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The Bioeconomy in economic literature: looking back, looking ahead

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Abstract. The objective of this paper is to provide a review of recent economic literature related to the Bioeconomy, in particular aimed at identifying relevant pathways for future research in this field. The paper is organised in four main parts. First, we illustrate the economic role of the Bioeconomy and its key statistics in the EU. Second we review economic topics related to the Bioeconomy production in a mainly private (company, consumer, market) perspective. Then we extend our attention to the review of wider social and environmental aspects with a focus on ecosystem services. Finally, we discuss the interplay of the above topics and cross cutting issues in the attempt to identify the most promising pathways for further research. While the economic literature is growing fast in all the fields of the Bioeconomy, we highlight in particular the need of more economic research focusing on transitions and innovation. However, we also highlight the need to take a system perspective and accounting explicitly for the trade-offs among the many objectives that the Bioeconomy is expected to target and to better account of the costs and benefits affecting different stakeholder groups.

Keywords: bioeconomy, sustainable development, bio-based economy, circular economy, ecosystem services.
JEL codes: Q57.

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1. INTRODUCTION AND OBJECTIVES

The editorial of the first issue of the journal Bio-based and applied economics in spring 2012 was entitled "From Agricultural to Bio-based economics? Context, state-of-the-art and challenges". The paper reviewed the trends in agricultural economic literature and asked whether there was a shift from traditional sectoral economics, such as agricultural economics, towards a more general discipline that could have been called "bio-based economics" (Viaggi et al., 2012). That title, in itself, provided somehow an agenda for the journal, and envisaged a potential evolution of the discipline in the next decade, though, at that time, the Bioeconomy was largely unknown by academic research in economics.

Since that article appeared, a lot of events and changes occurred: the Bioeconomy has become mainstream, while more and more countries have

their Bioeconomy strategy. The EU published an update of its Bioeconomy strategy in 2018, while Italy went under two versions of its country strategy.

The recent strategies in Europe, in particular the one from the EU, re-define the Bioeconomy as an aggregate of sectors using biological resources, emphasising the interconnection with ecosystems and the general contribution to economic development, while technologies, in particular biotechnologies, are much less prominent (European Commission, 2018). The Green Deal strategy has renewed the importance of the Bioeconomy and the circular economy, as the main means to achieve the transformative changes required to addresses global challenges, as the Bioeconomy can potentially create synergies among the various dimensions of sustainability (Giampietro, 2019; Peters, Jandrić and Hayes, 2020) secondary and tertiary resource flows and helps to identify what can and cannot be re-circulated within the metabolic pattern of social-ecological systems. Adopting the biophysical view, it becomes clear that the industrial revolution represented a linearization of material and energy flows with the goal to overcome the low pace and density of biological transformations. The required level of productivity of production factors in contemporary developed economies (flows per hour of labor and per hectare of land use).

The economic literature on the Bioeconomy has been growing steadily. At the end of April 2021, Scopus reports 849 papers in the fields of Social sciences, Economics and econometrics, and Business management and accounting, with title, keywords or abstracts mentioning the Bioeconomy. Papers published in 2020 were 187 in comparison to 21 published in 2012, while papers published in 2021 were already 97 at the time of writing this paper.

The literature on the Bioeconomy is taking shape, but did not substitute the literature in agricultural economics or food economics, both sectors being, on the contrary, flourishing. The Bioeconomy literature is rather focusing on new value chains and on topics that are more relevant for the Bioeconomy as a whole than for individual sectors.

The objective of this paper is to provide a review of recent economic literature related to the Bioeconomy, in particular aimed at identifying relevant pathways for future research in the field.

The approach is based on a literature review, but is far from being systematic. The papers used derive mainly from a screening of the Scopus database after searching for the keyword "Bioeconomy" and selecting papers in Economics, Business & management and Social sciences, or Bioeconomy and Ecosystem services. Then papers were selected based on a subjective evaluation of their ability to provide insights about recent trends, focusing mostly on the more recent papers. The outcome is discussed following an organisation of topics derived from an update of the structure proposed by Viaggi (2018). Though potentially relevant, for reasons of space we on purpose exclude studies focusing on descriptive developments on one single product and environmental assessment studies such as LCA, as well as studies describing the Bioeconomy in individual countries.

The remainder of the paper is organised as follows. In section 2 we illustrate key statistics and trends of Bioeconomy in the EU. In section 3 we review economic topics related to the Bioeconomy production in a mainly private (company, consumer, market) perspective. In section 4 we extend the topic to the review of wider social and environmental aspects with a focus on ecosystem services. In section 5, we discuss the interplay of the above and selected cross-cutting issues, in the attempt to identify the most promising pathways for further research. Section 6 concludes.

2. STATISTICS AND TRENDS OF THE BIOECONOMY IN THE EU

In spite of the relevance of the Bioeconomy, statistics related to the sector are still at a development stage. The main problem to obtain clear figures is the lack of a consolidated and harmonised methodology, which makes also difficult the comparison of results across countries. Also for sectors with well-established statistics (e.g. energy) disaggregating the Bioeconomy component may be a challenge.

The two main approaches for quantifying the Bioeconomy are the input-based and the output-based approach. The former attempts to measure the proportion of biomass in inputs used for the production of bio-based products (see for example Efken et al., 2016; Luke, 2019), while the latter tries to measure the biomass content of bio-based products (see for example Capasso and Klitkou, 2020; Vandermeulen et al., 2011).

