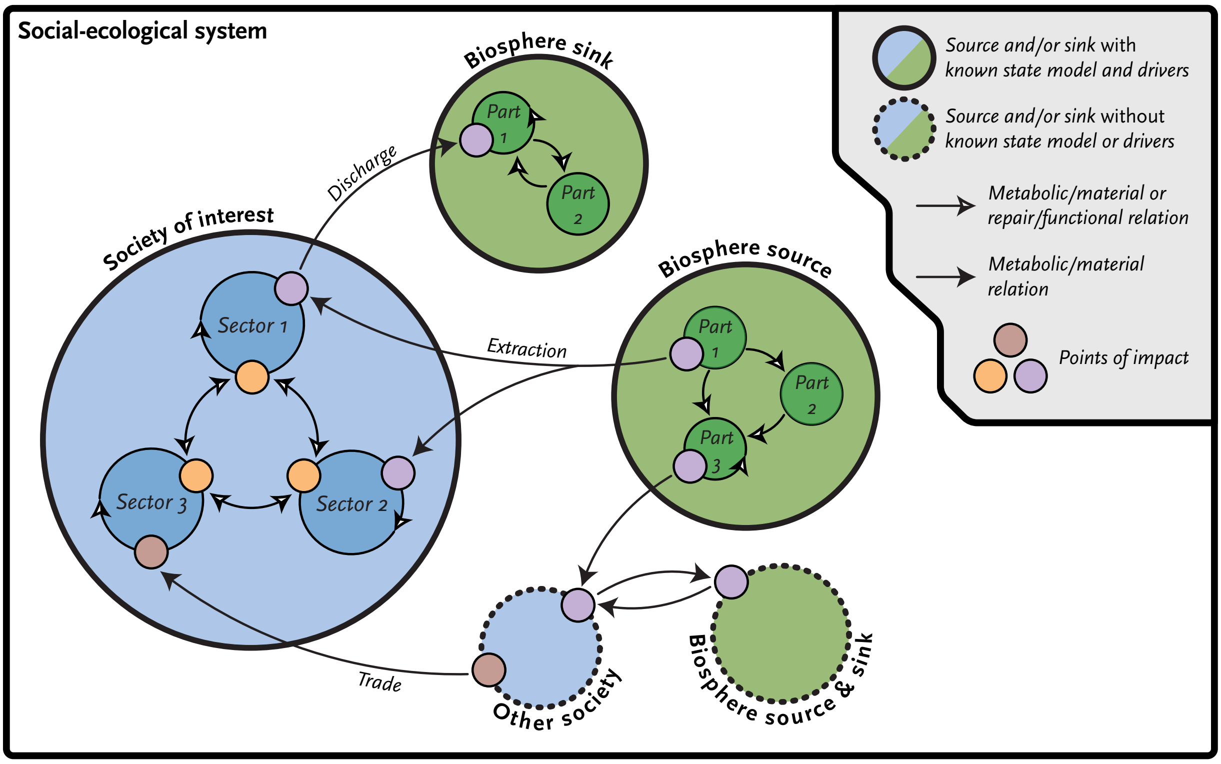
A pressure is an external flow—a flow between a system and its surroundings (Points 3 and 4 in Figure 32). A pressure might take the form of a resource extracted from the environment, like fish from a fishery or lumber from a forest. Or, pressure might take the form of a waste flow released into the environment, such as plastic dumped in an ocean or various gaseous pollutants discharged into the atmosphere. The profile of pressures generated by a society is assessed in terms of the necessity of favourable gradients of material and energy with the society's surroundings. In relation to influent, pressures must be matched by an adequate supply capacity; in relation to effluent, pressures must be matched by an adequate sink capacity. The term favourable in "favourable gradient" is meant here in two senses (1) that society is out of equilibrium with its surroundings, and (2) that pressures are identity dependent. To the second point, an example is due. Pork is a favourable energy and nutrient flow for Spanish society. Pork is not a favourable energy or nutrient flow for Iranian society nor for a passenger vehicle, the former due to religious identity and the latter due to technical identity. Hence, pressure variables—flows of material and energy—do not exist in general, rather they are defined in relation to the metabolic identities of the societal funds that generate them and the ecological funds that stabilise them. They serve specific functions for specific parts.

State and pressure come together to form the so-called state-pressure relation. The most basic assessment of a pattern of societal metabolism is a diagnostic of the state-pressure relation, which must be established simultaneously across different levels of analysis (macro, meso, micro, et cetera) studying the various constituent components of the society. This diagnosis is capable of informing in which ways system state and pressure could be adapted if a system's surroundings were to transition from favourable to unfavourable. When assessing a state-pressure relation, there is no preferred level of assessment. More in general, there is no preferred descriptive domain. Rather, multiple non-equivalent and non-reducible yet equally legitimate and relevant descriptive domains must be brought into play in an assessment of societal metabolism. This is a basic observation made by hierarchy theory (Ahl and Allen, 1996; Allen and Starr, 1988) and, more in general, by complexity theory. A variety of descriptive domains prove invaluable when society is confronted with an issue of sustainability. For example, agricultural products can be measured at different levels of resolution—the levels of soil, crop field, farm, productive region, country, bloc of countries, et cetera. Agricultural products can also be measured using different metrics—in terms of total mass, calories, specific nutrients, monetary value, et cetera. A relatively aggregate measure of total mass informs issues of transportation. A relatively disaggregate measure of calories and specific nutrients, detailed by crop variety, informs dietary concerns in relation to food security. Both measures are essential and neither measure directly translates into the other, at least not without prior knowledge of a host of context dependent conversion factors.

