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How big is the bioeconomy?

Reflections from an economic perspective

Kuosmanen, T., Kuosmanen, N., El-Meligi, A., Ronzon, T., Gurria, P., Iost, S., M'Barek, R.

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Contact information
Name: Tevecia Ronzon
Address: Edificio Expo. C/Inca Garcilaso, 3. E-41092 Seville (Spain)
Email: Tevecia.Ronzon@ec.europa.eu
Tel.: +34 9544-88496

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Authors

Kuosmanen, T.

Kuosmanen, N.

El-Meligi, A.

Ronzon, T.

Gurria, P.

Iost, S.

M'Barek, R.

Abstract

The critical role of the Circular Bioeconomy in the sustainable transition has been widely recognised, to the point that a number of countries worldwide have elaborated their bioeconomy strategies and others are in the process of framing their own. The purpose of this report is to advance more objective and rigorous measurement and analysis of the bioeconomy according to the broad definition of the European Commission in 2018. Our focus is mainly on the economic indicators, aiming at the inclusion of bio-based services derived from the symmetric input-output tables from the system of national accounts available from Eurostat and additional expert information.

As the main conclusion of the report, we propose a synthesis of input- and output-based approaches. This is motivated by the fact that determining the bio-based weights according to the input-output tables implicitly assumes that the bio-based share of outputs is the same as that of inputs. Clearly, this is not the case for the primary bio-based production sectors – agriculture, forestry, fisheries and aquaculture. Where the outputs are completely bio-based for these sectors, the inputs are far from being 100% bio-based. On the other hand, relying exclusively on the bio-based content of the output would ignore the use of bio-based inputs in the production process. To take into account the bio-based content in both inputs and outputs, we propose to consider weighted averages for the industries.

Before applying the new methodology, adjustments are performed with regard to the value added of the bioeconomy by adding the net subsidies, the bio-based shares of the wholesale and retail trade industries, the water supply, sewerage and recycling, as well as the sports and recreation sectors. Applying the methodology with the adjustments proposed, our estimate for the EU-28 bioeconomy in 2015 reaches €1,460.6 billion value added, which is 11% of the GDP. The nova-JRC methodology, used in many bioeconomy publications, calculates €621 billion value added for the same year. This difference is mainly explained by the contribution of €872 billion by the tertiary bioeconomy sectors in the proposed methodology.

This novel methodology addresses different challenges for measuring the size of the bioeconomy and eventually providing a basis for evaluating its contribution for a sustainable transition. The approach allows for yearly updates following the calendar of Eurostat I-O tables, probably with a 3 to 4 years delay. It relies on a thorough estimation of the bio-based shares of the inputs and outputs of the various sectors. The authors believe that these are fundamental elements to ensure that "The next era of industry will be one where the physical, digital and biological worlds are coming together" (European Commission 2020a). Taking account of the diversity of EU's bioeconomies and sectors, this report broadens the ongoing discussion on how to measure and determine the contribution of the bioeconomy to a sustainable and circular economy.

1 Introduction

It is increasingly acknowledged that progress towards a sustainable society will require fundamental changes in the core systems related to food, energy, mobility and the built environment (e.g., European Environment Agency 2019). Despite growing popularity of the term *sustainable transition* (also referred to as *sustainability transition*; e.g., Markard *et al*. 2012) in everyday language, achieving significant progress towards a sustainable society presents major challenges.

Recently, the European Commission published the communication on *The European Green Deal* (European Commission 2019) as "a new growth strategy that aims to transform the EU into a fair and prosperous society, with a modern, resource-efficient and competitive economy where there are no net emissions of greenhouse gases in 2050 and where economic growth is decoupled from resource use. It also aims to protect, conserve and enhance the EU's natural capital, and protect the health and well-being of citizens from environment-related risks and impacts."

Whereas the Green Deal covers the whole economy and all materials, the bioeconomy looks at the sustainable supply, processing and usage of the biological material, elaborated also in the context of the recently published Circular Economy Action Plan (European Commission 2020b). To this end, the Circular Bioeconomy is a central link between the *green growth* and the use/protection of natural resources, encompassing also many aspects of the United Nations' sustainable development goals (see Ronzon and Sanjuan 2020). In the following, we refer mainly to the term *bioeconomy*, acknowledging the inherent linkage to the *Green Deal* (and the SDGs).

The critical role of a bioeconomy in the sustainable transition has been widely recognised, to the point that a number of countries world-wide have elaborated their bioeconomy strategies and others are in the process of framing their own (see e.g., Lier *et al*. 2018, FAO 2018, Bracco 2019). The Bioeconomy Strategy of the European Union promotes the production of renewable biological resources and their conversion into vital products and bioenergy for achieving five societal challenges of the EU in the domains of food security, employment and competitiveness, climate change, sustainable management of natural resource and dependence on non-renewable natural resources (European Commission 2012). Consequently, most EU Member States have defined national bioeconomy strategies, policies and initiatives based on this vision (see e.g., Lusser *et al*. 2018, for a survey)[1].

Building a sustainable growth strategy, as featured in the *Green Deal* and the Bioeconomy Strategy, requires a sound understanding of the sectors involved and their economic, social and environmental metrics. This is also needed to monitor the evolution of these sectors and potentially adapt policy measures. However, despite the progress made, monitoring and impact assessment tools of the European bioeconomy are not mature yet. In its recent review of the European Bioeconomy Strategy, the European Commission observes that "better monitoring and assessment frameworks are needed to assess progress", and that "new actions are needed to develop relevant indicators and scientific evidence for policy making, and to implement a more holistic monitoring and assessment framework" (European Commission 2017).

The purpose of this technical report is to advance more objective and rigorous measurement and analysis of the bioeconomy. More specifically, we focus on methodologies to enhance the measurement of the bioeconomy (as defined by the European Commission in 2018), with the main emphasis on the economic indicators. The approach is largely rooted in the usage of existing European Commission statistical systems to allow a coherent analysis. It does not cover the very relevant question of ecosystem services – at least not directly.

The scientific literature related to the bioeconomy has grown substantially with the emergence of the bioeconomy topic on political agendas. A majority of studies are qualitative conceptual papers that discuss different visions and/or definitions of the bioeconomy. Research programmes on the analysis of available databases and indicators for monitoring the bioeconomy and on the collection of scientific evidence for policymaking (see e.g., M'Barek *et al*. 2014, Lier *et al*. 2018, EU BioMonitor project) have also been initiated in the EU. In their review of quantitative approaches for measuring the contribution of the bioeconomy to the total economy, Bracco *et al*. (2018) stress the lack of harmonized approaches for cross-country comparison, with the exception of the European Commission Joint Research Centre (JRC) dashboards for the EU Member States. The quantification reported in these dashboards follows a methodology elaborated by the JRC in collaboration with the nova-Institute. Expert opinion is mobilised for the estimation of the biomass content of the bio-based products produced in the EU (CPA eight-digit levels). The so-called "product bio-based shares" are then applied to Eurostat statistics to derive the relative contribution of industrial sectors adding to the EU's and EU Member States' bioeconomy (Ronzon *et al*. 2017, Ronzon and M'Barek 2018). However, this approach also has its limits and needs further development, as acknowledged in the respective publications.

For instance, relying on expert assessment can lead to very different results. As an example, JRC estimates that 20% of the Finnish chemical industry contributed to the bioeconomy in 2015, whereas the bio-based proportion of the same industry was estimated at 36% by the Natural Resources Institute Finland (Luke) for the same year. This implied a variation in the value added of the bio-based chemical industry ranging from €348,000 (JRC) to €734,000 (Luke).

In addition, to the subjectivity introduced by expert judgment, the bioeconomy concept varies over countries and stakeholders according to their priorities. For example, Luke recognises the industry of "nature tourism and recreation" as being part of the Finnish bioeconomy, contrary to current JRC publications. The inclusion of this industry alone corresponded to €1,344,000 of value added for Finland in 2015.

Because of methodological heterogeneities, the JRC reports the size of Finland's bioeconomy to be €13 billion, or 7% of the GDP in 2015, based on the value added approach, whereas the official statistics of Luke indicate considerably higher values

[1] Bioeconomy policy map is available at: https://ec.europa.eu/knowledge4policy/visualisation/bioeconomy-different-countries_en

of €21.3 billion or 12% of the GDP.[2] Such a large difference highlights the need for a more objective, unified approach to quantify the size of the bioeconomy.

This report intends primarily to serve scientific research on the bioeconomy and its contribution towards a sustainable transition. The aim of the present study is to develop an objective and systematic approach to measuring the bioeconomy, which might also serve statistical agencies around the world to further develop the official bioeconomy statistics and monitoring tools. Specific research questions to be addressed in this report include the following:

1) What explains the large divergence in the results from different approaches?
2) Why do the contribution of labour and value added to the bioeconomy differ so much?
3) How can the measurement of bioeconomy be improved?
4) How does the inclusion of different aspects (e.g., considering agricultural subsidies) influence the size of the bioeconomy?
5) How does the bioeconomy relate to sustainable transition?
6) What is the share of GHG emissions of the bioeconomy?
7) Does a higher share of the bioeconomy support a transition to a more sustainable economy or vice versa?

To address these research questions, we combine information from multiple data sources, but we mainly rely on the symmetric input-output tables from the system of national accounts available from Eurostat. We stress that this study is not about input-output analysis or input-output modelling. We utilise the input-output tables as empirical data only. While this report examines the measurement of the bioeconomy at the general level and is applicable to any country or region, we will use Finland in 2015, primarily, as an illustrative example, and compare to other EU countries and the EU-28 in Section 7. There are several reasons for considering Finland as an example. Firstly, bioeconomy ranks high in the political agenda of the Finnish government. Secondly, the Finnish bioeconomy strategy from 2014 aims to increase the output of the bioeconomy sectors to €100 billion by year 2025 and create 100,000 new jobs. We chose the EU Member States Denmark, Italy, Poland, Romania and Spain to represent different geographical regions and bioeconomies.

[2] Sources: JRC https://datam.jrc.ec.europa.eu, Luke http://statdb.luke.fi/PXWeb/pxweb/en/LUKE/.

2 Bioeconomy: background

The purpose of this section is to gain a better understanding of the nature and scope of the concept of the bioeconomy in order to develop operational measures for quantifying it. In Section 2.1, we consider different definitions of the bioeconomy concept. Section 2.2 discusses how different countries define the bioeconomy sectors. Section 2.3 provides a more formal classification of industries and sectors included in the bioeconomy. Section 2.4 lists the economic, social and environmental indicators and examines the measurement of the economic size of the bioeconomy in more detail.

2.1 Remarks on definitions of the bioeconomy

There are several definitions of the bioeconomy. Some of them overlap in terms of which sectors of the economy are included into the bioeconomy, but some differ in their scope. The concept of the bioeconomy is also evolving over time, as the following examples illustrate. For instance, the bioeconomy strategy and action plan (European Commission 2012) defines the bioeconomy as

"the production of renewable biological resources and the conversion of these resources and waste streams into value added products, such as food, feed, bio-based products and bioenergy".

In this report, we adhere to this conceptual definition of the bioeconomy, with a clearly articulated emphasis on the conversion of renewable biological resources to value added products.

In the recent review of the bioeconomy strategy, the European Commission (2017) concluded that the objectives of the 2012 strategy remain valid; however, the scope of the actions is broadened and refocused. Further, the updated bioeconomy strategy of the European Commission (2018) aims to accelerate the deployment of a sustainable European bioeconomy to maximise its contribution towards the 2030 Agenda and the Sustainable Development Goals (SDGs). According to the updated Bioeconomy Strategy (European Commission 2018),

"the bioeconomy covers all sectors and systems that rely on biological resources (animals, plants, micro-organisms and derived biomass, including organic waste), their functions and principles. It includes and interlinks: land and marine ecosystems and the services they provide; all primary production sectors that use and produce biological resources (agriculture, forestry, fisheries and aquaculture); and all economic and industrial sectors that use biological resources and processes to produce food, feed, bio-based products, energy and services (except biomedicines and health biotechnology)".