In 2018 the International Sustainable Bioeconomy Working Group (ISBWG) published a review of approaches, applications and indicators to measure economic, social and natural resources aspects of Bioeconomy in different EU countries (Bracco et al., 2018). From 2017, the European Commission and the Nova-Institute have presented a common output approach for a cross-country comparison in some publications where a quantification of performance indicators relying on sectors and sub-sectors of the Bioeconomy for all EU member States are illus-

trated (Ronzon and M'Barek, 2017; Ronzon et al., 2017; Ronzon and M'Barek, 2018; Piotrowski et al., 2019).

Ronzon et al. (2020) updates the methodology and data presented previously in 2018 and proposes a methodology based on the following approaches: a) for the sectors that fully belong to the Bioeconomy, existing statistics are harmonized and used; b) for those sectors which only partially belong to the Bioeconomy, estimation of a "bio-based share" is derived from experts' consultations. In particular, agriculture, forestry, fishing, the manufacturing of food, beverages, tobacco, and paper are considered as sectors fully belonging to the Bioeconomy. Other sectors, like the manufacture of textiles, wearing apparel, leather, wood products, furniture, chemicals, pharmaceuticals, plastics and rubber and the production of electricity are included only partially in the Bioeconomy. Eurostat is the main data source for a quantification of socio-economic relevance in all sectors of the Bioeconomy in EU. In particular, PRODCOM (Eurostat, 2020) and the Structural Business Statistics (SBS, Eurostat, 2020a) database are the two main data sources. The principal indicators presented in the reports are the turnover, the employment and the value added.

From Porc et al. (2020) Figure 1 reports the percentage share of turnover in the Bioeconomy in EU-28 in 2017 and the trends between sectors over the 2008–2017 period. The Bioeconomy as a whole shows a continuous increase from 2008 (turnover less than 2 trillion) to 2017 (turnover over 2,4 trillion Euro). Almost half of the Bioeconomy turnover comes from the food and beverages sectors, that also account for the majority of the increase over the period, while about a quarter is produced by agriculture and forestry. The last quarter is obtained by bio-based industries.

Ronzon et al. (2020) provide the EU Bioeconomy data in the post Brexit situation (Table 1). They estimated that Bioeconomy employed around 17.5 million people, and created €614 billion of value added in 2017. It is relevant to note that this data represents about 8.9% of the EU-27 labour force and 4.7% of the EU-27 GDP.

The updated analysis of Ronzon et al. (2020) also elaborates on the different trends and country developments of the Bioeconomy. In particular, they identify four groups of EU countries based on their performances on two dimensions: a) apparent labour productivity, and b) location quotient of the Bioeconomy (i.e. the specialisation rate of labour market in the Bioeconomy). The groups showing structural differences between national Bioeconomies, are:

- High specialisation (location quotient≥ 1.5) and below average apparent labour productivity (≤ half the EU-27 level): Eastern Member States (Romania, Bulgaria, Poland, Latvia, Croatia, Lithuania), Portugal, and Greece; this group is characterized by manufacturing of textiles and/or wood products with labour-intensive production and an high rate of Bioeconomy jobs located in agriculture, forestry, and fishing and aquaculture (biomass production sectors).
- Low specialistation (location quotient ≤ 1.3) and medium-high apparent labour productivity (between half the EU-27 level and the EU-27 level): Estonia and Central Member States (Slovenia, Hungary, Cyprus, Czech Republic, Slovakia) and Malta; in this group, apparent labour productivity is higher than the previous group, mainly in agriculture, forestry, and bio-plastics manufacturing.
- Low specialisation (location quotient ≤ 0.9) and an apparent labour productivity above the EU-27 level (but less than double the EU-27 level): Western

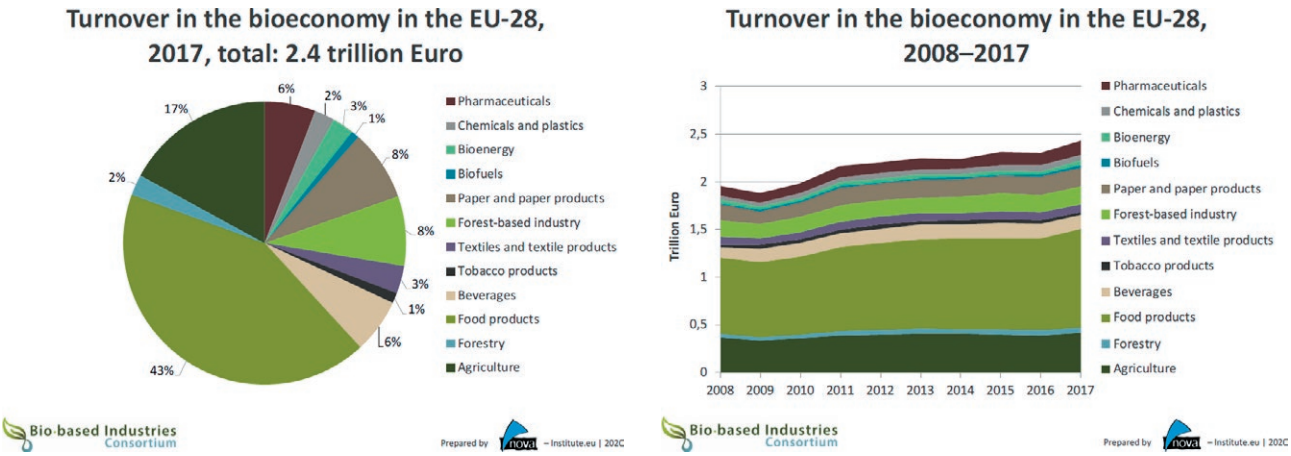

Figure 1. Turnover in the Bioeconomy in EU 28: percentage between sectors and trends over 2008-2017 (Porc et al., 2020).

Table 1. Number of persons employed, value added, and apparent labour productivity by sector of the Bioeconomy (EU-27, 2017). (Ronzon et al., 2020).