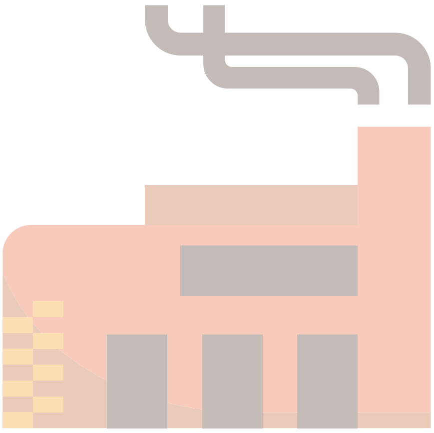
When the pressures exerted by the different activities carried out in a society are traced onto specific ecological funds operating in the society's surroundings, an impact can be assessed. To achieve this, the state of the ecological fund in the surroundings that is being related to, for example a forest system from which forest products are being extracted, must be modelled (Point 2 in Figure 32). Although sustainability science usually focuses on the characterization of impacts occurring in the natural environment, which in other words is a focus on ecosystem metabolism, impacts can just as well be on other social systems, for example impacts due to the externalisation of economic production through trade. As indicated by Points 5-8 in Figure 32, environmental impacts can occur both on the receiving of a flow, for example waste dumped on a sink (Point 8), or on the extraction of a flow, for example natural resources extracted from a source (Point 7). It must be stressed again that pressures cannot be defined in general but rather in relation to specific functions. Society demands forest products (Point 3) for both heat production in the energy sector and raw material for the manufacturing sector, for example. This detailing of pressures by the empirically observable purposes they serve is crucial to later be able to anticipate the societal impacts (Points 5-6) brought about by a changing environment.

Last, a response is an active change in a material or functional relation. "Active" is a keyword here—responses, even when evoked by a stimulus, are goal-oriented. Response therefore involves the future. In broad terms future studies can be broken down into the layers forecast, foresight, and anticipation (Poli, 2019). In a forecast it is assumed that the structure—the state-pressure relation—of the phenomenon being modelled will remain essentially the same over the relevant time period. Projection and extrapolation generally imply forecast and in general parlance "predicative models" are examples of forecasting devices. Inanimate systems such as astronomical systems are well-suited for forecasting, though the domain of appropriate application of forecasting is frequently put to the test with econometric models and climate change models, most of which are, in practice, used as forecasting devices. In contrast to a forecast, a foresight exercise generates a variety of possible futures, each characterized by qualitative change to the structure of the system of interest. These qualitative changes are discontinuities, not mere tweakings of quantitative parameters. In relation to bioeconomy, see, for example (European Environment Agency, 2022; Joint Research Centre, 2021). Finally, an anticipation synthesizes outputs from forecast and foresight and mobilizes that synthesis to guide action. Response is about anticipation and to say society anticipates is to say that society uses the future to guide action. Robust anticipation in a multi-scale integrated assessment of societal and ecosystem metabolism implies an open and adaptable approach to science, approach to policy, and approach to the science-policy interface. The canonical example of an anticipatory system is an organism and anticipation science is, like our theory of societal metabolism, grounded in relational biology (Louie, 2019). Figure 33 illustrates the subject matter of our discussion and summarises it.

Figure 33: Holistic modelling of societal and ecosystem metabolism, to be later used to inform deliberation over bioeconomy



Source: Own representation



5.2.3 Diagnostic assessment of a metabolic pattern

The model output of a diagnostic assessment can be used to generate dashboards of mixed quantitative and qualitative indicators, later useful in processes of informed deliberation. In this section, the theoretical pillars presented in Section 5.2.2 are operationalised in more practical terms. Several approaches complementary to the bioeconomy sustainability assessment are related to.

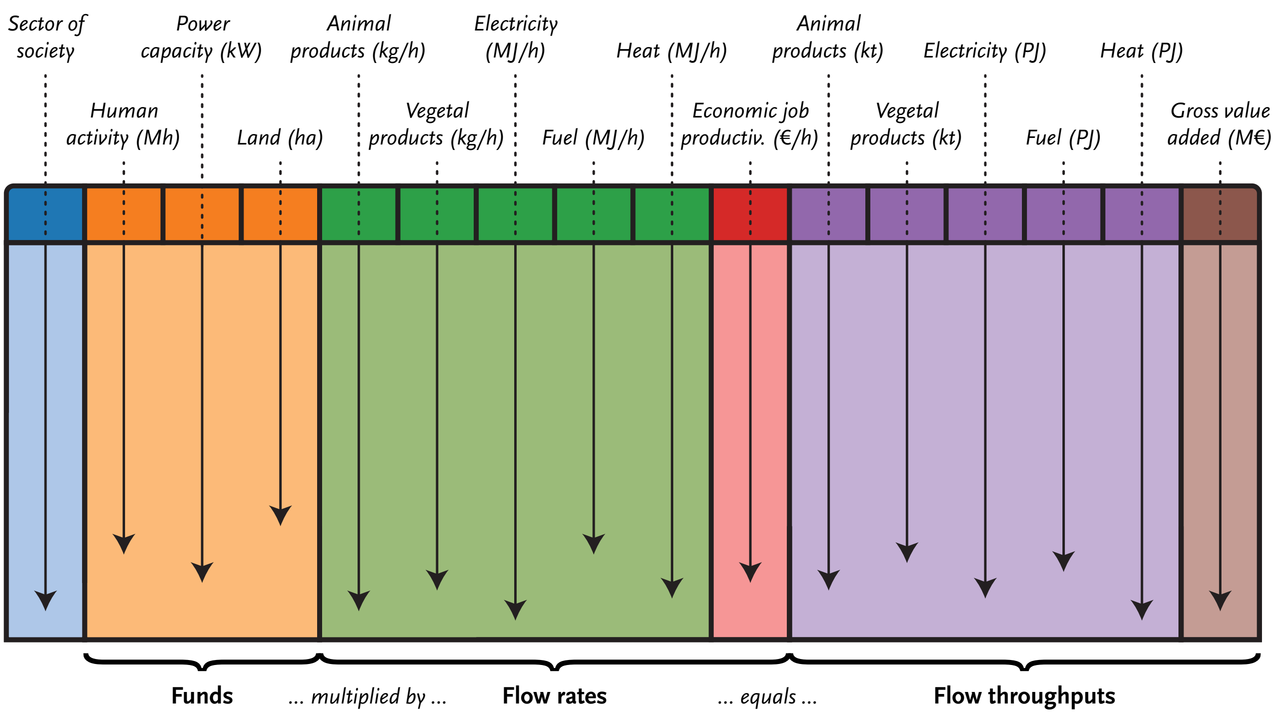
The levelized assessment of the state-pressure relation of a society requires at least three levels—a focal level, a superior level, and an inferior level. Across these levels one does not analyse metabolic flows and metabolic processors in general but rather flows are analysed with respect to processors—expected technical profiles—and the functions they serve in the metabolic pattern. One practical consequence is that key variables and the data arrays they summarise into include a wide mix of units. Just because two system variables could theoretically be measured using the same unit does not mean those two variables are commensurable or can practically be summed and often system aspects cannot even, from a biophysical perspective and with respect to the purpose of an analysis, be measured using the same unit. At the level of the transportation sector, for example, energy flows can be meaningfully accounted for in terms of fuel in Joules and electrical energy in watt-hours. This descriptive domain is not meaningful at the passenger vehicle level, however, where fuel must be broken down into such categories as diesel and gasoline and electrical energy in such categories as baseload, peak, and intermittent. If the purpose of the analysis is to assess, simply, the general long-term electrification of the transportation sector, the first, higher level might be primary. If the purpose is to understand how energy distribution networks need to be (re)organized in the face of renewable energy inroads and energy security concerns, the latter, lower level may likely be necessary. If a comprehensive assessment of the sustainability prospects of a society is needed, likely both levels must be considered simultaneously as they are non-equivalent, non-reducible and speak differently to the actual diversity of equally legitimate stakeholder concerns. Different descriptive domains entail the use of different accounting categories.