While the updated definition of European Commission (2018) quoted above includes both the ecosystem services and all economic sectors, in practice, valuing the non-market ecosystem services is a daunting task that falls beyond the scope of the present study. However, we do aim to cover *all primary production and industrial sectors* in the sense of this definition. It is worth emphasising that our study also covers bio-based services that are usually absent or under-represented in bioeconomy statistics.

In addition to the European Bioeconomy Strategy, the Member States have also their own national bioeconomy strategies. For example, the Finnish Bioeconomy Strategy (2014) refers to the bioeconomy as

"an economy that relies on renewable natural resources to produce food, energy, products and services. The bioeconomy strives to reduce our dependence on fossil natural resources, to prevent biodiversity loss and to create new economic growth and jobs in line with the principles of sustainable development".[3]

Compared to the European Bioeconomy Strategy, the Finnish definition is broader in that it does not restrict to *biological* resources, but covers all *renewable natural resources*, including solar and wind energy. The Finnish definition also explicitly refers to *services*; however, the bio-based service sector (further referred as tertiary bio-based production) is not included in the official bioeconomy statistics of Finland, as will be discussed in more detail below.

It is also interesting to note that both the European Commission (2018) and the Finnish Bioeconomy Strategy explicitly refer to *sustainable development*. However, it is not self-evident that activities included in the bioeconomy are conducted on a sustainable basis. Clear examples of unsustainable primary bio-based production include deforestation and overfishing. Agriculture is a major source of nutrients that contribute to eutrophication of water systems as well as a significant contributor to the greenhouse gas emissions. Final products of the bioeconomy include alcoholic beverages and tobacco, which are known to cause adverse health effects. While the term *bioeconomy* is often associated with such terms as *sustainable economy* or *green economy* (consider, e.g., the Finnish Bioeconomy Strategy quoted above), such an interpretation may be misleading. While this report will mainly focus on the measurement of the bioeconomy as it is, in Section 9 we will briefly explore sustainability of the bioeconomy and the role of the bioeconomy in the transition towards a more sustainable society.[4]

[3] The Natural Recourses Institute Finland (Luke) follows the definition of bioeconomy provided by in the Finnish Bioeconomy Strategy (Ministry of Economic Affairs and Employment 2014).

[4] Note, however, that methods and approaches developed in this study can be equally well applied to measuring the size of the renewable economy or the green economy, with some relatively minor modifications.

The latest report on the US bioeconomy (National Academy of Sciences, 2020) proposes to catalogue definitions in terms of three different visions of a bioeconomy's purpose: a biotechnology vision, bioresource vision, and a bioecology vision. In this context, it should be noted that the recently published "New Industrial Strategy for Europe" (European Commission, 2020) explicitly mentions "industrial biotechnology" as a key enabling technology. As the conceptual definitions quoted above illustrate, the boundaries of the bioeconomy are defined differently[5], which can to some extent explain the differences in the estimated size of the bioeconomy from different sources. In order to define the bioeconomy and its boundaries for the purposes of this study, in the next section we introduce a classification of the production sectors of the economy and bio-based industries analogous (or similar in spirit) to the classic 3-sector model.

2.2 A note on the bioeconomy sectors across countries

A common approach to estimate the size of the bioeconomy is to aggregate all industries that comprise the bioeconomy, based on the sectoral data. The advantage of this approach is that sectoral statistics are compiled in many countries with frequent updates and therefore allow for a monitoring of the bioeconomy. However, the industry composition may vary from one country to another due to variations in the bioeconomy concept used at the national level. This makes cross-country comparisons more difficult.

Tables 1 and 2 present the bioeconomy industry composition as defined in Argentina, Malaysia, South Africa, the USA and two EU Member States (Bracco *et al*. 2018), as well as in a sample of European countries (11 Member States, Norway and Turkey in Lier *et al*. 2018)[6]. Agriculture, forestry, fisheries/aquaculture and the food industry are consensually recognized as belonging fully to the bioeconomy sector. Renewable energies/biofuel and the chemical industry are included in the bioeconomy concept of all countries represented in Table 1, but its status varies from fully to partly included. Other industries comprise the bioeconomy, but they differ across countries. As a general feature, the industrial scope adopted in European countries is more homogeneous than at a wider level. Almost all European countries represented recognise the industries of pulp and paper and water purification and distribution as part of the bioeconomy (except Latvia for former and Estonia for the latter). In contrast, the inclusion of the health sector and of activities related to Knowledge and Innovation is a specificity of Malaysia and South Africa (although the two sources of Table 1 contradict in the case of Germany and the Netherlands). Mining activities are also included in the South African bioeconomy strategy because of the use of bio-based input in mining processes.

Table 1. Comparison of bioeconomy's industry composition in selected countries from Bracco at al. (2018).

	Argentina	Germany	Malaysia	The Netherlands *	South Africa	USA *
Agriculture	■■	■■	■■		■	■■
Automotive and mechanical engineering		■■				
Chemistry (incl. bioplastics)	■■	■■	■■	■■	■	■■
Biofuels/bioenergy	■■	■■	■■	■■	■	
Biorefining		■■	■■		■	■■
Construction/Building industry		■■				
Consumer goods (e.g., cosmetics, cleaners)	■■	■■			■	
Feed	■■	■■	■■		■	
Fisheries	■■	■■	■■		■	
Food and Beverage industry	■■	■■	■■		■	
Forestry	■■	■■	■■	■■ **	■	■■
Health			■■		■	
Knowledge/Innovation		■■	■■	■■	■	
Mining					■	
Pharmaceutical industry	■■	■■	■■	■■	■	
Pulp and paper	■■	■■		■■	■	
Textiles	■■	■■		■■	■	■■
References:	[11]	[12]	[32]	[20]	[23,33]	[29]

* The monitoring system analysis for the Netherlands refer to bio-based economy and the results for the United States refer to bio-based products industries. ** Only forest-based industry. Legend: ■: included in bioeconomy strategy, ■■: included in the bioeconomy strategy and monitored or measured.

Source: Bracco *et al*. 2018.

[5] Even more so from a global perspective. See for example the report "Safeguarding the Bioeconomy" (National Academy of Sciences, 2020), which provides the following definition: "The U.S. bioeconomy is economic activity that is driven by research and innovation in the life sciences and biotechnology, and that is enabled by technological advances in engineering and in computing and information sciences."

[6] A detailed analysis can also be found in Kardung et al. (2019).

Table 2. Comparison of bioeconomy's industry composition in selected countries from Lier et al. (2018).

Industries and activities according to the *European Classification of Economic Activities* (NACE, Rev. 2) (included= "++"/ partly included = "+" /not included ="-") in the bioeconomy sector at national level.

NACE category	DENMARK	ESTONIA	FINLAND	FRANCE	GERMANY	ITALY	LATVIA	NETHERLANDS	NORWAY	SLOVAKIA	SPAIN	TURKEY	UK
Agriculture	++	++	++	++	++	++	++	++	++	++	++	++	++
Aquaculture	++	++	++	++	++	++	++	+	++	+	++	++	++
Chemical industry	+	+	++	+	+	++	+	+	+	+	++	++	++
Construction	+	-	++	+	+	-	+	-	+	-	+	++	+
Fisheries	++	++	++	++	++	++	++	+	++	+	++	++	+
Food industry	++	++	++	++	++	++	++	++	++	++	++	++	++
Forestry	++	++	++	++	++	++	++	++	++	++	++	++	++
Hunting	+	++	++	-	+	-	++	-	++	+	-	++	-
Nature tourism, green care and recreation	+	++	++	+	-	-	+	-	+	-	+	++	-
Pharmaceutical industry	+	+	++	+	+	++	+	++	+	+	+	++	++
Pulp and paper industry	++	++	++	+	++	++	-	++	++	+	++	++	+
Renewable energy	+	++	++	+	+	++	++	++	++	++	++	++	+
Transportation of bio-based raw materials and products	+	++	++	++	+	-	-	+	+	-	-	-	+
Water purification and distribution	+	-	++	+	+	++	++	++	++	+	+	++	+
Wood products industry	++	++	++	++	++	++	++	+	++	+	++	+	++

Source: Lier et al. 2018.

As shown in these two tables, the, industries represented in national bioeconomy strategies reflect national policy priorities. These differences entail variations into: (i) the industry composition of the bioeconomy and (ii) the extent to which a sector is considered to be bio-based (i.e., fully bio-based or partially bio-based). Subsequently, a partially bio-based sector poses the methodological problem of quantifying its relative contribution to the bioeconomy.

2.3 Classification of industries and sectors included in the bioeconomy

The main challenge in the measurement is that the bioeconomy is not a clearly defined industry as such and as will become evident in the subsequent sections of this report: no sector is purely bio-based and all industries use bio-based materials to some extent in their production process or as ingredients to the final products. In this report we use the term ***industry*** to refer to the standard classification of activities (e.g., NACE),[7] reserving the term ***sector*** for a broader sub-section of the economy that generally spans multiple industries.

The classic three-sector model of the economy classifies industries in three sectors referred to as the primary, secondary, and tertiary sectors (e.g., Fisher 1939). The primary sector consists of extraction, collection and cultivation of natural resources. The secondary sector consists of the manufacture of goods. The tertiary sector refers to the production of services. Following Grealis and O'Donoghue (2015), we propose an alternative classification, analogous to the three-sector classification, to distinguish between bio-based and non-bio-based primary, secondary, and tertiary sectors, hence extending the number of sectors to six. Table 3 illustrates the classification with some examples of industries.

[7] NACE (*Nomenclature des Activités Économiques dans la Communauté Européenne*) is a European industry standard classification system. See, e.g., https://ec.europa.eu/eurostat/documents/3859598/5902521/KS-RA-07-015-EN.PDF.

Table 3. Proposed classification of sectors and industries with some examples.

Sector	a) non-bio-based industries	b) bio-based industries
I Primary production sector	Ia: e.g., mining, quarrying	Ib: Primary production of biomass, e.g., agriculture, forestry, fishing, aquaculture
II Secondary production sector	IIa: e.g., other manufacturing industries	IIb: Transformation of raw biomass, e.g., food industry, textiles, wood, paper
III Tertiary production sector	IIIa: e.g., computer programming, financial services	IIIb: Transformation of processed biomass, e.g., restaurants, trade and transportation of bio-products

Source: Own elaboration.

The classification into six sectors is exhaustive (i.e., it covers the entire economy) and mutually exclusive (i.e., there is no double counting of activity in two or more sectors). Our main interest is in the three bio-based sectors of the economy, labelled as Ib, IIb, and IIIb, respectively. The primary bio-based production consists of the extraction, collection and cultivation of bio-based materials from nature, to be mainly used as raw materials: this is the sector of the economy that interacts with the biological processes of nature. In the two-digit NACE industry classification, Sector Ib includes industries A01 – A03 (A1 - Crop and animal production, hunting and related service activities, A2 - Forestry and logging, and A3 - Fishing and aquaculture). The list of industries included in Sector Ib is exhaustive.

The secondary bio-based production refers to the manufacturing of goods using bio-based raw materials in the production process or as ingredients of the final products. The large traditional industries of this sector are the manufacturing industries C10 – C17 (10 – food, 11 – beverages, 12 – tobacco, 13 – textiles, 14 – wearing apparel, 15 – footwear, 16 – wood and cork, 17 – pulp, paper and paperboard). Since only portions of these industries are considered bio-based, the manufacturing industries are referred to as "mixed bio-based industries". In the present study, the list of manufacturing industries is not exclusive: all industries that use inputs from Sector Ib are considered as mixed bio-based industries. Therefore, a part of the industry is counted in Sector IIb.