Sector	Workers	Value Added	**Apparent Labour Productivity**
	(Number of Persons Employed)	(€ million)	(€000 per Person Employed)
Agriculture	9,273,470	188,519	20
Forestry	517,480	25,301	49
Fishing	166,610	6698	40
Manufacture of food, beverages, and tobacco	4,398,761	215,311	49
Manufacture of bio-based textiles	692,906	21,103	30
Manufacture of wood products and furniture	1,424,540	47,268	33
Manufacture of paper	590,456	41,702	71
Manufacture of bio-based chemicals, pharmaceuticals, plastics, and rubber (excluding biofuels)	396,712	60,312	152
Manufacture of liquid biofuels	20,506	3216	157
Production of bioelectricity	22,550	4208	187
Bioeconomy	**17,503,992**	**613,637**	**35**

Member States (Austria, Italy, Spain, France Germany, Luxembourg), characterised by more diversified in high productive biomass manufacturing sectors.

- Low specialisation (location quotient ≤ 0.9) and an apparent labour productivity more than double the EU-27 level: Northern Member States (Belgium, Denmark, Finland, Ireland, Netherlands, Sweden).

The study by Ronzon et al. (2020) also highlights trends over the 2008-2017 period for the apparent labour productivity and location quotient of the Bioeconomy in the EU27 member states, showing that different speed of increase are in place. Consequently, while the composition of the four groups did not change, the heterogeneity of the EU's Bioeconomy remains and get stronger.

The quantifications presented in this section refer mainly to a set of studies that apply the same analytical methods refining and updating over time. Nevertheless, the discussion on alternative methods, different rate in sectors or choice in including/excluding sub-sectors still evolves and needs to be further developed in order to ensure advances in the Bioeconomy definition for practical purposes (see for example Vivien et al., 2019).

3. DEMAND, SUPPLY, MARKETS AND CHAIN ORGANISATION IN THE BIOECONOMY

3.1 Demand

Demand for Bioeconomy products come from the combination of two main forces, consumers and policy, that need to be understood in the light of major scenarios and driving forces providing incentives for societal change.

Part of the literature focuses on classical analyses of demand elasticity of Bioeconomy products (Schier et al., 2021; traditional forest products markets change and diversify. Fossil-based inputs in the chemical, textile, apparel and downstream industries can be replaced by lignocellulose-based products such as dissolving pulp, cellulose-based chemical derivatives and textile fibres. When looking ahead, these previous niche products are likely to gain in economic importance. So far, little attention has been paid to the characteristics of macroeconomic relations of emerging lignocellulose-based materials on macroeconomic level. Key economic parameters for such materials are not available neither at regional nor at global level. Schier et al. (2021) to contribute to a better understanding of the market behavior of emerging forest products that are not yet covered by forest products market analysis. Therefore, they investigate how lignocellulose-based products respond to changes of main economic drivers and compute global market elasticities for dissolving pulp, cellulose-based chemical derivatives and textile fibres. To conduct the evaluation, they first test historical input data for non-constancy in time series due to structural changes using change-point estimator (MOSUM test in Skjerstad et al., 2021). However, a large part of the literature rather points attention to consumers behaviour in the Bioeconomy as linked to the issue of acceptance of new product and differential willingness to pay.

Early literature was largely driven by attention to potential negative impacts of biotechnologies and willingness to pay (WTP) to avoid products implying the use of e.g. GMO crops. The most recent literature is more related to WTP for positive Bioeconomy-related attributes (such as bio-based nature of feedstock in comparison to fossil materials) or for new products. For example in Petruch and Walcher (2021) the the public perception of wood as a sustainable building material that can facilitate the shift towards a bio-based economy is crucial. This study aimed to explore the attitudes towards timber construction among young millennials in Austria, a cohort that in the coming years will increasingly occupy decision-making positions and gain purchasing power.

Most recent studies tend to integrate concepts from psychology and behavioural economics into consumer studies, revealing the complexity of choices on Bioeconomy products. An example is provided by Wensing et al. (2020) explaining why the food industry is increasingly interested in pro-environmental packaging alternatives-such as bio-based plastic. As the market share for bio-based plastic packaging is still small, strategies to raise consumer awareness and willingness to pay are increasingly investigated.

Another relevant area of recent research concerns the fact that consumers are not deciding in isolation and, on the contrary, are more and more networked. In this context, how the digitalisation and the role of online intellectual capital impact on consumers behaviour related to the Bioeconomy is a key issue. Vătămănescu et al. (2018) address a demand-side perspective of bioeconomy by laying emphasis on the digitalization of markets and, subsequently, on the consumption patterns at the macroeconomic scale. They investigates the influences of online intellectual capital on bio products consumption in two European countries (Romania and Italy). The imperative for a sustainable economic model corroborated with the advances in digital technologies usage have reconfigured consumers' approaches and expectations and availed new forms of consumer behaviour. Among these, the development of consumer-based online communities and of the online intellectual capital have often come forth as an undertaking of empowered consumers pursuing knowledge-based consumption patterns. The quest for sustainable, bio-labeled products on the digital markets has cemented the formation of new social aggregations built on the similarity of interests, goals, values, expectations, preferences, etc., giving way to consistent communication and interaction flows among their members and engendering profound transformations in today's society.

The behavioural aspects highlighted above can be detected through consumer studies but also by addressing stakeholder views (Kakadellis, Woods and Harris, 2021), which may help in gaining a more aggregated view of different positions and understanding interactions among groups.