What is the result of this all? A quite convoluted dashboard. Such is unavoidable when making a robust biophysical assessment and is known as the “curse of dimensionality”—a term originally coined in the field of dynamic programming to refer to practical and analytical problems that arise when dealing with high-dimensional spaces. To complicate matters further, in general, all variables considered in an assessment can be represented both intensively (per unit) and extensively (in scale). When represented intensively, several denominators can and usually should be selected. Intensive representation, though still numerical, speaks more towards a process quality. Technical coefficients are intensive. A flow of timber from a biosphere source, for example, can be represented in extensive form with units of cubic metres. This representation of metabolic throughput could be useful when informing potential impact on society. That same flow can also be represented in intensive form with units of cubic metres per hour of human labour. This representation of metabolic rate could be useful when informing labour allocation needs or labour efficiency gains. It can also be represented with units of cubic metres per hectare, which could serve as a proxy of ecosystem stress, related to impact.

With a view towards practical application, it must of course be admitted that it is difficult for dashboard users to understand a set of indicators that covers several expert domains—one indicator expressing timber extraction in cubic metres and the next gigajoules of natural gas. Progressive disclosure of the indicators helps manage the complicatedness and otherwise indicators can often be expressed in relative terms against a benchmark or, sometimes, in composite form. Beyond these methods, a method of reducing the dimensionality presented by a dashboard of biophysical indicators à la carte, as during a deliberation cycle, is needed. Section 5.2.4 discusses just such a method. Meanwhile, it is informative to compare biophysical economical modelling to conventional economic modelling. One of the usual features of conventional economic modelling is the representation of all (or most) variables in monetary terms. One of the key functions money serves is its ability to act as a broad equivalence class, allowing variables to be directly compared with each other without the need for any conversion factors. This desirable characteristic comes at the price of a dramatic loss in biophysical relevance. What is the impact on a forest ecosystem of €100 worth of timber extraction? Is a given forest ecosystem capable of providing €100 worth of timber? It is impossible to tell and difficult to convert that €100 back into biophysical units, such as cubic metres. It must also be admitted that, in a holistic assessment of the sustainability of different societal states, many variables simply cannot be expressed in monetary units. What is the price of one’s kin? What is the price of a loss of biodiversity, or a loss of human life? Having given due consideration to these points, expression in monetary terms is a key leverage point for governance initiatives—it is a necessary consideration but not a sufficient consideration. As was the case with input-output analysis, biophysical economics can be seen to cast a broader net than conventional economics, including consideration of monetary concerns among many other considerations.

Putting order to the situation, the set of variables emerging from a multi-scale integrated analysis of societal and ecosystem metabolism can be summarised into several key data arrays, foremost (1) an array of end-uses and (2) an array of environmental pressures. An array of end-uses details resource flows against their societal end-uses, for example agricultural product consumed in the household sector and agricultural product consumed in the service sector—by restaurants and so forth. This agricultural product is represented extensively, giving an idea of the total stress on agroecosystems and demand by societal function, and intensively against stable elements of system state. Stable elements of system state are our fund elements (metabolic processors). For example, agricultural product could be represented per hour of human activity in the service sector or agriculture sector, per kilowatt of power capacity, per infrastructure requirement, per land use, et cetera. Figure 34 presents the basic notion behind an array of end-uses. An array of environmental pressures then summarises the pressure flows between society and the natural environment. This array of pressures can be compared with the expected capacities and conditions of the source and sink resources in the biosphere being related to. As discussed in Section 5.2.2, pressures can be translated into environmental impacts where they are temporally and spatially localised against specific ecosystem resources. To do so, a model of system state for those specific resources must be had—this is the domain of ecological modelling. Once calculated, such impacts can be summarised in an array of environmental impacts.