In this study, the tertiary bio-based production refers to further refining of the manufactured bio-based products (e.g., construction of buildings using inputs from wood industry) and intermediating and logistic services to facilitate final consumption of the bio-based goods (e.g., trade and transportation services of bio-based products). While the list of industries in Sector Ib is exhaustive, in contrast, the industries included in Sectors IIb and IIIb are neither exhaustive nor mutually exclusive. Indeed, an industry may be part of multiple sectors. For example, restaurants buy inputs from both primary production (e.g., fresh fish from fisheries and aquaculture industry) and secondary production (food industry), hence a part of restaurants' activity that is based on the primary bioproducts is considered as sector IIb, while another part of restaurants' activity based on the secondary bio-based products is classified as sector IIIb. The restaurant example illustrates how the bio-based classification of sectors used in this paper differs from the usual classifications of industries.

Given the six-sector classification presented in Table 3, we define the bioeconomy as the sum of three bio-based sectors.

Definition: The bioeconomy is the sum of the primary bio-based production, secondary bio-based production, and the tertiary bio-based production, that is,

(1) Bioeconomy = Sector Ib + Sector IIb + Sector IIIb

While there are notable measurement issues in Sector Ib, the main challenge in the measurement of the bioeconomy obviously concerns the so-called mixed bio-based Sectors IIb and IIIb.

From an analytical point of view, the proposed classification would allow insights into the broad distribution of value along the value chain. This is crucial, as the political debate on the bioeconomy is very much focused on the share of value added for the (primary) producers of biogenic raw material in a vision of a booming bio-based industry.

2.4 Indicators for measuring the bioeconomy

To date, the most commonly used indicators to monitor the impact of national bioeconomy strategies and to measure the size of bioeconomy include the gross output (or turnover)[8], value added, investments, exports of bioeconomy goods and employment. The first four indicators reflect the economic dimension of sustainability, whereas employment can be seen as an indicator of social sustainability. In Section 8, we also consider greenhouse gas emissions (GHG) as an environmental indicator relevant to sustainability.

[8] The term "turnover" is commonly used in business economics (e.g., accounting) to refer to the total sales of the firm. At the industry level, the term "output" analogously refers to the total value of production in a given year (including also the changes in inventory).

The main source of the economic indicators are the annual national accounts (see Box 1 for further details). The national accounts of the EU countries comply with the global SNA2008 (reference) recommendation and are therefore comparable across countries. Among the multiple economic indicators of the bioeconomy, the value added is clearly preferable to that of gross output. Note that the sum of value added over all industries is equal to the GDP of the economy. Turnover is a useful accounting measure at business company level, and an analogous measure of gross output is useful at the industry level, but the aggregation of gross outputs over multiple industries is highly problematic as it involves double counting. In spite of this major drawback, turnover remains widely used as a bioeconomy indicator. For example, the bioeconomy strategy of the Finnish government from year 2014 aims to increase the turnover of the bioeconomy sectors to €100 billion by year 2025. Therefore, there is a need to clearly articulate the measurement problems involved with the gross output and turnover as indicators of the economic performance of the bioeconomy.

To better understand the problem it is helpful to consider the six-sector classification of the economy presented in Table 3. Note that the monetary value of the primary bio-based production that is used as a raw material in domestic manufacturing is counted at least twice, firstly as the output of the primary bio-based production and secondly as the input of secondary bio-based production. The problem becomes even more serious if the tertiary bio-based production is included in the calculations because the same bio-based material is counted multiple times as it is transformed from a raw material to manufactured products and further to services to facilitate final consumption. The cascading use of renewable resources, with several reuse and recycling cycles, as a key principle of a circular economy and proposed for example in the Bioeconomy Strategy (European Commission 2012 and 2018), is therefore also a veritable challenge from an economic accounting perspective.

Box 1. National accounts terminology.

Output (*O*) at basic price consists of products manufactured during a calendar year. Three categories of output are (1) market output, (2) output for own final use, and (3) other non-market output. Non-market output is not included in the system of national accounts, and hence we exclude it from the bioeconomy calculations.

Value added (*V*) refers to the total value generated by units engaged in production activities. In market production, it is calculated by deducting the value of intermediate activities (goods and services) from the unit's output:

Value added = Output – Intermediate inputs

Number of people employed (in national accounts) includes all people drawing a salary and independent entrepreneurs who participate in production activities in the national economy. The statistics are more comprehensive than those of labour force surveys, as no age limits are defined for employed people in national accounts, and men and women doing their national service, for example, are counted as employed.

Source: Eurostat.

Another significant problem with the use of gross output as bioeconomy indicator is that it includes the imports to bio-based industries. It seems counterintuitive to count imports from other countries (whether bio-based or not) to the bioeconomy of the given country of interest. Furthermore, summing the bioeconomy outputs of Member States also involves double counting at the EU level: if bio-based raw materials are traded from one EU country to another, the value of the traded bio-material is included in the gross outputs of both the exporting and importing countries. One remotely rational justification for using the gross output as a bioeconomy indicator concerns the measurement of inputs to primary bio-based production in Sector Ib. For example, consider the Finnish agriculture in 2015. Of the gross output of €4.1 billion, €3.2 billion were spent on inputs from other sectors and hence the value added was only €1.2 billion. It could be argued that other industries contributed to Finnish primary bio-based production by providing inputs to agriculture, and that this contribution of €3.2 billion should be taken into account in the measurement of the size of the bioeconomy. We return to this issue in more detail in Section 4.3. While the gross output minus imports has certain intuitive appeal in the primary bio-based production sector, we conclude by stressing that the use of gross output as the bioeconomy indicator is highly problematic in the secondary and tertiary bio-based sectors, especially if one wants to aggregate the results over countries or regions.

3 Existing approaches to measure the bioeconomy

As the bioeconomy gained importance in national agendas, the necessity arose to quantify and monitor this concept. The objective of this section is not to list all methodologies employed but to illustrate the diversity of such methodologies with four examples: the socioeconomic oriented approaches by nova-JRC, and Finland (Luke), the physical supply and use approaches developed by JRC, Statistics Netherlands – CBS and the Thünen Institute.

3.1 Output-based Nova-JRC method

Following the launch of the EU bioeconomy strategy in 2012, the JRC cooperated with the nova-Institute[9] in developing a methodology for the quantification of jobs, turnover and value added generated in bioeconomy sectors. With the aim to further monitor those three indicators, the methodology had to (i) be replicable in every EU Member State, (ii) deliver numbers with a time-lag of maximum two years, (iii) be easily updatable every year, and (iv) deliver harmonised data across bioeconomy sectors.

Such methodology and its consecutive update are described in Ronzon *et al*. (2017) and Ronzon and M'Barek (2018). The methodology proceeds as follows. First, the biomass content of the bio-based products that are not fully bio-based - e.g., textile made of cotton (biomass) and synthetic fibres (non-biomass) - is determined. This biomass content, further coined "product bio-based share" is determined by industrial and market experts during interviews held by the nova-Institute. It covers the list of manufactured products as defined by the CPA classification (eight-digit level). Further, the contribution of each manufacturing sector is defined as specified by the NACE classification to the bioeconomy. This step consists in computing the production value of all bio-based products belonging to a given NACE sub-sector/industry and consequently calculating the corresponding "sectorial bio-based share" by dividing the bio-based production value of this sector by its total production value. Sectorial bio-based shares are calculated country-wise and for each year of the time series so to reflect the evolution of national production mixes.

The sectorial bio-based share of manufacturing sector *i* is defined as:

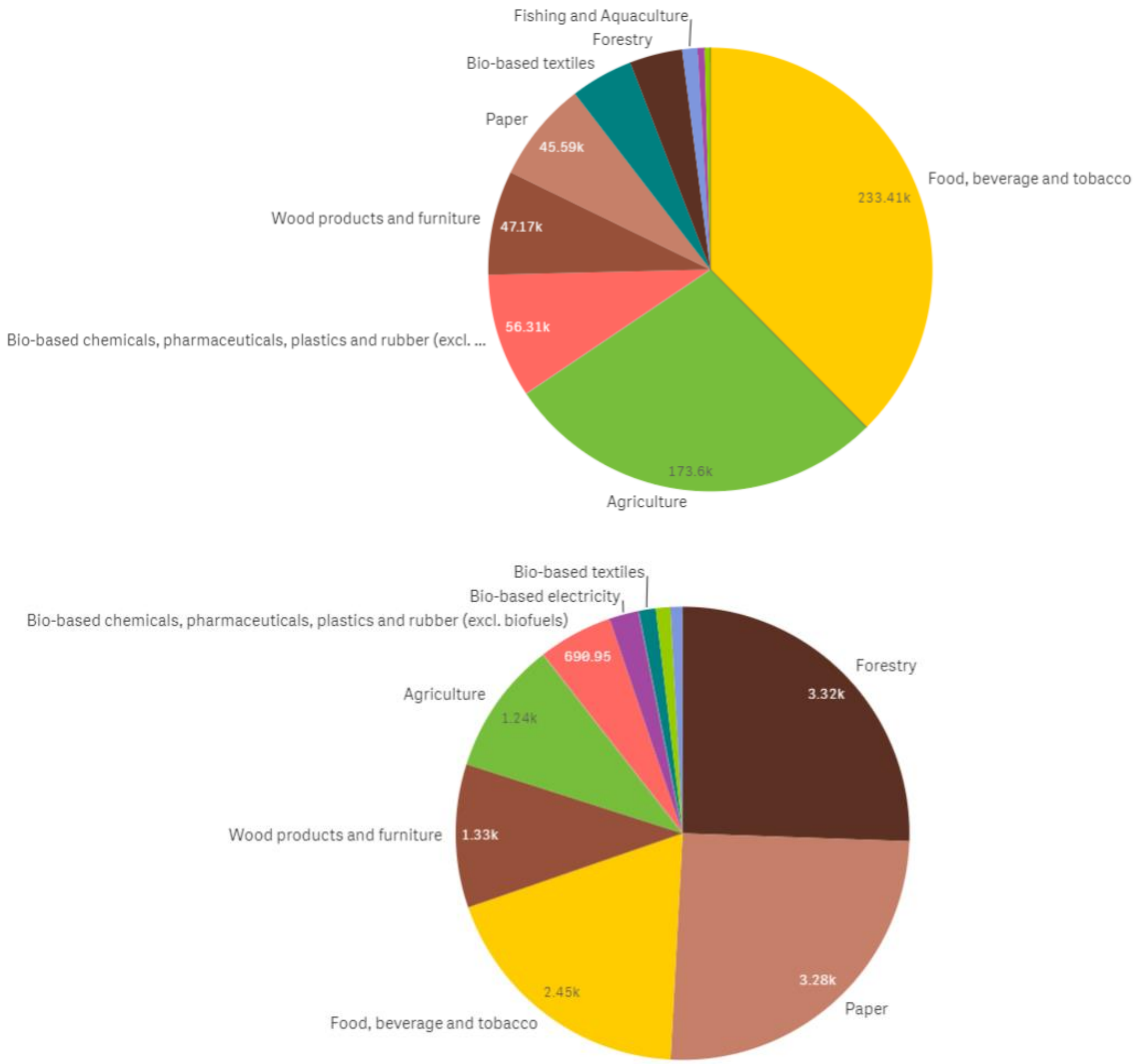
(2) $$BBS_{i,k,l} = \frac{\sum_{j=1}^{n} bbs_j \times production\ value_{j,k,l}}{\sum_{j=1}^{n} production\ value_{j,k,l}},$$

where $BBS_{i,k,l}$ is the bio-based share of sector *i*, in EU Member State *k* and for year *l*; bbs_j is the bio-based share of product *j*, given that sector *i* manufactures *j=n* products, $production\ value_{j,k,l}$ is the production value of product *j*[10], by EU Member State *k* and for year *l*. As an illustration, consider the case of Finland in 2015 (see Figure 1).

[9] http://nova-institute.eu/

[10] Production value measures the amount actually produced by the unit, based on sales, including changes in stocks and the resale of goods and services. The production value is defined as turnover, plus or minus the changes in stocks of finished products, work in progress and goods and services purchased for resale, minus the purchases of goods and services for resale, plus capitalised production, plus other operating income (excluding subsidies). Income and expenditure classified as financial or extra-ordinary in company accounts is excluded from production value. Source: Eurostat.

Figure 1. Value added of the bioeconomy sectors in the EU-28 2015 (top) and Finland (down), in million €.