Being a new concept, in addition attached to a number of socially relevant attributes (such as climate change, sustainability, biological resources), the development of the Bioeconomy is connected to visions, imagery and perceptions by the different stakeholders involved. Several papers address this issue. Some of them emphasise the general positive perception of renewable vs. non renewable products, in particular at consumer level (Navrátilová et al., 2020), while others emphasise the contrasting views and the different potential positions by different stakeholders. However, the review by Holmgren, D'Amato and Giurca (2020) concludes that most of the scientific literature tends to reproduce policy concepts linked to weak sustainability rather than introducing original ideas into the process of Bioeconomy development.

Media and communication are also important in shaping these aspects. Early work on genetic modifications has shown the potential role of media in changing public opinion. More recent research on this topic thought reveals relatively little attention on elaborating novel ideas and rather a discourse mostly driven by government positions (Sanz-Hernández et al., 2020).

An important part of demand is driven by public policies. This has been relevant up to now in particular in the bioenergy sector, with studies largely focusing on biofuel mandates or biogas production depending on aspect most relevant in each country.

3.2 Supply

The primary production of biomass needed for the Bioeconomy is the first issue in supply analysis. This is addressed in different ways through technical economic studies investigating, for example, the land footprint, land bio-capacity, degree of (de)coupling and self-sufficiency (Naah, 2020).

From an economic point of view, supply elasticity of specific products is also an issue for analysis (Schier et al., 2021). Also concepts such as the need to exploit economies of scale and reduce transaction costs are addressed with respect to biomass production (Wen and Chatalova, 2021).

Farm level incentives and trade-offs among different product streams are a key to supply analysis (Jansen et al., 2021), in particular in the context of the competition for land use by most Bioeconomy supply chains.

Not surprisingly, in a growing and innovative sector, many supply-side papers focus on specific new products either at the level of biomass production or processing, such as microalgae (Orejuela-Escobar et al., 2021), new sources of protein including insects and seaweeds (van der Heide et al., 2021), forest Bioeconomy and new forest-based products (Kallio, 2021; Jonsson et al., 2021).

Biorefinery are a key approach to biomass processing, aimed at the valorisation of different sources (including waste) into a range of valuable products and are becoming the object of a dedicated stream of economic research (Clauser et al., 2021).

Another interesting area of research is that concerning emerging links among different value chains. These are rather countless and are part of the main nature of the Bioeconomy. Some of them are even surprising from the point of view of old technologies, for example the connection between the wood production and aquaculture (Solberg et al., 2021).

3.3 Markets

The study of markets for Bioeconomy products largely relates to two issues: development of new markets and relationships among markets of Bioeconomy products and other products, in particular competing products based on fossil resources.

The first point entails in particular the issues of launching new products on the market, even when they are already at a stage advanced enough for marketing and even more when they are in the process of moving from research to market through innovation processes. The difficulties and the actions needed to activate new products is visible in the example on market implementation of active and intelligent packaging (AIP) technologies specifically for fiber-based food packaging provided by (Tiekstra et al., 2021). They identify the following areas of concern: a) market drivers that affect development; b) the gap between science and industry, c) the gap between legislation and practice; d) cooperation between the producing stakeholders within the value chain, and e) the gap between the industry and consumers.

The second point (relationship with non-Bioeconomy markets) concerns directly the perceived specificity of Bioeconomy products. Assuming Bioeconomy products are perfect substitutes of fossil-based products, the early models mostly focused on interaction between bio-based and non-bio-based products, and related market shares, due to different marginal costs. In addition, in the most recent literature this has expanded to considering the issue for recycled vs. non recycled. The interaction among the three (four) types can be addressed as well.

When the product is different in terms of attributes, instead, the issue is more market differentiation than costs-competition, also in relation to consumer segmentation.

Finally, the problem of externalities and public goods needs to be taken into account. Many positive attributes of Bioeconomy products take the nature of public goods or externalities, which implies that market itself cannot take them fully into account and will tend to produce the Bioeconomy goods in a sub-optimal amount. This issue is better discussed in the next section.

To address some of the topics above, the role of policies is key. Besides direct incentives, mentioned in demand and supply, certification, often related to sustainability, can be a strategic tool to connect demand and supply (Vogelpohl, 2021).

3.4 Organisation and business models

Organisation aspects of the Bioeconomy derives from two main issues. The first is the growing degree of separability among different stages in Bioeconomy processes. The second is the emergence of specific technologies in the treatment of biomass around the concept of biorefinery. An intermediate and connected issue is that of flexibility both in feedstock and processing, that allows plants to switch from one feedstock to the other and from one product to the other.

As an answer to these trends, new concepts are increasingly being used to represent complex systems. One is that of value web approaches. Biomass value webs can be defined as "complex systems of interlinked value chains in which biomass products and by-products are produced, processed, traded, and consumed" (Callo-Concha et al., 2020). Examples of use of value webs concern the representation of different Bioeconomy systems in the context of developing countries (Callo-Concha et al., 2020; Naah, 2020; Virchow et al., 2016). Some of these approaches are supported and build on analyses of biomass flows (Gonçalves, Freire and Garcia, 2021).

Networking and collaboration are an important part of the new organisation landscape emerging for the Bioeconomy and several papers address this issue, in particular looking at collaboration among companies (Guerrero and Hansen, 2021), but also among different actors. In most cases, the key topic for collaboration is that of innovation.