Figure 34: A rudimentary matrix of end-uses—a single level of description taken from a larger multi-level array of end-uses; the flow rates are "intensive" variables and could also be per kilowatt of power capacity or per hectare of land rather than the shown per hour of human activity



Source: Own representation

All these data arrays can be divided into a local or "domestic" version and an external or "virtual" version. One key insight from the field of biophysical economics is that modern civilization has become materially wealthy precisely by linearising the economy—by working against circularity. The economy has achieved this in large part by increasing by several orders of magnitude the scale and scope of power capacity, fuelled by dense fossil resources. In modern forestry operations, for example, a very small fraction of the energy invested is direct human or domesticated animal power. The vast majority is linearised mechanical power. The economy has also achieved immense material wealth due to externalisation, both externalisation of procurement and handling efforts onto ecosystems and externalisation onto second societies. The most materially developed societies indeed generally exhibit high degrees of externalisation, importing a wide range of commodities from second societies as typified by imperial and colonial relations (Hickel et al., 2022). If the circularity of resources in society is to be increased and a more sustainable bioeconomy achieved, externalisation will need to be closely analysed. To get an idea of the local biophysical savings gained by a society importing commodities from a second society, an external or "virtual" array of end-uses for that second society can be generated. The environmental pressures required by that second society to produce the goods imported can then be summarised in a second external or "virtual" array.

Capable of integrating information from a wide range of sources, the approach could be used to structure the knowledge space surrounding the sustainability of bioeconomy in the European Union, offering flexibility and transparency. The approach has been applied previously at scales ranging from global down to the provincial watershed level. Among many possible examples it has been applied to the resource nexus in general (Giampietro, Renner, and Cadillo-Benalcazar, 2022), specifically on food systems (Cadillo-Benalcazar, Renner, and Giampietro, 2020; Giampietro, 2004; Renner et al., 2020), on energy systems (Di Felice, Ripa, and Giampietro, 2019; Giampietro, Mayumi, and Sorman, 2013; Manfroni, Bukkens, and Giampietro, 2022), on waste systems (Chifari et al., 2018; Chifari et al., 2017; Torrente-Velásquez et al., 2020), on water systems (Madrid-López and Giampietro, 2015; Cabello-Villarejo and Madrid-López, 2014), on urban systems (Pérez-Sánchez et al., 2019), et cetera. Following the structuring of the knowledge space, the approach can be used to inform deliberations over the future of bioeconomy in the European Union, for example, considering in a holistic manner environmental feasibility, economic viability, and social desirability in policymaking cycles.

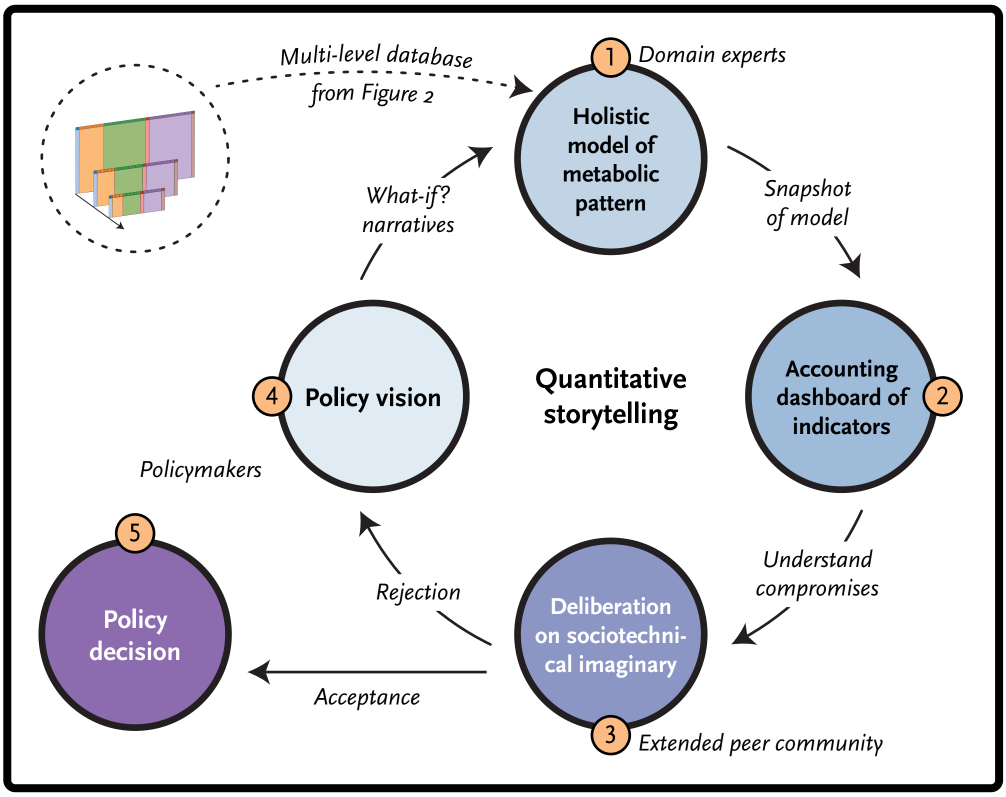
5.2.4 Informed deliberation using quantitative storytelling

The outputs of a scientific procedure of accounting for societal and ecosystem metabolism can be used to inform deliberation over bioeconomy policies through a process of quantitative storytelling. The basic idea of quantitative storytelling for bioeconomy discussion is to bring into play a diversity of storytellings, built of non-equivalent narratives, and use quantification via negativa to both define the boundaries of the bioeconomy option space and identify desirable pathways forward (Giampietro, 2023; Saltelli and Giampietro, 2017; Kuc-Czarnecka, Piano, and Saltelli, 2020). When governing in complexity it is critical to make an earnest and continual effort to falsify hegemonic narratives, identifying and consequently removing from the discussion the narratives that are unfeasible or unviable. Resilience is gained as a result. Faced with an issue of sustainability, such falsification process may often entail societal confrontation with uncomfortable knowledge, that is "unknown knowns" otherwise denied, dismissed, diverted from, or displaced in business-as-usual (Rayner, 2012). Several examples of such confrontations together with related resources are made available on the Uncomfortable Knowledge Hub[53].