Source: JRC. (https://datam.jrc.ec.europa.eu/datam/mashup/BIOECONOMICS/index.html).

The five largest sectors were considered to be 100% bio-based. There is a lot of effort to estimate the bio-based content of outputs in rather marginal but promising industries such as chemical and pharmaceuticals. On the other hand, major sectors of tertiary bioeconomy such as wholesale and retail trade as well as accommodation and food services (restaurants) are not included in the measured size of the bioeconomy. They are the focused of an "Extended nova-JRC" approach that is still work-in-progress and presented at section 5.2.

3.2 Physical supply and use flows

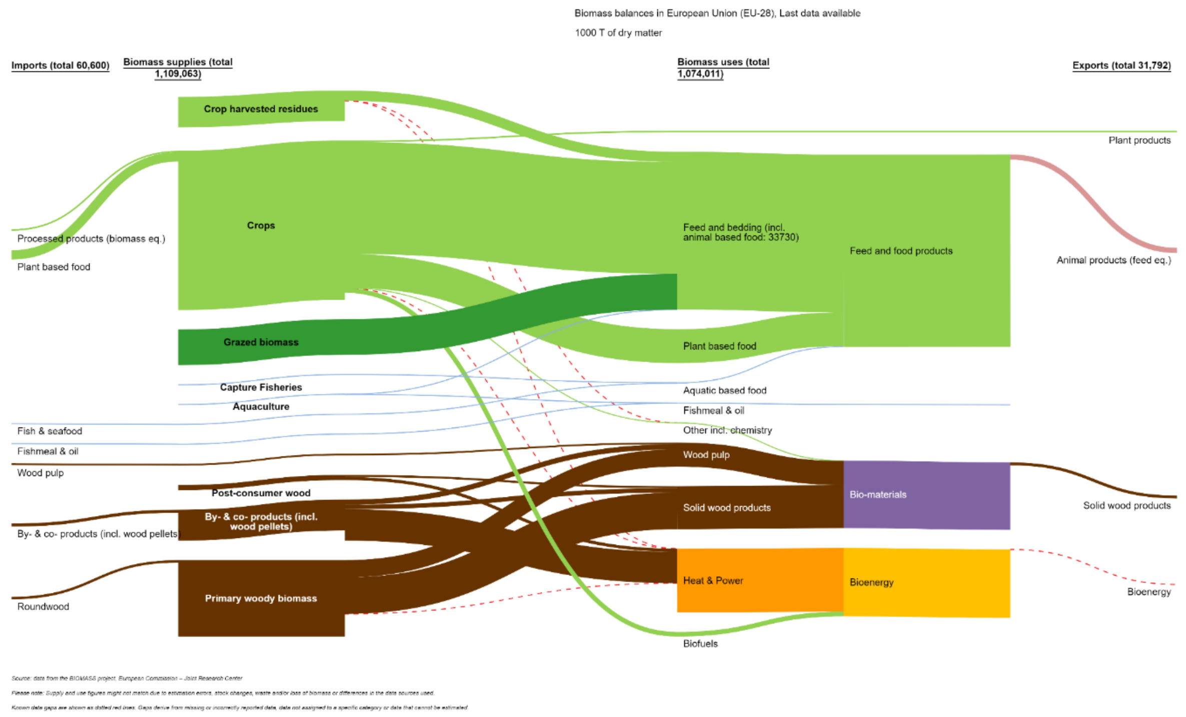
The input-output tables are usually assembled in monetary units. However, it is worth noting that Leontief originally developed the I-O model in physical units (see, e.g., Miller and Blair 2009, for further discussion and references). With the emergence of energy and environmental concerns, the I-O modelling with physical units has gained renewed interest. There exist also so-called mixed-units I-O models where economic transactions are measured in monetary terms and ecological and/or energy transactions are recorded in physical terms (e.g., tonnes, joules).

As an alternative approach, the input- and output-based weights applied in the previous sections could be replaced by weights determined using data of supply and use flows measured in physical units. However, biophysical data that can be integrated across sectors is scarce at the moment. Several studies have attempted to measure the availability and flows of biomass in the economy. These biomass estimations exclude all non-biobased materials and are therefore a valuable indicator for the bioeconomy. In particular, in combination with additional data, these biomass flows can increase the understanding of how the same biomass type is used to produce different materials (e.g., agricultural products used to produce food as well as biofuels) and the potential effects across sectors of substituting non-biobased products with their bio-based equivalents. The biomass flows can also include indicators of sustainability (CO_2 emissions) and circularity of the bioeconomy (recycled materials or cascading of use of the same materials).

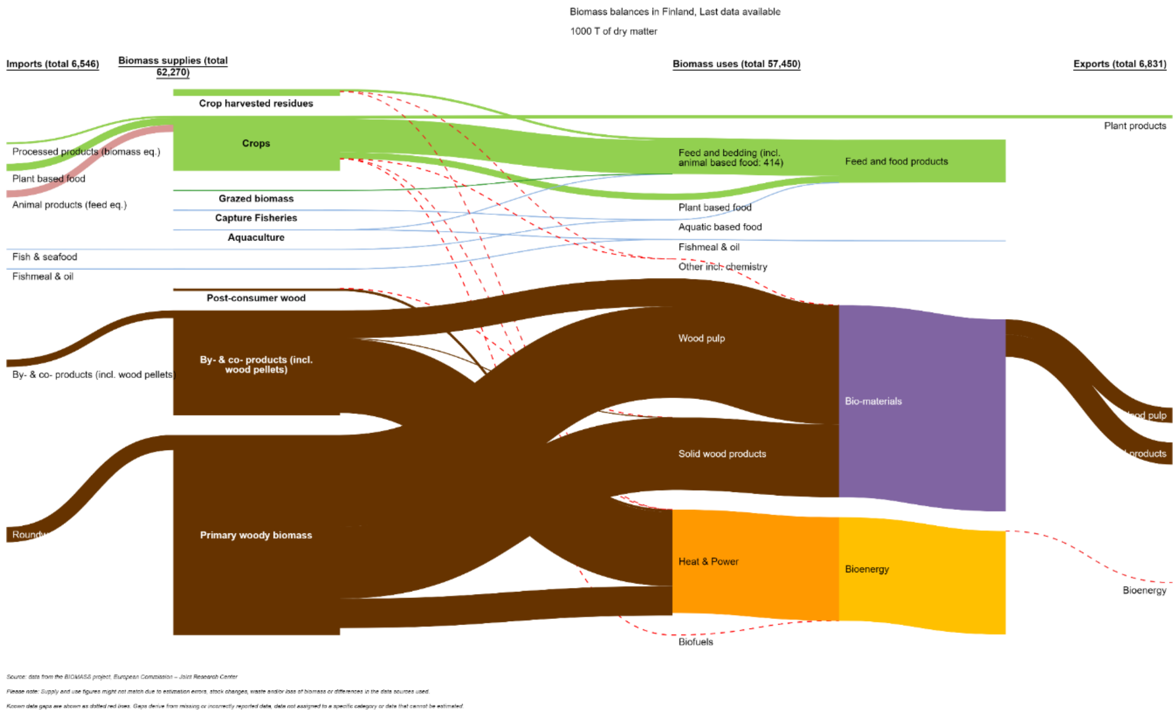
An example of such research is the Material Flow Monitor developed by Statistics Netherlands – CBS (Van Berkel and Delahaye 2019), which describes the physical material flows of the Dutch economy, measured in million kilograms. The physical flows also include imports and exports of goods. The Material Flow Monitor originates from the monetary supply and use tables published in the National Accounts and is converted into physical flows of materials. The level of disaggregation achieved with these material flows, both in terms of commodities (products) and activities (sectors and subsectors) makes it possible to estimate the size of the bioeconomy in physical terms within the whole Dutch economy. Unfortunately, it is currently only available for The Netherlands.

Another example is the biomass flow diagram developed by the JRC in the context of the Biomass Mandate. This diagram describes the flows of biomass across sectors of the economy. In this case, the physical flows have been directly estimated without conversion from monetary data. The methodology is described by Gurria *et al*. (2017) and Camia et al. (2018). While the data is only available at a higher level of sectorial aggregation, it represents the flows of materials for all 28 Member States and the EU totals. The diagrams can be found in the Data portal of agro-economics research of the European Commission[11]. Figure 2 shows Sankey biomass diagrams for Finland and the EU-28. Figure 3 represents the composition of total biomass supply and biomass uses for Finnish and the EU-28. Both figures illustrate how Finland is more adapted to biomass of forestry origin than the average of the EU-28, including for the production of energy. Finland also appears to produce and export more materials of wood origin than the EU-28 average.

Figure 2. Sankey biomass diagrams for the EU-28 (top) and Finland (bottom).

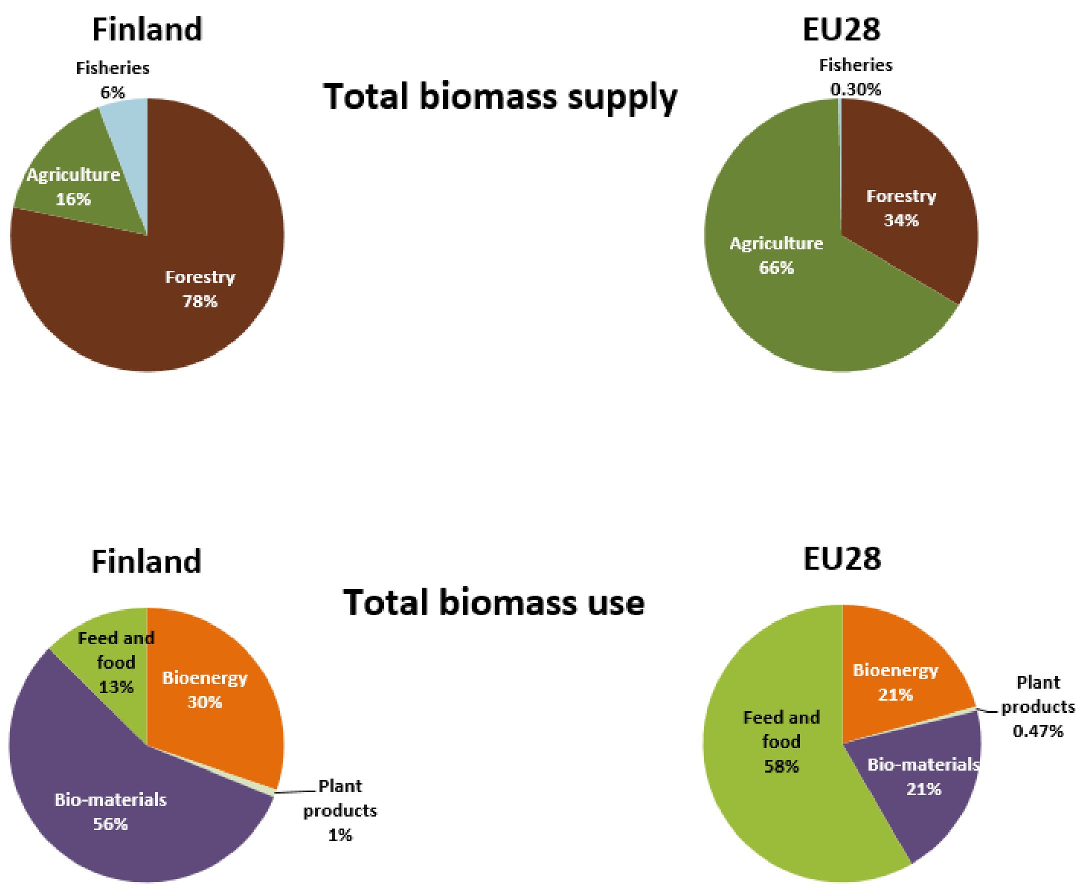


[11] Data portal of agro-economics research – DataM. Source: data from the BIOMASS project, European Commission – Joint Research Center. https://datam.jrc.ec.europa.eu/datam/mashup/BIOMASS_FLOWS/index.html



Source: JRC. (https://datam.jrc.ec.europa.eu/datam/mashup/BIOMASS_FLOWS_NEW/index.html).