Also part of the literature focuses on innovative business models related to the Bioeconomy. They rather often address the specific topic of circular Bioeconomy (Donner and Radić, 2021; Donner et al., 2021). Business models are a particularly relevant concept in

relation to the innovation process and to the interpretation of the ability of the innovation systems to speed up innovation development and uptake, also in relation to appropriate policy instruments (Gatto and Re, 2021). Salvador et al. (2021) review the literature on business models and Bioeconomy and identify key aspects for implementing and managing business models, namely; "the role of innovation and new markets, taking the customer perspective into account in the value creation process and being close to customers, adequate management of logistics and feedstock collection systems, being aware of different routes for valuing biomass, seeking technological development, building resilient value chains, and focusing on value creation to cover costs. Issues that need addressing in the existing literature include product-service-systems, take back-systems, seasonal availability of resources, social impacts, rebound effects, and aquatic activities."

The topic of circular Bioeconomy has taken an increasing relevance over time, due to its potential to reduce environmental impact and better exploit the economic value of biological resources. Large part of it is related to food waste (Ferreira, Pié and Terceño, 2021; Santagata et al., 2021). The current state of the art in patents shows that this field is still far from expressing its full potential. Ferreira, Pié and Terceño (2021) conclude their review by highlighting that for further progressing towards an impactful circular Bioeconomy, further evidence is needed that circular Bioeconomy products "are indeed preferable to their fossil-based counterparts, from both the economic and societal points of view, including environmental sustainability, and to communicate extensively the findings to the society at large."

3.5 Innovation mechanisms and entrepreneurship

Innovation is at the core of the Bioeconomy and was actually the main field of research at the early stages of the development of the sector. Two main areas of concern appear from the literature. The first regards the shape taken by innovation systems. This partly connect to wider approaches to innovation, for example the triplequadruple or quintuple helix approach (Grundel and Dahlström, 2016). The second concerns the impact of regulation and its effects in shaping innovation pathways.

With growing investment in demonstration plants, for example in the field of biorefineries, attention is also moving to managerial difficulties. For example, using a survey concerning pilot and demonstration plants in Sweden, Mossberg et al. (2020) provide a description of various challenges, such as the division of responsibility for the operation and ownership, unclear roles and objectives, and the lack of specific competences and resources in the actor networks.

Research also concerns new areas of innovation and technology as they emerge. Large part of economic research related to Bioeconomy is in the field of biotech innovations. Recently, an emerging field of research is that of digitalisation also in view of its potential support to collaboration in management and innovation processes (Ryymin, Lamberg and Pakarinen, 2021). The application of digital innovation hub concept to the Bioeconomy is a promising pathway to boost networking and innovation (Aragonés et al., 2020).

Governance of innovation systems is also a widely addressed issue (Toivonen, Vihemäki and Toppinen, 2021), with implication in shaping the form of supply chain network and its impact on the sustainability (see section 4).

Innovation and research are connected to economic development also through education and intellectual capital. Though little explored by the literature, Cristea et al. (2020) highlight that education, innovation and research, along with main Bioeconomy features, are at the core of economic development in the EU.

New business models and innovation are strictly linked to the issue of entrepreneurship. Kuckertz, Berger and Brändle (2020) provide a holistic framework on the role of entrepreneurships in the Bioeconomy identifying three main aspects: entrepreneurial activity on the micro level, entrepreneurial ecosystems (or clusters and innovation systems) on the meso level, and governmental vision and support on the macro level. While entrepreneurship is identified as important in most of the Bioeconomy strategies worldwide, actions to strengthen its role are often lacking or too weak (Kuckertz, 2020).

The connection between entrepreneurship and academic activities is also a relevant area of debate, in particular in relationship to emerging new processes (Rosenlund and Legrand, 2021).

3.6 Governance and political economy

Governance and policies are cross-cutting areas of concern in all the previous points and specific policies are mentioned above in relation to issues they intend to address. Some cross cutting issues are however worth to be mentioned here. While there are now many Bioeconomy strategies worldwide, Bioeconomy policies as such are almost absent. On the contrary, there are important policy interventions in specific sectors of the Bioeconomy (e.g. energy, agriculture). As a result, the literature on policies related to the Bioeconomy is rather

fragmented and largely incorporated in sectorial policies, such as agriculture and forestry. This is a more or less important topic depending on the sector. For example the topic of Bioeconomy has a much higher degree of attention in connection to forestry (Elomina and Pülzl, 2021) than in connection to agriculture. Governance landscape for forest Bioeconomy and ecosystem services in Europe is mapped by Primmer et al. (2021).

Besides a lot of work on national or local policies and governance approaches, the international dimension of the Bioeconomy is now emerging, together with a growing attention at the role of international institutions (Bößner, Johnson and Shawoo, 2021).

Political economy analyses of regulation have accompanied the development of the Bioeconomy, with a stronger focus on new technologies and, in particular, biotechnologies (Smith, Wesseler and Zilberman, 2021).

Recent political economy contributions also touch the more theoretical and global vision of the Bioeconomy. For example, Vertommen, Pavone and Nahman (2021) propose the concept of "global fertility chains", which "articulates the reproductive Bioeconomy as a nexus of intraconnected practices, operations, and transactions between enterprises, states, and households across the globe, through which reproductive services and commodities are produced, distributed, and consumed".

Potential for sharing good practices and replication in policy and governance solutions is also an issue in a period when the sector is expanding (Andersson and Grundel, 2021).