Figure 35 roughly illustrates an informed deliberation schematic following the assumption of a perspective of societal metabolism and subsequent building of a quality model. After having built a quality model (Point 1 in Figure 35), in an act of foresight, a snapshot of the model is taken, entailing the consideration by domain experts of a range of qualitative inputs on the configuration of the state of the metabolic pattern being modelled—the consideration of a specific "sociotechnical imaginary". This snapshot is summarised in a large dashboard of indicators (Point 2). The dashboard and the compromises it embraces is then deliberated over by the extended peer community (Part 3). If the result is found to be unfeasible, unviable, and/or undesirable, it is rejected and through constructive disagreement a new policy proposal is formed (Part 4). This policy proposal and the fresh sociotechnical imaginary it entails is fed back into the quality model of the metabolic pattern, restarting the cycle. If, in the alternative, the result of the dashboard deliberation is an acceptance of the vision, a policy decision is made (Part 5). In the following discussion, the schematic is rationalised and described in more detail. The discussion, indeed quantitative storytelling itself, helps resolve the tension between quantitative modelling and qualitative judgement, gaining analytical rigor from the former and plausibility from the latter.

([53]) *https://uncomfortableknowledge.com/*

Figure 35: Quantitative storytelling in a decision-making process for the addressing of bioeconomy futures



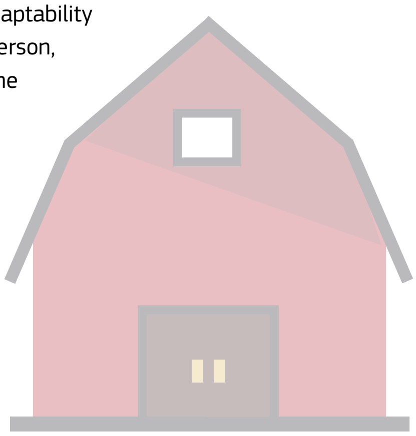
Source: Own representation

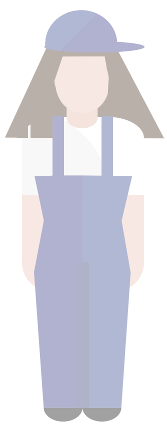
The current discussion over a transition towards a more sustainable bioeconomy reflects on a situation where a large dose of uncertainty exists, where stakes are high, and where decisions are urgent. These three premises of our modern predicament mean that, in terms of modelling, we are operating in the space of post-normal science (Funtowicz and Ravetz, 1993). On the science-policy interface we must learn to manage, rather than ignore, the unavoidable uncertainties involved (including risk, ambiguity, ignorance, et cetera). Insofar as these uncertainties make it difficult to directly judge the quality of outputs, emphasis is placed on obtaining the highest possible procedural quality. In this way the assumption is made that the quality of outputs, where impossible to judge directly, can be substantially improved by increasing the quality of the procedure generating the outputs. In contrast to the relatively controlled situation where normal science applies, said quality procedure must include not only domain experts but rather the full gamut of users and producers of results. In other words, to be able to identify a pathway towards a societal future that is simultaneously environmentally feasible, economically viable, and socially desirable, quantitative storytelling for bioeconomy deliberation must include insights from the extended peer community, going beyond a traditional collaboration between scientific experts and policymakers and including a broader range of society's citizens (Funtowicz and Ravetz, 1990).

This approach has been prominently used in the framework of the MAGIC-NEXUS project to evaluate the narratives used in several policy areas, including several bioeconomy-related topics. For example, efforts were made in relation to the European Union's Circular Economy Action Plan, the Common Agricultural Policy, a host of energy directives including the Renewable Energy Directive, the Water Framework Directive, and several directives related to the protection of the environment . A wide variety of biophysical incompatibilities were identified in the course of those efforts, in that way informing and substantial improving future policy.

As first discussed in Section 5.2.2's presentation of theoretical foundation, societal response to issues of sustainability requires anticipation, which is to say it requires a study of the future that gives due consideration to forecast and foresight but moves beyond both. Faced with a post-normal situation, quality results are not delivered through a rote process of "prediction and control" based on mechanistic simulations. Rather, to deliver quality results, multiple sociotechnical imaginaries must be generated, understood, and deliberated over (Jasanoff, 2015). This is how living systems function, contrasted to how machines function.

If not "prediction and control", how then can a responsible development pathway be selected among an ensemble of sociotechnical imaginaries? Optimality is a slippery concept when dealing with complexity. Following an iterative cycle of deliberation, to ultimately make a favourable policy decision, social multi-criteria evaluation must be used. As Section 5.2.3 showed, the indicator dashboard emerging from a holistic model of societal metabolism is complicated and multifaceted. Social multi-criteria evaluation works to reduce that complicatedness through (1) selection of a set of most relevant indicators in accordance with a set of identified concerns, and (2) synthesising that set of indicators through the attribution of weights, per se "optimising" within a certain narrative structuring (worldview). For example, one key insight from theoretical ecology is that there exists an unavoidable tension between efficiency and adaptability (see the adaptive cycle in (Holling and Gunderson, 2002)). Whereas efficiency is important in the short term, adaptability is important in the long term, such as for the sake of resilience. Whereas efficiency goals are typically seen as part and parcel to traditional optimisation procedures, one must take care to not overemphasise efficiency—technological progress cannot be relied on in and of itself. Focus on efficiency generates lock-in, a reduction of diversity meaning a reduction in redundancy in the expression of given functions, and the focal aspect itself may ultimately prove to have misled. Overemphasis on efficiency can, furthermore, lead to counterproductive discontinuities. For example, during the transition to coal as an energy carrier in the economy in the mid-to-late 1800s, economist (Jevons, 1865) observed a certain paradox where, as the efficiency of coal use increased, the overall magnitude of coal use also increased. Jevons' paradox differs from the more well-known rebound effect in that the observed increase in coal use resulted primarily from qualitative change to the state of society—a diversification of coal end-uses rather than a mere multiplying of current uses. Qualitative change to a system's state is not possible to predict within a given computational model, hence the need, when dealing with post-normal predicaments such as that considered in the governance of bioeconomy, for a semantically open multi-scale integrated assessment of societal and ecosystem metabolism (Section 5.2.2 and Section 5.2.3) coupled with a deliberative process of quantitative storytelling (this section). It bears mentioning that, thanks to his insightful contributions, Jevons is sometimes referred to as the "father of anticipation" within the economic sciences.