Figure 3. Composition of total biomass supply and use for Finland and the EU-28.



Source: Own elaboration.

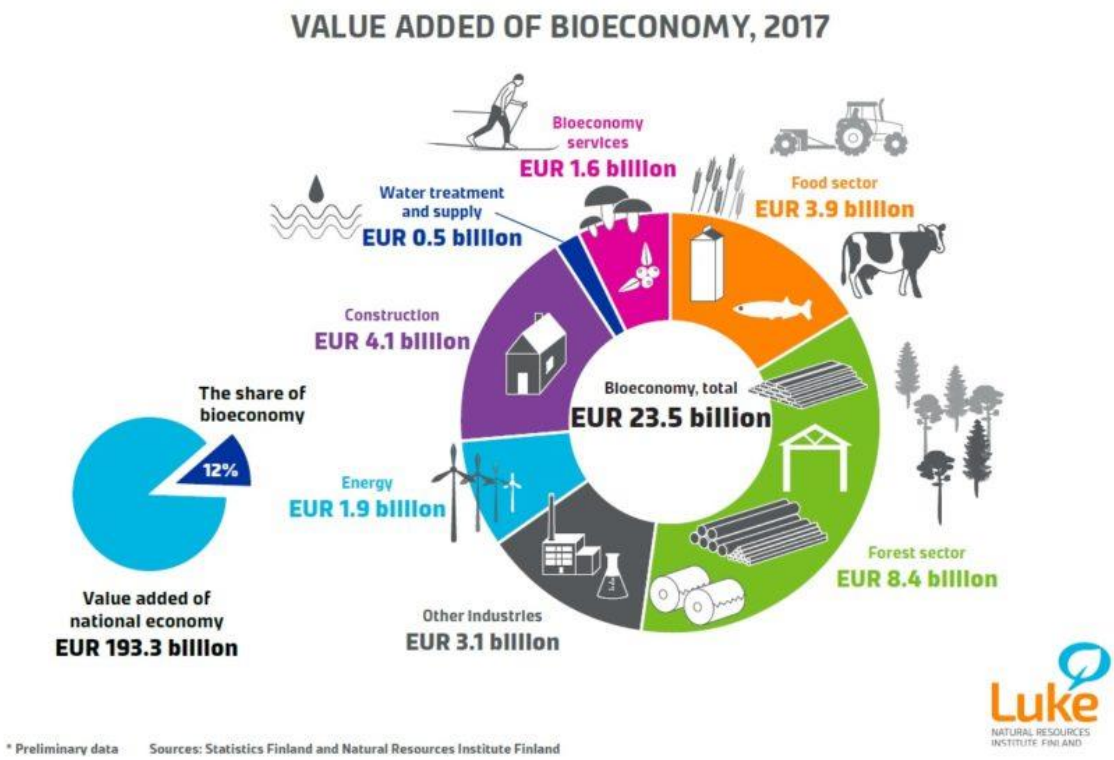
3.3 Finnish bioeconomy statistics

As an illustrative example, consider first the Finish approach to measure the size of the Finnish bioeconomy. Natural Resources Institute Finland (Luke), together with Statistics Finland provides calculations of bioeconomy statistics in order to monitor the development of the Finnish bioeconomy and significance of bioeconomy sectors in the national economy. These two organizations are jointly in charge of developing the methodology and substance of Finnish bioeconomy statistics.

Finnish bioeconomy statistics include five indicators such as output, value added, investments, employment and exports of bioeconomy goods. These indicators are based on the annual national accounts produced by Statistics Finland, which are compliant with the System of National Accounts (2008 SNA2008) and are internationally comparable.

The Finnish bioeconomy sectors are classified based on the Standard Industrial Classification TOL 2008, which is compatible with the classification of economic activities in the European Union (NACE, rev. 2). The three-digit industry classification is used. Some of the sectors are entirely included in the bioeconomy, such as agriculture, forestry, fishery, food industry. Other sectors, such as construction and chemical industry, are included partially. For a number of sectors statistical information is unavailable, and therefore relative shares of the bioeconomy are mainly based on expert estimates. Further, Luke's calculations consider only direct effects generated by the bioeconomy sectors, but exclude the indirect effects on sectors, such as inputs to the bioeconomy (e.g., supply of machinery and equipment, raw materials or services).

Figure 4. Value added of the bioeconomy sectors in Finland 2017.



Source: Luke.

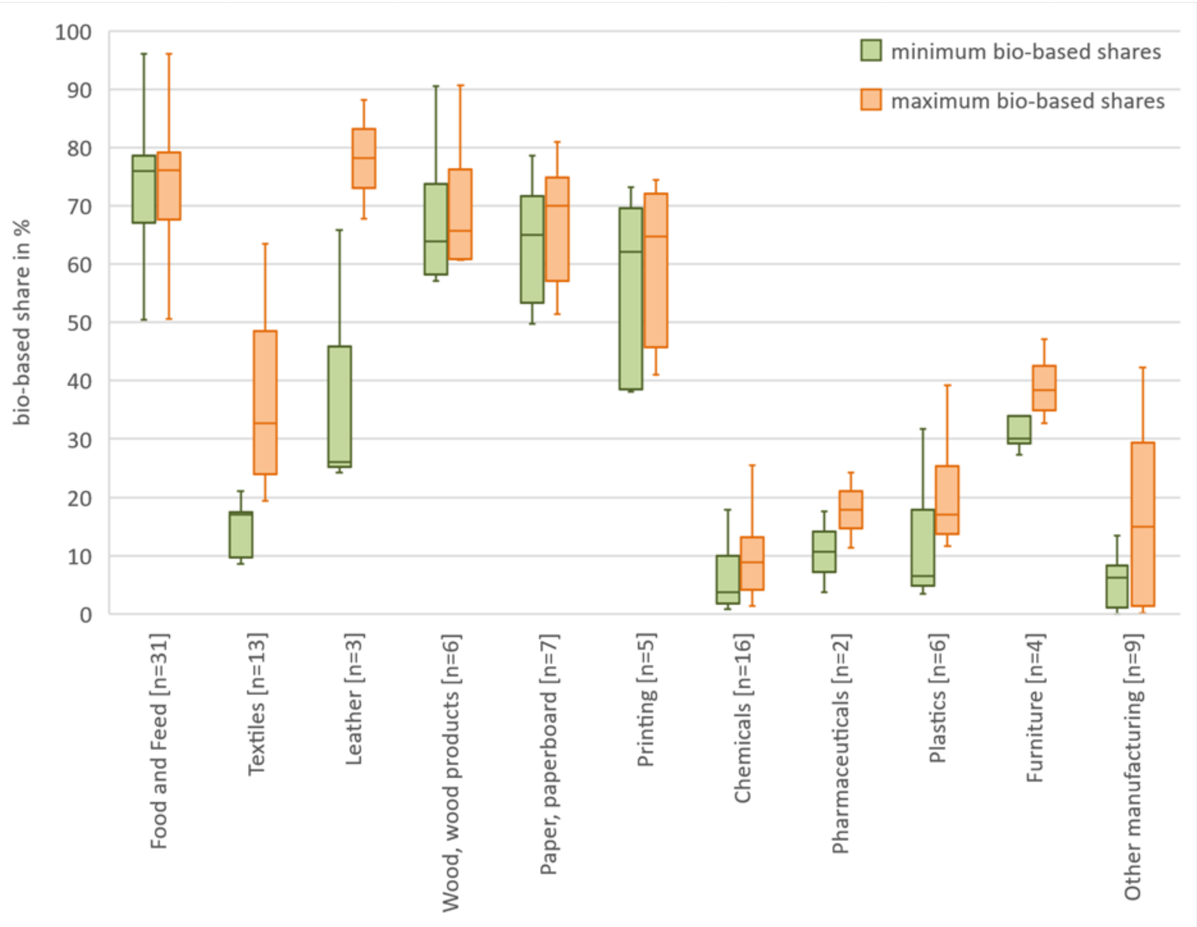
3.4 Thünen Institute's methodology

The German Bioeconomy strategy (BMEL 2014) provided the basis for the bioeconomy definition that focuses on flows of renewable materials. The Thünen-Institute developed a concept for monitoring the bioeconomy with focus on resource base and sustainability. The elaborated concept consists of a twin approach, which covers material flows and sectors relevant in the bioeconomy.

Thünen's sectoral approach to estimate bioeconomy in Germany (described in Iost *et al*. 2019) includes the production of biomass and any manufacturing or processing of partly or fully bio-based materials, semi-finished and end use products. Based on that understanding, economic activities as classified according to NACE Rev. 2.0 (Nomenclature Statistique des Activités Économiques dans la Communauté Européenne Revision 2) are selected as relevant for the bioeconomy. Agriculture, forestry and fisheries, parts of wood construction and as well as food and beverage service activities are considered fully bio-based. Manufacturing, electricity, gas, steam and air conditioning supply and further parts of wood construction are considered partly bio-based. Fundamentally, partly bio-based shares were calculated as the share of bio-based inputs of all inputs into the respective economic activity. The Federal Statistical Office (for further details see Iost et al. 2019) provided relevant data.

The same institution collects data on acquisition costs of all material inputs into the economic activities of sector C (Manufacturing) at four-digit level every four years. Based on this information for manufacturing activities, the bio-based shares are calculated as the sum of acquisition costs of bio-based material inputs in relation to total acquisition costs (Figure 5). Some of the surveyed material input are only partly bio-based. For those the bio-based share is calculated using production statistics. The bio-based share of an input (four-digit level) is calculated as the sum of bio-based production value (nine-digit level) in relation to the production value on the four-digit level of German production statistics. Bio-based products are determined using additional information like market and empirical studies and expert opinions. Thus, in the Thünen approach information on bio-based inputs is extended by information on bio-based shares of products (outputs). However, for many products the exact bio-based share cannot be determined. Consequently, minimum and maximum bio-based shares are calculated. Minimum bio-based share considers only those inputs and products that are fully bio-based. The maximum bio-based share relates to inputs and products that are partly and fully bio-based.

Figure 5. Distribution of bio-based shares of relevant NACE sections (Manufacturing) at four-digit level.



Source: Iost *et al.* 2019.

For economic activities other than section C, bio-based shares are estimated as described in Iost et al. (2019) using official German statistics. The bio-based shares are then applied to selected indicators like number of persons employed, gross value added and turnover. The following Table 4 presents bio-based shares for bioeconomy NACE categories other than manufacturing and the respective bio-based jobs, gross value added and turnover.

Table 4. Distribution of bio-based shares of relevant NACE sections (Manufacturing) at four-digit level.

Code	Description	Bio-based share, %	Jobs, Million	Gross value added, M. EUR	Turnover, M. EUR
A Agriculture, Forestry, Fisheries		100	0.649	25,683	41,511
C Manufacturing		See Figure 5 Minimum	1.091	53,471	243,770
		Maximum	1.283	66,819	289,154
D 35.1/3	Electric power generation, transmission and distribution & Steam and air conditioning supply	9.1	0.019	3,315	46,044
D 35.2	Manufacture of gas; distribution of gaseous fuels through mains	94.3	0.013	3,806	51,321
F 41.20	Construction of residential and non-residential buildings (except prefabricated constructions) & Assembly and erection of prefabricated constructions	7.81	0.022	1,012	3,316
F 43.32.0	Joinery installation	100	0.146	4,287	11,332
F 43.91.2	Erection of frames and constructional timber works	100	0.187	7,792	18,389
I 56.1 - 3	Food and beverage service activities	100	1,542	23,036	51,013
M 72.11.0	Research and experimental development on biotechnology	100	0.012	740	1,248
M 72.19.0	Other research and experimental development on natural sciences and engineering	57.3	0.083	4,946	6,857

Source: Own calculations.

The Thünen approach covers input and output data in order to estimate the size of the bioeconomy. It mainly relies on official statistics, but also on empirical and market data. Further research is needed in how to interpolate data on material inputs into economic activities for manufacturing, as the relevant survey is done only every four years. Furthermore, estimating reliable bio-based shares of services like transport and retail remains a challenge.