A notable area of research is that concerning the potential of the Bioeconomy for development. At local level, this discussion is partially related to the valorisation of marginal areas. The recent literature advocated that this opportunity is not straightforward in the current settings and it would require the designing of a new "'resilience governance' based on integration, innovation and future orientation to rural transformation" (Sanz-Hernández, 2021)

4. BIOECONOMY, SDG AND ECOSYSTEM SERVICES

The literature shows conflicting views on the potential contribution of the Bioeconomy to sustainability, with the academic debate on its benefits and risks driven by strong polarised opnions (Kirkels, 2012). Pfau et al., (2014) identify different visions on the impact of the Bioeconomy on society that span from unconditional sustainability as an inherent characteristic (i.e. using biomass to replace fossil resources, see for example Székács, 2017) to potential harm due to increasing competition with the food sector, changes in the demand for productive factors or unknown environmental and social consequences (see for example DeBoer et al., 2020). These multiple visions of the Bioeconomy can be a consequence of the evolution of the Bioeconomy concept itself (Vivien et al., 2019), or of the nature of the socio-technological transition of the Bioeconomy that requires deep knowledge and technology as drivers of its development (Vainio, Ovaska and Varho, 2019). Therefore, reconciling environmental and social goals with economic development requires a deep understanding of the human-biosphere-technosphere nexus (Giampietro, 2019). This complexity has the practical consequences that the economic literature on Bioeconomy fails to provide a comprehensive assessment of their positive or negative impact on sustainability and ecosystem service (Heimann, 2019) and properly addressing these issues requires strong multidisciplinary and interdisciplinary research. The sustainable management of biological resource and their circular transformation in food, feed, energy, and biomaterials relies on improving social well-being through ecosystem services (Figure 2).

Although El-Chichakli et al., (2016) consider the Bioeconomy as directly or indirectly involved in reaching several millennium development goals, (i.e. food security (SDG 2), prosperity and economic growth (SDG

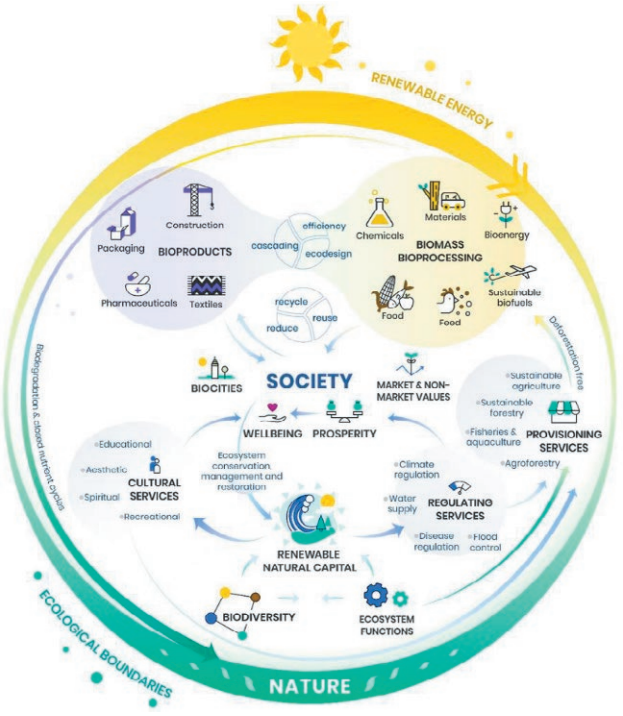

Figure 2 Circular Bioeconomy and wellbeing. Source: European Forest Institute.

2; 8, 9, 11, and 12), protection of natural capital (SDG 6; 7; 14 and 15) and the mitigation of climate change (SDG 13), its linkages to the provision of ecosystem services are not yet established (D'Amato, Bartkowski and Droste, 2020). The prerogative of the ecosystem services concept is to help understanding the synergies and trade-offs between various societal objectives highlighting the natural capital contribution to human wellbeing (Fisher, Turner and Morling, 2009). However, the provision of services depends on the socio-technological context of individuals or groups of beneficiaries (Oteros-Rozas et al., 2014).

While the contribution of the Bioeconomy on provisioning services is quite evident, other ecosystem services (i.e. regulating, cultural and supporting) are less investigated (D'Amato, Bartkowski and Droste, 2020). Lower attention is often given to the indirect effects on ecosystem services through a different land and resource management. Table 2 provides an overview of the possible Bioeconomy contribution on the ecosystem service.

The bulk of studies that link the Bioeconomy with ecosystem services concerns the provisioning service by forest and agricultural systems. They are perceived as a primary source of biomass from the Bioeconomy (Bugge, Hansen and Klitkou, 2016; D'Amato, Bartkowski and Droste, 2020). Differently, the literature studying circular-economy in the Bioeconomy sector remains anchored to the provisioning sector but with the use of municipality or industrial waste or co-products as a primary source of biomass (DeBoer et al., 2020). Except for biomass from algae for animal feed or energy provision, the contribution of marine ecosystems to the Bioeconomy is less investigated. Van Schoubroeck et al. (2018), in a recent review, compare the sustainability of different types of bioeconomic products. The authors observe that bio-based chemical production has been investigated less than bioenergy and biofuels. Hamelin et al. (2019) argue that the source of biomass is the main factor leading to sustainability. While the urban greenery management (i.e. residue from managing public green spaces or roadside vegetation) and, agricultural, industrial, and municipal waste are considered sustainable as implicit in the circular economy[1], the sustainability of biomass from dedicated crops or by-products (i.e. straw, manure, residues, co-product from food (wheat, maize), and non-food crops (i.e. hemp) or by forestry and forestry residues is largely debated. Many studies have described a potentially harmful impact of Bioeconomy on ecosystem services due to shirking the global food security or reducing the adaptive capacities of local food system due to simplification of cultivated crops (Marsden and Farioli, 2015). As for a local or regional biorefinery, cultivation of first- or second-generation biomass affects ecosystem services. The development of biomass crops instead of traditional crops can impact the landscape quality (Cattaneo, Marull and Tello, 2018) and reduce the crop diversity (Bartolini, Gava and Brunori, 2017) with a further increase in exposure to climatic or market risks (Bartolini et al., 2015). Some authors, comparing the dedicated crops to invasive species, consider the food systems more likely to be food-insecure (see, for example, Ferdinands et al., 2011). In contrast, other authors have highlighted the positive impact on soil quality (Schrama et al., 2018) and on reducing water demand (Bartolini, Gava and Brunori, 2017) and the synergies in providing a feedstock supply while enhancing ecosystem services for perennial crops (Mitchell et al., 2016). The other ecosystem services are less investigated by the literature due to the complexity of socio-technical transformation of the ecological system (Giampietro, 2019), to the difficulties in define and assess the counterfactual carbon-based production and technology (Spierling et al., 2018) or to the lack of understanding of the nexus between direct and indirect changes in land use with multifunctional ecosystem (Egenolf and Bringezu, 2019).