6 Conclusions and way forward for monitoring and assessing the EU bioeconomy

This document reports the trends and progress related to the bioeconomy and its sectors in the EU-27; contributes a discussion on the European, national and regional policy landscapes (Chapter 2); explains the EU-level monitoring efforts (Chapter 3); describes results from the EU Bioeconomy Monitoring System (Chapter 4); and elaborates on proposals for new approaches to monitor and assess the state of the bioeconomy (Chapter 5).

The overarching and cross-sectoral nature of bioeconomy is reflected in the diversity with which European countries have adopted the concept. Bioeconomy policies and initiatives exist, or are being developed, in many of the EU Member States and their regions as well as at macro-regional level. In Europe, there are three large macro-regional bioeconomy initiatives involving governmental authorities from several European countries. At national level, ten EU Member States have dedicated bioeconomy strategies (as of December 2022); seven others have national strategies under development; another six MS have other policy initiatives dedicated to the bioeconomy; and the remaining four MS have strategies related to the bioeconomy.

Regardless of the bioeconomy approach taken, a monitoring system can support and facilitate decision-makers in their assessments of the performance and progress towards specific strategic objectives that reflect an overall vision for a sustainable and desirable bioeconomy. The bioeconomy consists of complex social, economic, and environmental integrated systems: comprehensive, reliable and comparable information is needed to steer these systems towards the desired outcomes.

The JRC was tasked in 2018 with the definition and implementation of an EU-wide monitoring system to assess the progress towards the five objectives in the EU Bioeconomy Strategy. In 2020 the JRC and FAO have published a general guidance to design and implement an effective monitoring system for a sustainable bioeconomy that could be internationally coherent for different geographical levels and contexts. The guidance presents a series of general steps to establish an effective and robust monitoring system to monitor grouped in three stages: (1) A conceptual stage, where all the elements of the monitoring system are defined; (2) An implementation stage, where the conceptual framework is populated with indicators and data collection methodologies are selected; and (3) An assessment and communication stage, where the trends are evaluated and communicated. This report realizes the third stage by presenting a first assessment of the state of the EU Bioeconomy, as derived from the monitoring system established following the first two stages.

In this report, we distinguish four components of EU Bioeconomy Monitoring activities currently on-going at the JRC: The EU Bioeconomy Monitoring System itself (the BMS), the assessment of bioeconomy progress, a research component and engagement aspects. The system itself includes the conceptual framework, as well as the whole set of indicators and their metadata, including the gaps and placeholders (known unknowns). It includes the activities that contribute to data collection, filling of gaps in indicators, and progressing the understanding of the bioeconomy as a system. This component is summarized in an online dashboard where all indicators and their trends are provided for a detailed and real-time evaluation of the multiple aspects of a sustainable bioeconomy. The assessment and communication component is a periodical evaluation and interpretation of the progress of the EU bioeconomy (this report). The research component, which is an on-going set of research activities carried out at JRC in collaboration with experts outside of the JRC, is a means to maintain the system useful and up to date considering the changing policy arena. Currently, the research component can be summarized as focusing on understanding the social-ecological outcomes of the EU Bioeconomy, as demonstrated by the activities in several Focus Boxes and in Chapter 5, and on reflecting on the normative basis for the bioeconomy with a focus on capturing aspects of a 'desirable' bioeconomy emerging from the broader societal context and translating them into the conceptual framework (Giuntoli et al., 2023). The engagement component consists in a set of activities that aims to foster collaboration with other institutions and experts, for instance by collaborating in defining new indicators or new approaches for the assessment of the bioeconomy, and could broaden in the future to include a wider range of disciplines (especially from social sciences and humanities) and of knowledge types (e.g. citizen engagement) (Robert et al., 2020).

6.1 The EU Bioeconomy Monitoring System

Since its first web-based appearance in 2020, the JRC has been further developing the EU Bioeconomy Monitoring System by gathering indicators and, where not already publicly available, generating new approaches and indicators in order to fulfill the comprehensive and broad-ranging scope of the conceptual framework designed for the BMS.

The conceptual framework of the BMS was designed as such to be able to operationalise the five objectives defined in the EU Bioeconomy Strategy. The framework is a hierarchical nested structure, whose advantage is to be able to aggregate the indicators into logical vertical clusters thanks to the location of the indicators within the framework and their contribution to give a clear indication of directionality towards the Strategy objectives, which are at the top of the hierarchy (see Figure 9).