4 Input-based approach to quantify the shares of mixed industries

Input-output (I-O) analysis has been indicated as one possible approach to use monetary flows in input-output tables from the national accounts to obtain a more objective and harmonised measure of the size of the bioeconomy (e.g., FAO 2018). A key advantage of the input-output approach is that it is based on the standardised data of national accounts, which allows for international comparison and aggregation, for example at the EU level. We note that input-output tables and I-O analysis have been used for measurement and analysis of the agribusiness sector since Davis and Goldberg (1957). More recent I-O studies of the bioeconomy include Grealis and O'Donoghue (2015), Budzinski *et al.* (2017) and Loizou *et al.* (2019).

The use of I-O analysis also raises some scepticism related to its restrictive assumption. For example, a FAO (2018) report articulates the sceptical point of view as follows:

I-O analysis depends on the crucial assumption that sectoral production is completely demand-driven, implying that there is always excess capacity in all sectors that is capable of meeting increased demand with no price increase. Prices are assumed constant. Moreover, I-O models assume constant returns to scale production function with no substitution among the different inputs. Since these assumptions are likely to be unrealistic in the long term, I-O models are more useful for short term descriptive analysis (SAT-BBE Consortium, 2014). Moreover, the lack of substitutions among inputs could be a limitation to analyse the contribution of bioeconomy, since flexibility in inputs adds value.

While the I-O analysis indeed depends on a number of restrictive assumptions, we must stress that the use of input-output tables as empirical data does not require all these assumptions. In the present study, we are mainly interested in estimating the cost share of the bio-based raw materials in the total input use. For that purpose, we do not need to impose such restrictive assumptions as constant returns to scale or no substitution.

The purpose of this section is to develop the use of input-output tables for measuring the size of the bioeconomy sector. To this end, we first briefly review Heijman's (2016) two-sector approach in Section 4.1.1 and present an equivalent, alternative interpretation that relaxes some of its restrictive assumptions in Section 4.1.2. In Section 4.2 we generalize and extend the two-sector model to account for heterogeneity of industries and incorporate the tertiary bio-based production of Sector IIIb. In Section 4.3 we further extend the proposed approach to incorporate inputs to primary bio-based production.

4.1 Two-sector model

4.1.1 Heijman's approach

Recently, Heijman (2016) proposed a two-sector model where the measurement of the bioeconomy is based on the material flow of bio-based inputs to secondary bio-based production.[12] In the system of national accounts, the economy is classified to *n* mutually exclusive industries. Following Heijman (2016), the industries are indexed by $j = 1,\ldots,n$. Since the classification of industries in Heijman's model differs to some extent from our proposed classification in Section 2.2, for the sake of clarity, in this section we apply Heijman's original notation. Heijman classifies the industries to two broader sectors. Sector 1 is referred to as *primary bio-based production*, and it includes specifically agriculture, forestry, fishery, aquaculture and veterinary services. Sector 2 includes all other sectors. To quantify the size of the bioeconomy, Sector 2 is further divided into two subsectors, referred to as non-bio-based production (Sector 2a) and secondary bio-based production (Sector 2b). Thus, Heijman defines bioeconomy as the sum of Sectors 1 and 2b.[13]

Heijman focuses on measuring the size of bioeconomy based on the value added. Given the classification, the value added of Sector 1 is easy to calculate by simply summing the value added of agriculture, forestry, fishery, aquaculture and veterinary services. Following Heijman's notation, the industries included in Sector 1 are indexed by $k = 1,\ldots,m$.[14] The value added of Sector 1 can be formally expressed as

(3) $$V_1 = \sum_{k=1}^{m} O_1^k - \sum_{j=1}^{n} I_1^j,$$

where V indicates the value added of a sector indicated by the subscript, O is the output of the industry indicated by the superscript, and I are the inputs to the sector indicated by the subscript from the industries indicated by the superscript.

The main challenge concerns the estimation of the value added of Sector 2b. To this end, Heijman assumes that Sector 2, which includes both bio-based and non-biobased manufacturing and services, generates value added by a constant factor α defined as

(4) $$\alpha = \frac{O_2}{\sum_{j=1}^{n} I_2^j}.$$

In other words, one unit of input from any industry to Sector 2 generates α units of output, irrespective of which specific industry within Sector 2 the input is used for and whether the input is bio-based or not. Heijman explicitly notes that the method assumes that inputs are perfectly substitutable and admits that the "method fully relies on the assumed fixed

[12] This approach is also applied and further investigated in the Horizon 2020 project BioMonitor (http://biomonitor.eu/).

[13] In Sections 4.1.1 and 4.1.2, we refer to Heijman's classification of Sector 1 and Sector 2, which differ from some extend from classification described in Section 2.3.

[14] In general, the method is applicable to any industry classification. In our empirical application that applies the two-digit NACE classification, Sector 1 consists of industries A01-A03 and M75.

relationship between the output of sectors and inputs indicated by the coefficient *α*". This assumption disregards the heterogeneity of industries within Sector 2 as well as the heterogeneity of inputs themselves.

Coefficient *α* can be easily computed form the input-output tables. Given coefficient *α*, the value added of Sector 2b can be then computed as

(5) $V_{2b} = (\alpha - 1)\sum_{k=1}^{m} I_2^k$.

That is, Sector 2b expands the bio-based inputs from Sector 1 by factor *α*, which is assumed to be constant across all industries of Sector 2. In practice, perhaps a more natural interpretation of coefficient *α* is that of the average marginal value product of inputs in Sector 2. In essence, Sector 2 is divided between sub-sectors 2a and 2b solely based on the share of bio-based inputs from Sector 1, assuming the average marginal value product applies to all inputs and to all industries within Sector 2.

The value added of the bioeconomy is subsequently obtained as the sum

(6) $V_b = V_1 + V_{2b}$.

Note that Heijman's definition of Sector 1 is slightly broader than our Sector Ib as it also includes veterinary services. Sector 2b is similar to our Sector IIb. However, note that Sector 2 is broader than our Sector II as it also includes the service industries. Except for the veterinary services, the tertiary bio-based production of Sector IIIb is ignored.

Applying Heijman's two-sector model to the Finnish input-output tables of year 2015, the total value added of the Finnish bioeconomy was €12.3 billion, which was 6.8% of the GDP. The value added of the primary bioproduction Sector 1b was €4.7 billion, that of the secondary bio-based production was €7.7 billion (including the value added generated by imported bio-based inputs worth €1.7 billion). We note that the simple two-sector model yields a slightly lower estimate of the Finnish bioeconomy than the nova-JRC approach, and a substantially lower estimate than the official Finnish bioeconomy statistics. We will examine some of the reasons for these differences in Sections 4.3 and 5.

4.1.2 Alternative interpretation

Heijman's two-sector model can be equivalently stated as follows. Instead of relying on the average marginal product, an alternative input-oriented approach to estimate the size of Sector 2b is to use the input-share of the bio-based inputs from Sector 1. More specifically, define coefficient *β* as

(7) $\beta = \frac{\sum_{k=1}^{m} I_2^k}{\sum_{j=1}^{n} I_2^j}$,

where the sum in the nominator is the sum of all bio-based inputs from Sector 1 to Sector 2b and the sum in the denominator is the sum of all inputs to Sector 2 from all sectors of the economy. In other words, coefficient *β* indicates the share of bio-based inputs in the total input use of Sector 2. Given coefficient *β* that can be readily computed from the input-output tables, the value added of Sector 2b is simply

(8) $V_{2b} = \beta(O_2 - I_2)$,

where *V* indicated the value added of a sector, O is the output of the sector, and I is the inputs of the sector (indicated by the subscript).

Proposition: The value added of Sector 2b can be equivalently calculated using weights α or weights β, that is,

$V_{2b} = (\alpha - 1)\sum_{k=1}^{m} I_2^k = \beta V_2 = \beta(O_2 - I_2)$.

Proof. Starting from Heijman's formulation, simple substitution of term reveals that

(9) $V_{2b} = (\alpha - 1)\sum_{k=1}^{m} I_2^k$

$= \left(\frac{O_2 - \sum_{j=1}^{n} I_2^j}{\sum_{j=1}^{n} I_2^j}\right)\sum_{k=1}^{m} I_2^k$

$= \frac{O_2 \sum_{k=1}^{m} I_2^k - I_2(\sum_{k=1}^{m} I_2^k)}{\sum_{j=1}^{n} I_2^j}$

$= O_2 \frac{\sum_{k=1}^{m} I_2^k}{\sum_{j=1}^{n} I_2^j} - I_2 \frac{\sum_{k=1}^{m} I_2^k}{\sum_{j=1}^{n} I_2^j}$

$= \beta(O_2 - I_2)$.

We find the alternative division of Sector 2 based on the input shares *β* more intuitive as it completely avoids such restrictive assumptions as the fixed relationship between the output of sectors and inputs or perfect substitutability of inputs. Note that the input-based division of Sector 2 is equally simple to implement based on the national accounts and yields exactly the same empirical results. The size of Sector 2b is solely defined based on the monetary material flow of bio-based inputs from Sector 1b. Since Sector 2b consists of secondary bio-based manufacturing, the output of this sector is also to a large extent bio-based material. This argument will be expanded further in Section 3.

4.2 Improved input-output approach

4.2.1 Heterogeneity of industries

The previous two approaches treat Sector 2 as a single entity and ignore heterogeneity of manufacturing and service industries. For example, banking industry cannot use fish as its raw material, and it is not economically feasible to use wheat as a raw material in oil industry. To better account for the heterogeneity of inputs and industries, the input-shares of bio-based inputs can be calculated separately for each industry i = m+1, ..., n within Sector 2 as

(10) $\beta_i = \frac{\sum_{k=1}^{m} I_i^k}{\sum_{j=1}^{n} I_i^j}$.

Note that β_i measures to what extent industry i is using bio-based inputs from Sector 1, and it can be of considerable interest as such: the larger the value of β_i in industry i, the more extensively the industry contributes to Sector 2b and hence to the bioeconomy. Indeed, the approaches based on expert opinion are geared towards eliciting weights β_i based on biomass content in final products.

Given industry-specific coefficients β that can be readily computed from the input-output tables, the value added of Sector 2b is simply

(11) $V_{2b} = \sum_{i=m+1}^{n} \beta_i (O_i - I_i)$.

In this approach the contribution of each industry within Sector 2 to the bioeconomy is first estimated separately based on the share of bio-based inputs, and subsequently Sector 2b is calculated as the sum of the industry-specific contributions. Therefore, both the bio-based share of inputs β_i and the marginal value product of inputs (α) can freely differ across industries within Sector 2.

4.2.2 Imports of bio-based inputs

While the shares of domestic bio-based inputs can be readily calculated using input-output tables, we have thus far ignored the imported raw materials. The input-output tables reported by Eurostat also indicate the total value of imports from industry k to industry i, which allows us to estimate the share of bio-based imports similar to the domestic input share. Denoting the bio-based share of imported inputs to industry i by β_{Mi} and the total value of imports to industry i by M_i, the formula for calculating β_i can be adjusted for imports as

(12) $\beta_i = \frac{\sum_{k=1}^{m} I_i^k + \beta_{Mi} M_i}{\sum_{j=1}^{n} I_i^j + M_i}$.

Thus far, one can simply consider the imports of primary bio-based production from Sector 1 to calculate the share of bio-based imports β_{Mi}. To briefly anticipate the developments in the next section, one could also include imports of secondary bio-based products from Sector 2b (e.g., food, textiles, furniture, pulp and paper products), multiplied by the weights β_i. Note that this would involve an implicit assumption that the bio-based shares of the imported goods are similar to those of the domestic goods. In an empirical application covering multiple countries or regions (e.g., the EU Member States), one could alternatively track imports from specific countries and apply the bio-based weights β_i of the exporting country rather than the importing country. For the most practical purposes, applying the bio-based shares of the importing country would yield sufficient accuracy.