The contribution of the Bioeconomy to climate change is a debated topic. On the one hand, the literature has shown that the Bioeconomy can sequester carbon from the atmosphere into biomass or store carbon in bioproducts, consistently with its main objective to replace fossil-based feedstocks with renewable sources (European Economic and Social Committee, 2018). On the other hand, several studies provide shreds of evidence supporting incremental effects of CO2 emissions due to mainly indirect land-use changes or deforestation (Weiss et al., 2012; Marchetti et al., 2014; Haddad, Britz and Börner, 2019). Bais-Moleman et al. (2018) pinpoint that the cascade approach could shrink the climate change mitigation potential of biomass used by altering the efficiency of solutions among alternative uses.

Egenolf and Bringezu (2019) show that a very complex multilevel interaction exists, highlighting possible trade-offs and synergies across scale and space. Such complexity can be a consequence of the different governance structures of the Bioeconomy (Dietz et al., 2018), as governance can affect either the typology of the supply chain itself and the value exchanges

[1] Although the debate about circular economy assumes implicitly and simultaneously economic growth, protection of natural environment and social equity, its real contribution on ecosystem services remains quite vague. Millar, McLaughlin and Börger, (2019) note a minor effect of circular economy with respect the linear model due to the existence of a) absence of an agreed definition of circular economy; b) the persistence of trade-off among sustainability dimensions and c) lack of knowledge about long term and rebound effects.

Table 2. summarises the linkages between ecosystem services, SDGs and Bioeconomy.

Ecosystem service	SDGs[1]	Examples of Bioeconomy contribution
Provisioning	SDG 2 End huger	More efficient animal production and cultivation (i.e. new vaccines and molecular diagnostics to reduce antibiotic use or use of a bio-based product as feed for animal)
	SDG 3 Good Health and well being	Sustainable medicines: biopharmaceuticals and microbiome-based approaches; improving knowledge on genetic resources
	SDG 7 Affordable and Clean Energy	Use of biomass instead of carbon-based products (Biofuel, biogas, wood from forestry systems)
	SDG 8 Economic Growth (Economy)	Re-connect local and actors in new supply chain networks based on form better material/ energy flow. New green and innovative business model, income and job opportunities
	SDG 9 Industry, Innovation & Infrastructure	Substitution of non-renewable with bio-based and renewable products could link a rural regeneration or re-industrialisation process; investment in R&D in marginal areas. Development of green infrastructure of new green section (i.e. bio-construction, pharmaceutical and medical technology)
Regulating	SDG 6 Clean Water (Water)	Biological wastewater treatment (in developing countries), with the inclusion of water nutrients removal
	14 Life Below Water	Increasing aquatic biodiversity by reducing pressure on marine ecosystems making more efficient aquaculture productions and bio-products products (i.e. genetically modified tilapia in developed countries)
	15 Life on Land	Increase terrestrial biodiversity through decoupling farm and industry from the fossil-fuel industry Soil regeneration through co-products or by-products (i.e. digestate used as fertiliser) Mediation of wastes or toxic substances
Cultural	Aesthetics 17 Partnerships (Partnerships) Build partnerships	Develop new business opportunities from the extensive farming system and agro-forestry Re-balance the material and energy flows between rural and urban systems
Supporting	SDG 11 Sustainable Cities	Reduction of emission and waste by using biomass form local production, recycling systems or from urban waste
	SDG 12 responsible production and consumption	Integration and use of renewable resources, or the diffusion of innovative and sustainable production and biotechnology can improve the efficiency of material and energy cycles as well as create new and multiple material and energies loop. Diffusion of bio-based products and material would alter reduce the plastic waste or improve the efficiency of waste disposal and/or material recycle
	13 Climate Action (Climate)	Bioeconomy is contribute strongly in carbon storage and in reducing emission by making C02 into the bio-based chemicals and biofuels

Source Own elaboration.
[1] Yang et al. (2020) provide an explanation of the linkages between Ecosystem services and SDGs.

among the constellation of actors involved in the supply chain. Growing concerns arose about bioprocessing due to access to technology and knowledge, with the possibility of further creating disparities among countries between those with high capacities to create and internalise added value from industrial biotechnology and those that remain biomass growers. Moreover, the environmental upgrading of some Bioeconomy value chain may cause outsourcing of environmental damages in these countries with high export but low environmental and social standers (Fuchs, Brown and Rounsevell, 2020). The inclusion of a specific concept on the governance of Bioeconomy (i.e. cascade and circularity) can move toward sustainability by prioritising high-value biomass uses (health, pharmaceuticals, chemistry, construction), instead of, for example, bioenergy (El-Chichakli et al., 2016).

5. DISCUSSION

The concept of Bioconomy is in the process of becoming mainstream. Over time it has moved from a focus on innovation in some specific sectors (biotech, bio-based materials, bioenergy), to the broader identification with all sectors using biological resources. In addition, the connections with sustainability, ecosystem services, circular economy and climate change have

become more prominent and taking shape in more concrete policy and business actions.