6.1.1 Limitations of the EU Bioeconomy Monitoring System

The main limitation for the current EU Bioeconomy Monitoring System is the number of gaps in indicators. The system was designed starting from a conceptual framework, meant to be meaningful and comprehensive, rather than following a data-driven approach; this had the advantage of producing a consistent overview of the multiple facets composing a sustainable bioeconomy, but it implied massive investment in data collection, data generation and gap-filling. Thus, while the assessment presented in Chapter 4 provides useful insights into the direction of progress of the EU Bioeconomy, this assessment is necessarily incomplete from a whole bioeconomy perspective. In particular, we are aware that aspects connected to the social, justice and equity dimensions of the EU Bioeconomy are lacking from the current dashboard, either because many of these aspects are hard to quantify due of the nature of the issues considered, or simply because useful datasets/proxies do not yet exist. (Giuntoli et al., 2023) highlight the importance of including perspectives from Environmental Justice scholarship when deliberating on the objectives of a sustainable and desirable EU bioeconomy. This could thus be an area of further development for the BMS.

Another main limitation is of course in the quality of the data. We often see trends with sharp dips and peaks. This is often a sign that there is an issue with the data or indicator itself.

6.1.2 Improving the EU Bioeconomy Monitoring System quantitative assessments through weighted indicators

While the BMS was constructed to assess progress towards EU Bioeconomy Strategy targets, it was not constructed to assess interlinkages and dependencies throughout the bioeconomy, hence causal effects of indicators on one another, nor are we able to weigh the importance of particular indicators within the system. All indicators were equally weighted in importance in Chapter 4, yet if we consider that for some key components, only one indicator was used, whereas for other key components, more than one indicator was used, by default we are giving more importance to the single indicators representing an entire key component.

As pointed out by Strona (2022): "Try thinking of whatever aspect of reality, and it will most likely reproducible in the form of a network". He suggests that a deeply informative means of understanding a system is through using nodes and connections, and where possible, add direction and weight. The bioeconomy is a set of intertwined interconnections of various degrees of strength and with directionality, but quantifying such a network would be very challenging. We may, however, want to think about how to identify the most critical nodes and connections in order to focus on indicators in those areas, or to attribute weights to indicators. This type of exercise would improve the understanding of interactions within the bioeconomy itself, but would also lead to a more robust monitoring system.

6.2 Assessment of EU bioeconomy

The assessment, both at indicator and at a higher-level aggregation (key component level, see Chapter 3), shows that while some aspects of the EU bioeconomy are following positive trends, others are not. There may be room to assume that trade-offs are also taking place. For instance, while the trends show (at EU level) that the resource efficiency is improving, gauged by the improvement in energy efficiency, waste recovery and value of raw biomass, the pressures on ecosystems from forestry and agriculture are in fact increasing, and in the case of forestry, this is impacting the carbon sink.

Applying a bioeconomy lens to scrutinizing the indicators that are often used in other monitoring frameworks, we move beyond sectorial interests, and academic and political silos, allowing instead to take a broad, holistic and systemic perspective to evaluate the bioeconomy as a complex social-ecological system. However, through this exercise we have observed that it is nonetheless still quite challenging to interpret indicators. Hence more research is always welcome to this effect.

6.3 Research in monitoring the bioeconomy

The monitoring system itself cannot be considered a static and "final" item, but it also needs to be flexible and able to change in order to adapt to changes in priorities, concerns, and values, as well as to changes in understanding of the bioeconomy. For this reason, research must be pursued on the topic.

A first line of action is related to the integration of bioeconomy services in the BMS (Section 5.1). While the purpose of the indicators related to Objective 5 is to measure the socioeconomic relevance of the bioeconomy, the services activities are still not considered in the current scope of the BMS. However, the academic literature already proposes some approaches to quantify the contribution of services to the bioeconomy. From an output-based approach, the value added of the bioeconomy would be comparable to that of biomass-producing and transforming sectors. According to our estimates, the value added in the bioeconomy sectors (including services) was between 10.9% and 16.0% of total EU GDP in 2019 (vs. 5-4 – 5.8% from the biomass-producing and transforming sectors currently considered in the EU-BMS). In the same year, the bioeconomy sectors provided between 20.5% and 29.6% of total employment, from which the biomass-producing and transforming sectors contributed with 8.9% - 9.5% of total employment. Substantial differences in both the size and the sectoral composition of the bioeconomy services are also found among Member States. Moreover, some countries, for which the estimated size of the bioeconomy is below the average with the current numbers in the BMS, would see the importance of the total bioeconomy substantially increased due to the integration of services. As a consequence of the above, the development of bio-based services markets, as stated by the EU bioeconomy strategy, would bring economic value beyond the targeted sectors of biomass production and bio-based industries, providing further opportunities to enable the green transition.

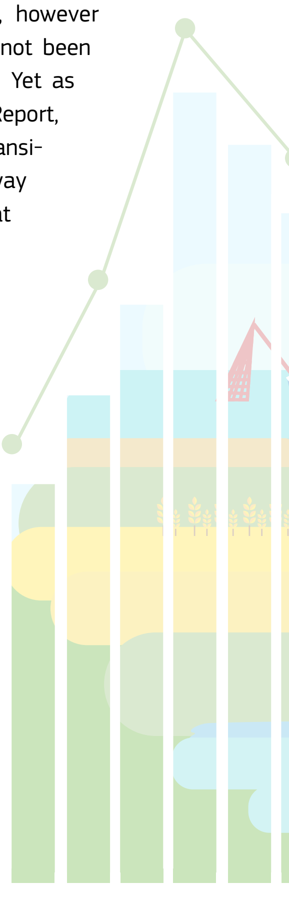
While the results in Chapter 4 and in the online dashboard provide a comprehensive picture of several individual trends, different tools are needed to provide an integrated assessment of the bioeconomy state. The MuSIASEM sociometabolic approach described in chapter 5.2 can provide a valuable way forward to support the governance of bioeconomy. By integrating into a coherent accounting framework the functional relations among societal, including economic transactions, and environmental components of the bioeconomy system, this approach allows to look at the bioeconomy through a holistic perspective. The outputs of accounting for societal and ecosystem metabolism can be used to inform deliberation over bioeconomy policies through a process of quantitative storytelling. The basic idea of quantitative storytelling for bioeconomy discussion is to bring into play a diversity of storytellings, built of non-equivalent narratives, and use quantification via negativa to both define the boundaries of the bioeconomy option space and identify desirable pathways forward.