4.2.3 Tertiary bio-based production

As noted above, Heijman's two-sector model does not include the tertiary bio-based industries such as restaurants and retail trade of food. As argued in the introduction, the increasing complexity of the economy has increased the share of tertiary bio-based production. For example, if consumers increase the share of food consumption in restaurants while decreasing cooking at home, the measured share of the bioeconomy would decrease according to the input-output framework introduced in Section 2. To address this issue, we next extend Heijman's two-sector approach to the classic three-sector model of the economy. In the following, we return to the classification of Sectors I, II, and III introduced in Section 2.3.

Recall that j = 1,...,n is the index of all industries. Borrowing Heijman's notation, let the industries included in Sector Ib be indexed by k = 1,...,m, and let the industries in Sector IIb be indexed as l = m+1,...,o. Applying this notation, we can measure the contribution of industry i in Sector IIIb to the bioeconomy by coefficient γ_i defined as

(13) $\gamma_i = \frac{\sum_{k=1}^{m} I_i^k + \sum_{l=m+1}^{o} \beta_l I_i^l + \beta_{Mi} M_i}{\sum_{j=1}^{n} I_i^j + M_i}$.

The three components in the nominator of this ratio include the primary bio-based inputs from Sector Ib, the secondary bio-based inputs from Sector IIb, and bio-based imports, respectively. The denominator includes the sum of domestic inputs from all industries and the imports.

Note that the outputs of secondary bio-based production in Sector IIb are here considered as bio-based inputs to Sector IIIb according to the bio-based input shared β. In practice, industries included in Sector IIb typically produce mixed products that include both bio-based and non-bio-based material (consider, e.g., vegetables packed in plastic material). Coefficients β_i measure the bio-based content of the input use, so we here assume that the output of the processing industry also contains the same proportion of bio-based material after removing non bio-based packaging.

In order to discount non bio-based packaging from the output of the processing industry, we proceed as follows: (i) we first calculate the total expenditure of bio-based inputs from Sector Ib and the secondary bio-based inputs from Sector IIb, including both domestic inputs and imports, (ii) we then calculate the total expenditure of inputs from industries 22-25, which include the manufacture of rubber and plastic products, other non-metallic mineral products, basic metals, and fabricated metal products, which can be used as packaging materials, (iii) taking the ratio of bio-based input cost and the sum of bio-based inputs and inputs of industries 22-25, we obtain the bio-based output shares for the industries of sector IIb non bio-based packaging excluded[15].

Given the coefficients γ_i that also include the secondary bio-based inputs, the value added of Sector IIIb can be calculated analogous to Sector IIb by using coefficients γ_i

(14) $V_{IIIb} = \sum_{i=o+1}^{n} \gamma_i (O_i - I_i)$.

Further, it seems logical to include use of the secondary bio-based products as inputs to Sector IIb to take into account intra-industry trade and the use of secondary bio-based products manufactured in other industries of Sector IIb. For example, there is extensive intra-industry trade in the food industry (e.g., 21percent of the inputs used by the Finnish food industry in 2015 were intra-industry trade from one food manufacturer to another), and the use of paper and cardboard as packaging material involves inputs from the paper industry. Note that the same formula for calculating γ_i is directly applicable to industries in Sector IIb to take into account the intra-industry trade of bio-based products and inputs from other secondary bio-based manufacturing industries. Subsequently, the value added of Sector IIb is analogously

(15) $V_{IIb} = \sum_{i=m+1}^{o} \gamma_i (O_i - I_i)$.

Note that since $\sum_{j=m+1}^{n} \beta_j I_i^j \geq 0$, we must have $\gamma_i \geq \beta_i$ for industries in Sector IIb. Therefore, the bio-based share of Sector IIb can only increase if we use weights γ_i instead of weights β_i.

Counting the value added of Sector Ib using the 100% weight, the size of bioeconomy is

(16) $V_b = V_{Ib} + V_{IIb} + V_{IIIb}$.

Obviously, including the tertiary bio-based production in Sector IIIb increases the total bioeconomy.

Note that for practical reasons, we consider as inputs from sector IIb only the inputs coming from industries C10 to C17, i.e. inputs from the manufacture of food, beverage, tobacco, bio-based textiles, wood products and paper. They indeed represent the vast majority of inputs from sector IIb and this simplifying assumption should not change significantly the results. The same holds for the calculation of bio-based imports (see section 4.2.2).

Applying the proposed extensions to the Finnish input-output tables of year 2015, the total value added of the Finnish bioeconomy increases to €16.7 billion and 9.2% of the GDP, compared to the €12.3 billion and 6.8% of the GDP obtained with Heijman's approach. The value added of the primary bio-based production Sector Ib remains at €4.7 billion, the secondary bio-based production of Sector IIb was €3.7 billion, and the tertiary bio-based production of Sector IIIb amounted to €8.3 billion. Note that the size of Sector IIb is not directly comparable with Heijman's Sector 2b because the latter sector also includes a part of tertiary bio-based services that uses primary bio-products (consider, e.g., restaurants that buy ingredients directly from farms or fisheries).

4.3 Inputs to primary bio-based production

Thus far, we have extended the measurement of secondary bio-based production in Sector IIb and included tertiary bio-based production in Sector IIIb. However, we have thus far ignored the contributions of other industries to the primary production of biomaterials in Sector Ib. As noted in Section 2.3, an intuitive rationale for using the gross output instead of value added might relate to the desire to account for inputs of other industries to primary production as a contribution to bioeconomy. For comparison, Heijman (2016) includes veterinary services to the primary bio-based production in his Sector 1. With the increasing complexity of the economy, parts of conventional primary production tend to be outsourced to other industries, and hence it would seem natural to include the inputs to primary production to the bioeconomy sector, similar to Davis and Goldberg (1957).

Of course, if contributions of other industries to primary production are counted towards the bioeconomy, we need to carefully adjust the calculations of Sectors IIb and IIIb to avoid double counting. This can be done simply by adjusting the formulations for Sectors IIb and IIIb as follows:

(17) $V_{IIb} = \sum_{i=m+1}^{o} \left[\sum_{k=1}^{m} I_k^i + \gamma_i (O_i - I_i - \sum_{k=1}^{m} I_k^i) \right]$,

$V_{IIIb} = \sum_{i=o+1}^{n} \left[\sum_{k=1}^{m} I_k^i + \gamma_i (O_i - I_i - \sum_{k=1}^{m} I_k^i) \right]$.

where $\sum_{k=1}^{m} I_k^i$ indicates the sum of outputs of industry i that are used as inputs in the primary bio-based production sectors $k = 1,\dots,m$. In contrast to the corresponding formulations presented in the previous section, these outputs $\sum_{k=1}^{m} I_k^i$ going to

[15] These output-based shares excluding non bio-based packaging are presented in column 2 of Table 5. They can be compared with the output-based weights estimated according to the nova-JRC methodology (third column of Table 5) and the extended nova-JRC methodology (fourth column of Table 5).

the primary bio-based production are now counted with 100% weight, and the weight γ_i is applied to the remaining value added of industry *i*. These adjustments will obviously increase the bio-based shares of Sectors IIb and IIIb.

If the inputs to primary bio-based production are included in the bioeconomy, assigning 100% bio-based share to Sector Ib seems no longer justifiable. Indeed, it is interesting to assess to what extent the primary bio-based production uses bio-based inputs (e.g., biofuels instead of fossil fuels) and monitor how the bio-based share of primary production differs across countries and develops over time. To this end, we can simply apply the weights γ_i to inputs of primary bio-based production in Sector Ib as well. Calculating the weights γ_i for the Finnish primary bio-based production industries in 2015, we obtain the following bio-based input shares: agriculture 39.7%, forestry 59.5%, and fishing 63.6%. Comparing the input-based shares of the primary bio-based production with those of the assumed 100% output shares reveals a large gap. The purpose of the next section is to propose a method to bridge this gap.

5 Synthesis of input- and output-based approaches

Determining the bio-based weights based on the input-output tables implicitly assumes that the bio-based share of outputs is the same as that of inputs. Clearly, this is not the case for the primary bio-based production sectors – agriculture, forestry, and aquaculture – where the outputs are completely bio-based whereas the inputs are far from 100% bio-based. Indeed, the bio-based shares of the inputs and outputs of an industry can differ considerably. On the other hand, relying exclusively on the bio-based content of the output would ignore the use of bio-based inputs in the production process. For example, consider the use of wooden frames for casting concrete in the construction industry: building of large concrete structures such as bridges or tunnels may involve considerable amounts of wood and plywood even though none remains present in the final product.

5.1 Extending output-based weights

The nova-JRC approach presented in section 3.2 only assigns an output-based weight to the main manufacturing industries producing bio-based products (see column 2 of Table 5). The present document extends this approach to the remaining manufacturing and service industries and is therefore coined "extended nova-JRC shares" (see column 3 of Table 5). When the remaining sectors are not considered 0% bio-based, output-based weights are estimated by using the most disaggregated Eurostat statistics available and then aggregated at the industry level reported in the I-O tables for comparison with the "improved input-output approach" presented at section 4.2. Therefore, the output-based weight of a given I-O industry reflects the relative contribution of sub-industries weighted by their corresponding output-based weight. For example, in the case of industry 37_39 "Sewerage, waste management, remediation activities", bio-based weights are assigned to the collection and treatment of waste by type of waste in *env_wasgen* and *env_wastrt,* assuming that the output-based weight of a given type of waste (e.g. Textile wastes) is equal to the output-based weight of the industry that has generated this type of waste (e.g. 13_15 Manufacturing of Textile). Note that the "extended nova-JRC" methodology is still work-in progress and does not cover yet all sectors of the I-O tables (those sectors are marked with a "-" in column 3 of Table 5).

5.2 Averaging the input- and output-based weights

To take into account the bio-based content in both the inputs and the outputs, we propose to calculate the industry weights as the weighted average of the input- and output-based weights. Specifically, let δ_i be the bio-based output share of the industry, and recall that γ_i is the bio-based input share. To reconcile both the input-side and output-side information, we use the weighted average

(18) $\theta_i = (\gamma_i I_i + \delta_i V_i)/O_i = \gamma_i(I_i/O_i)+\delta_i(V_i/O_i)$.

Regarding the weights, it seems intuitive to apply the ratio of total cost of inputs and gross output as the weight of the input-side bio-based share, and ratio of value added and gross output as the weight of the output-side bio-based share.

Note that for the industries with no output-based weight quantified in column 4 of Table 5, the weighted average is equal to the input-based weight calculated at section 4.2.

Table 5. Output-based weights packaging excluded (in percentages).