In this section, we discuss the most promising pathway for research after considering two horizontal issues: the topic of conflicting objectives on the Bioeconomy and the issue of methods.

The transition to the Bioeconomy is subject to trade-offs among different sustainability dimensions, including the possibility to alter ecosystem services functioning. While strategies promoting the Bioeconomy typically put emphasis on the expected beneficial effects it can bring, the consideration of SDGs clearly highlights a number of potential conflicts among different objectives related to the Bioeconomy.

The different views on Bioeconomy can generate tension among stakeholders and shrink the Bioeconomy impact on sustainability or make its transition more difficult or risky. Some authors have argued that difficulties in social acceptance of the Bioeconomy arise from the typology of innovation itself, which implies a large amount of asymmetric information among actors along the supply chain. Other authors argue that the development of technology often has not paid attention to stakeholders' needs and to its acceptability, but merely to achieving a large adoption, making very complex the communication about the practical benefits of the Bioeconomy (Mukhtarov et al., 2017). This was particularly evident in the early stages of Bioeconomy development, in which the advanced biotechnological innovation has shaped the debate on the transition towards a Bioeconomy purely on the acceptability of GMOs, which is partially a misleading debate without fully understanding the potential of many other existing technologies (Chapotin and Wolt, 2007). In addition, Gava et al. (2017) show that the actors involved in Bioeconomy value chains are strongly different from the traditional agricultural networks, making dialogues among these stakeholders difficult.

Partly for this reason, perception and vision studies are key to the understanding of the Bioeconomy. Vision analysis of the transition process start to emerge also for the agricultural sector, moving attention beyond sustainable intensification and rather highlighting the topic of landscape and country level diversification (Bayne and Renwick, 2021).

Some of the trends above have been dramatically touched by the COVID pandemic. Some literature is emerging about the Bioeconomy in the post-covid era, in particular in relation to food security (Farcas et al., 2021).

Different branches of Bioeconomy research have been using different methods and concepts, with a large use of qualitative methods.

To fully understand the possible trade-off implied by the Bioeconomy, there is a strong requirement for scientific advances to understand different opportunity costs and environmental benefits and costs among alternatives pathways in each specific ecosystem. Although the LCA is the most used method in the literature, it is still far from measuring the proper impact of the Bioeconomy on the ecosystems and the complexity of nexus between biomass sources, bioproducts, supply chain governance and ecosystem services provided (D'Amato, Bartkowski and Droste, 2020)

The changing landscape and the increase in data is also bringing changes in methods. Among others, modelling intended for simulation and forecasting is a growing field of activity for the Bioeconomy. Cingiz et al. (2021) use an input-output model of the EU Bioeconomy. Ferreira, Pié and Terceño (2021) use a bio-socio accounting matrix approach to assess the impact of Bioeconomy in Spain. Gatune, Ozor and Oriama (2021) model Bioeconomy futures in eastern Africa using the International Futures (IFs) modelling platform, based on the dynamic interaction of demographic, social, economic and environmental factors.

Farm level models including Bioeconomy-specific concerns are also emerging. For example, Jansen et al. (2021) develop a farm level decision making model including the choice of quality, losses and bio-based alternatives.

Given the number of variables affecting the development of the Bioeconomy, it is not surprise that several studies further cast the problems in the framework of scenario analysis (Rojas Arboleda et al., 2021) and/or transition theory (Wydra et al., 2021). An example of modelling scenarios related to forestry is provided by Morland and Schier (2020).

Based on the above, the most interesting trends of the recent Bioeconomy literature rest probably in the search for a more systemic view of the sector, or, at least, in the attempt to account for cross-sector interrelationships and for the consequent market and organisational changes. The areas of innovation and organisation are probably two of the most relevant for understanding the Bioeconomy, with a growing role of the latter. The combination of qualitative and quantitative methods can allow to provide evidence-based support to policy while at the same time offering the possibility to account for views from different stakeholder groups.

6. CONCLUSIONS

Looking back and looking forward, the economic literature on the Bioeconomy appears to be still at this

inception while the sector of the Bioeconomy is taking shape and tends to become mainstream. The period from the 2010 to 2020 has been to some extent exploratory in keeping pace with strategy and policy documents providing a vision of the Bioeconomy, as well as in exploring new sectors developing within the Bioeconomy. A variety of different economic aspects of the Bioeconomy have been addressed, from consumer behaviour to governance issues.

The drivers that have pushed for the development of the Bioeconomy remain very prominent and attention can be expected to grow in the next future. This will also depend on the ability of policy to bring together in a consistent way the many areas of intervention presently affecting the Bioeconomy. Although many countries have developed specific policies or even programs on the Bioeconomy, the literature shed light on the lack of a clear policy landscape to support a sustainable transition of the Bioeconomy. Reaching the challenge set out by UN 2030 agenda also requires a multilevel policy framework with the design of a mix of policy instruments addressing the negative impacts (short term objectives), together with policies promoting ecosystem services provision and supporting the scaling up of a sustainable Bioeconomy (long term objectives).

Altogether, this promises to become an even more interesting field for economic research in the next future. In this context, it may be expected that the next decade will be key to see to what extent the literature on the Bioeconomy will consolidate into a well-defined field of economic research. In turn, economic literature can likely help the further development of the sector.

Two key challenges can be envisaged in this direction. First, economics will need to take up the need for more holistic and systemic views required by the sector. Secondly, research will need to better account for the role of citizens and institution, with a stronger consideration of equity in the distribution of private and public costs and benefits. Summing together these issues, economics may contribute to the engagement of different views and in facilitating reflexive spaces to co-create shared transition pathways toward a sustainable Bioeconomy.

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