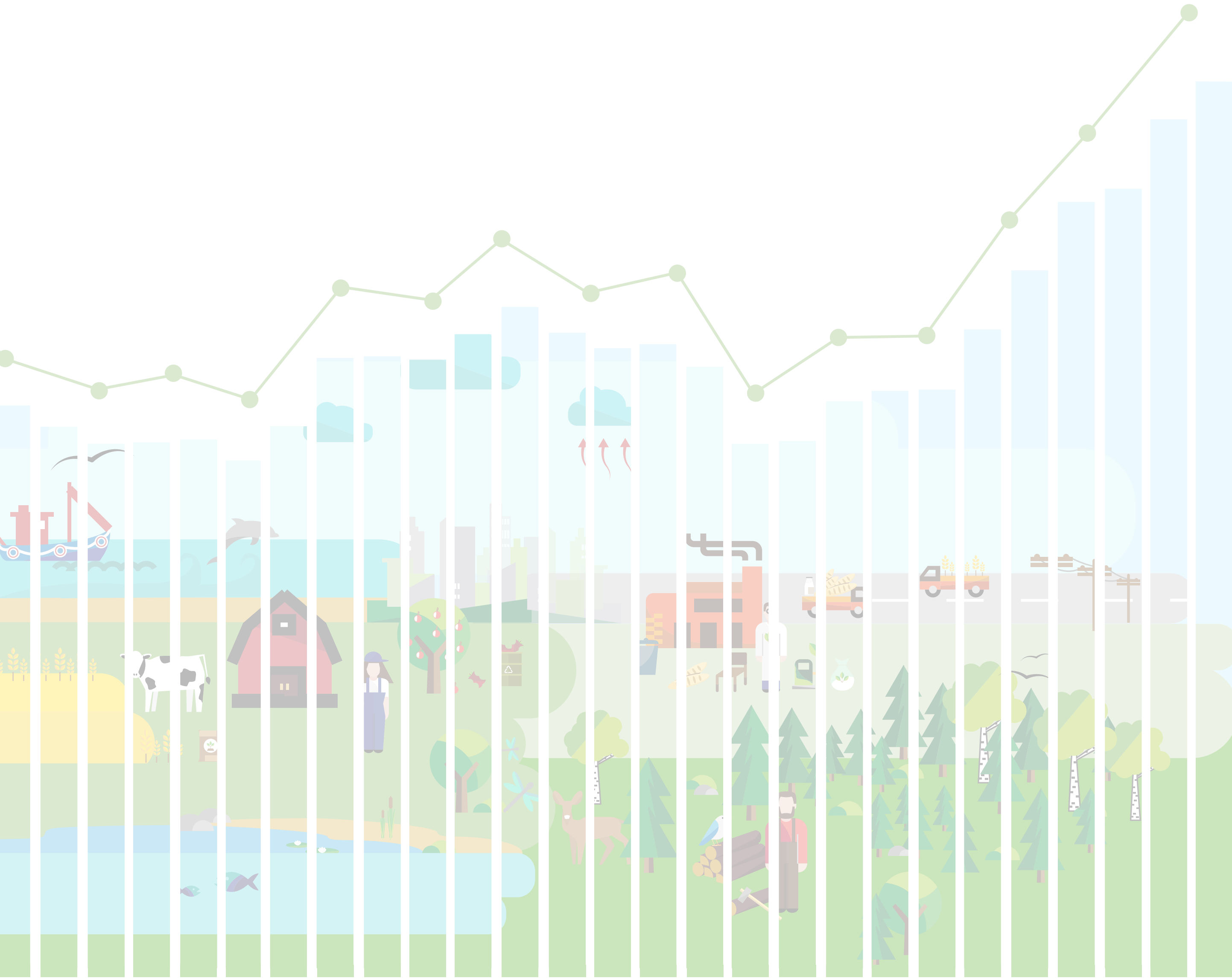
With time, the policy landscape of the EU bioeconomy has changed, namely following the proposal and implementation of the European Green Deal initiatives, leading also to an emerging overarching questioning of what a sustainable bioeconomy really means. Scholars have highlighted how narratives surrounding the EU Bioeconomy have predominantly focused on a techno-scientific and industry- and economy-oriented interpretations and concerns, centered around economic output, technological innovation, and the substitution of fossil carbon with biological. However, new diverse visions for a sustainable bioeconomy are emerging from various sectors of society. This large unexplored solution space could be crucial to achieve the societal transformation envisioned in the European Green Deal. (Giuntoli et al., 2023) present a potential new vision for a "green, just, and sufficient bioeconomy" and then venture into analysing what potential consequences embracing this new vision could have for bioeconomy research and governance. A key conclusion is that alternative visions should be explored in modelling as well as foresight exercises.

6.4 Engagement

Open discussions on aspects and characteristics of a sustainable and desirable bioeconomy should continue with integration of multiple actors and perspectives, however up to now, some actors, such as citizens, have not been dominant voices in Europe's bioeconomy scene. Yet as described in the Bioeconomy Strategy Progress Report, bioeconomy is not only an enabler for a green transition, but also an envisaged result, hence a new way of life of Europeans. Thus, it stands to reason that citizens should be heavily involved in deliberating how this new way of life could look like, and how it could be realized.

A broad unexplored solution space exists with different visions and configurations for the bioeconomy that could better support the EGD transition. The potential formulation for a new vision of bioeconomy (with its research and governance implications) could only come with sufficient engagement and participatory action.





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