Industry	Bio-based output weight used for the quantification of Sector IIIb bio-based weights	Av. nova-JRC bio-based output weight (EU-28, 2015)	Extended nova-JRC bio-based output weight (EU-28, 2015)
B Mining and quarrying		-	0
C10_C12 Food, beverage and tobacco industry	94	100	100
C13_C15 Textile, clothing and leather industries	84	40 (35-46)	40 (35-46)
C16 Woodworking industry	90	100	100
C17 Paper industry	91	100	100
C18 Printing and reprod. of recorded media		-	69 (41-97)
C19 Mfr of coke and refined petroleum products		-	0
C20 Mfr of chemicals and chemical products		10	10 (9-11)
C21 Pharmaceutical industry		49	49
C22 Mfr of rubber and plastic products		4 (3-4)	4 (3-4)
C23 Mfr of other non-metallic mineral products		-	0
C24 Mfr of basic metals		-	0

C25 Mfr of fabricated metal products, except machinery and equipment	-	4 (0-8)
C26 Electronics industry	-	0
C27 Mfr of electrical equipment	-	0
C28 Mfr of machinery and equipment n.e.c.	-	0
C29 Mfr of motor vehicles, etc.	-	0
C30 Mfr of other transport equipment	-	0
C31_C32 Mfr of furniture and other products	-	25 (18-33)
C33 Repair and installation of machinery and equipment	-	0
D35 Electricity, gas, steam and air conditioning supply	-	9
E36 Water collection, treatment and supply	-	100
E37_E39 Sewerage, waste management, remediation activities	-	35 (31-39)
F41_F43 Construction	-	-
G45 Wholesale and retail trade and repair of motor vehicles and motorcycles	-	0
G46 Wholesale trade, except of motor vehicles and motorcycles	-	35 (27-44)
G47 Retail trade, except of motor vehicles and motorcycles	-	39 (30-49)
H49 Land transport and transport via pipelines	-	18 (14-22)
H50 Water transport	-	26 (20-32)
H51 Air transport	-	1 (1-2)
H52 Warehousing and support activities for transportation	-	37 (28-46)
H53 Postal and courier activities	-	50 (0-100)
I55_I56 Accommodation and food service activ.		84 (68-100)
J58 Publishing activities	-	41 ()
J59-M70	-	0
M71 Architectural and engineering activities; technical testing and analysis	-	-
M72 Scientific research and development	-	-
M73 Advertising and market research	-	-
M74_M75 Other professional, scientific and technical activities; veterinary activities	-	36 (0-72)
N77_Rental and leasing activities	-	-
N78 Employment activities	-	0
N79 - Travel agency, tour operator and other reservation service and related activities	-	-
N80_N82 Security and investigation, service and landscape, office administrative and support activities	-	7
O84 - Public administration and social security	0	0
P85 - Education	-	-

Q86 - Human health activities	-	0
R87_R88 Residential care activities and social work activities without accommodation	-	0
R90_R92 Creative, arts and entertainment activities; libraries, archives, museums and other cultural activities; gambling and betting activities	-	-
R93 - Sports activities and amusement and recreation activities	-	-
S94 – Activities of membership organisations	-	-
S95 - Repair of computers and personal and household goods	-	10 (7-13)
S96-T98	-	-

Source: own calculations.

6 Additional industry specific adjustments

The previous sections develop a general approach for measuring the size of the bioeconomy. In the case of some specific industries, certain additional adjustments may be needed. In this section, we discuss how to incorporate the agricultural subsidies and adjust the weights of the wholesale and retail trade, sewerage and waste management, as well as sports and recreational services.

6.1 Subsidized primary bio-based production

Primary bio-based production is subsidised all around the world, particularly agriculture but also fishing and to some extent forestry as well. The EU countries are no exception. With the additional domestic subsidies paid on top of the EU subsidies, Finland shows one of the highest levels of subsidies to primary bio-based production within the EU. For example, the net subsidies to agriculture in Finland in 2015 amounted to €1.59 billion, which exceeds the value added of the sector, which was only €1.23 billion. Since the subsidised agricultural production is subtracted from the value added in the system of national accounts, the contribution of agriculture to the bioeconomy is systematically underestimated. Even though a large proportion of agricultural subsidies have been decoupled from the production in the EU, meaning that subsidies are paid based on the input use (e.g., utilized agricultural area) instead of agricultural output, the subsidies are by no means non-contributory benefits: subsidised agricultural production does generate biomass for the secondary and tertiary bio-based production. In the absence of subsidies, the present level of value added would be clearly insufficient to maintain the present level of agricultural output.

Before proceeding, we must acknowledge that there is no perfect solution to adjust for the subsidies. Instead of tampering the value added of the three sectors of the bioeconomy, we propose to treat the subsidies to primary bio-based production as a transfer to Sector Ib from all other sectors of the economy. Obviously, subsidies to Sector Ib must be financed by taxing other industries (a part of which is channelled through the EU, another part through domestic transfers). To avoid double counting, we assume that all other sectors contribute to subsidising Sector Ib by a constant percentage τ, defined as the ratio of the net subsidies to Sector Ib and the net taxes paid by all other sectors. Note that τ can be easily estimated from the input-output tables. Subsequently, we propose to estimate the size of the bioeconomy while taking into account the subsidised primary bio-based production as follows:

(19) $B_b = V_b + S_{Ib} - \sum_{i=m+1}^{n} \theta_i T_i$,

where $V_b = V_{Ib} + V_{IIb} + V_{IIIb}$ is the value added of the bioeconomy, S_{Ib} is the net subsidies paid to Sector Ib, T_i is the net taxes paid by industry *i,* and θ_i is the bio-based share of industry *i*. In other words, we adjust the value added of the bioeconomy by adding the net subsidies paid to the primary bio-based production in Sector Ib, and subtract the share of taxes allocated to subsidies of Sector Ib from the secondary and tertiary bio-based Sectors IIb and IIIb.

For example, in Finland in 2015, the net subsidies to the primary bio-based production in Sector Ib totalled €1.61 billion, of which the share of agriculture was 98.7%. The net taxes of all other sectors of the economy were €6.73 billion. Therefore, the subsidies of Sector Ib could be financed by transferring 22% (= 1.61 / 6.73) of the taxes paid by all other industries to Sector Ib. Applying the constant percentage of 22% to all industries, the notional contribution of Sectors IIb and IIIb to the subsidies of Sector Ib amounts to €0.24 billion. Therefore, the net transfer from other sectors to the bioeconomy amounted to €1.37 billion.[16]

6.2 Wholesale and retail trade

Wholesale and retail trade contribute about9.5% of the value added in the EU-28 economy. Retail trade is also the main interface to the consumers and creates high gains in the food (bioeconomy) value chain.

According to the Finnish input-output tables, only 3% of the wholesale trade (46) and 2.6% of the retail trade (47) inputs were bio-based material. These percentages appear rather low considering the fact that food and clothes form the two largest segments of retail trade sales with the combined market share of 42.4% in 2012 (Statistics Finland). One reason for the difference in the percentages cited above is that the retail trade industry is also increasingly involved in further processing of food: consider e.g., in-house cafes and bakeries in super-markets.

Based on Eurostat's Annual detailed enterprise statistics for trade (sbs_na_dt_r2), the nova-JRC approach extended to new industries estimates the bio-based content of the final output by multiplying the bio-based shares of food, beverages, clothes, and other product groups by their retail sales volume. It finds that 33% (24-41%) of the value added generated in the retail trade industry came from the trade of bio-based products in Finland 2015, and 30% (22%—38%) from the wholesale trade industry. The share of bio-based retail trade is close to Knuuttila's (2015) estimates of the share of food products in the Finnish wholesale and retail trade in years 2006-2012. Applying the bio-based output share of 30% and 33% for both wholesale and retail trade and combining this information with the input-shares of bio-based products, the

[16] As the contribution of Finland to the EU budget exceeds the transfers from the EU to Finland, a proportion of the taxes paid by Finnish industries is used for supporting primary bio-production in the other EU Member States. In this section, we restrict to adjusting the subsidized bio-production at the national level, noting that further adjustments may be needed to ensure consistent aggregation of the Member States to the EU level.

overall bio-based shares of the wholesale and retail industries become 17.2% and 18.7%, respectively. In other words, approximately one fifth of the wholesale and retail trade sectors are considered as bio-based industries.

These adjustments to the bio-based shares of the wholesale and retail trade industries have a major impact on the estimated size of the bioeconomy for four reasons. First, the adjustment itself is large, tripling the bio-based weights of these two industries. Second, the wholesale and retail trade industries themselves are large, with the GDP shares of 4.3% and 3.6%, respectively. Third, these two sectors are intimately connected to all other sectors of the economy, and hence are critically important hubs for transporting bio-based materials from the secondary bio-based production to tertiary bio-based production and further to service industries. In other words, the bio-based output weights of the wholesale and retail trade influence the bio-based input shares of other sectors. Finally, the combined share of the wholesale and retail sector in the food cluster has been growing over time, and this trend is expected to continue in the future.

The absence of wholesale and retail trade of food in the bioeconomy statistics by Luke and nova-JRC can be considered a major drawback (see Section 3.1). Moreover, these two data sources assign a 100% bio-based share to primary agricultural production and secondary food processing. One might argue that consumers can rarely buy their food directly from a farm or a food manufacturing plant. Indeed, a very large share of value creation in the supply chain of food nowadays occurs in the wholesale and retail industry. Making the food products available to consumers in a fresh, hygienic and refrigerated environment requires a lot of labour, capital and energy. The important role of the wholesale and retail trade in the supply chain of food in Finland is well recognized (see, e.g., Kuosmanen *et al*. 2009, Knuuttila 2015, and references therein) and motivates the incorporation of trade of bio-based products' activities into the industry composition of the bioeconomy at the time of estimating the size of the bioeconomy. Section 7 stresses the significance of bio-based trade and the large size differences obtained when considering versus disregarding their value added into the bioeconomy size.

6.3 Water supply, sewerage and recycling

The water collection industry, the treatment and supply industry (36) and the sewerage and waste management industries (37-39) have bio-based input shares of 1.0% and 4.1%, respectively in Finland. For comparison, Luke treats the water industry (36) as 100% bio-based. While clean water is not as such bio-based, bio-based processes are indeed used in water treatment. We recognize that the input-output tables may underestimate the use of bio-based materials such as bacteria in the production process, noting that the final output of water supply should contain almost no bio-based content. In the absence of better estimates for the bio-based input share, we maintain the bio-based share of water industry as 1.0% obtained from the input-output tables. Note that the GDP share of this industry is very small, only 0.2% of the GDP. Increasing the bio-based weight of the water sector would have at best a marginal effect on the size of the bioeconomy as a whole.

For the sewerage and waste management industries (37-39), we have considered detailed data of waste management, which includes 52 different categories of waste, of which 15 categories are considered bio-based (Table 6).

Table 6. Bio-based categories of waste.

Waste category	Total
7.5 Wood wastes Non-hazardous	2 923 480
12.4 Combustion wastes Non-hazardous	1 178 582
10.1 Household and similar wastes Non-hazardous	1 080 955
10.2 Mixed and undifferentiated materials Non-hazardous	872 866
9.1 Animal and mixed food waste Non-hazardous	642 285
7.2 Paper and cardboard wastes Non-hazardous	603 095
9.3 Animal faeces, urine and manure Non-hazardous	355 171
9.2 Vegetal wastes Non-hazardous	191 644
7.5 Wood wastes Hazardous	24 789
7.6 Textile wastes Non-hazardous	11 514
7.3 Rubber wastes Non-hazardous	7 976
10.2 Mixed and undifferentiated materials Hazardous	6 093
12.4 Combustion wastes Hazardous	4 754
5 Health care and biological wastes Non-hazardous	3 237
5 Health care and biological wastes Hazardous	467

Source: own calculations.

The value estimated in the extended nova-JRC approach for industry E38 in Finland in 2015 was 7.6% (min-max range of 6.9% – 8.2%) based on Eurostat env_wasgen and Eurostat env_wastrt. Similar to the approach followed for the estimation of bio-based trade, the extended nova-JRC approach considered that the bio-based share of the waste generated by industry *x* is equal to the bio-based share of industry *x*. However, data in input-output tables are aggregated for the category E37_39 that includes *Sewerage* (E37), *Waste collection, treatment and disposal activities*; *materials recovery* (E38) and *Remediation activities and other waste management services* (E39). Considering that the sewerage industry (E37) belongs fully to the bioeconomy (i.e. 100% output-based share) because it ultimately delivers clean water and that the proportion of remediation activities and other waste services (E39) belonging to the bioeconomy is unknown (i.e. share ranging from 0 to 100%), the extension of the nova-JRC approach to new industries estimate that the output bio-based share of industry E37_39 is on average 21.3%. It ranges between 18% and 25% (weighted average on the value added generated in industries E37, E38 and E39 as reported in Eurostat sbs_na_ind_r2 for Finland in 2015).

The bio-based output share of 21.3% proposed by the extended JRC-nova approach is used in this study for industry E37_39 (Sewerage, waste management, remediation activities). Taking the weighted average of the input and output side bio-based shares, we obtain the overall bio-based share of 11.8%. We note that the bio-based shares of these industries could be updated if more detailed data were available. However, the GDP share of these industries is only 0.7%, and hence adjusting the bio-based weights of these sectors would have at best a marginal effect on the size of the bioeconomy as a whole.

6.4 Sports and recreation, including tourism

Sport, amusement and recreation activities (R93) have a bio-based input share of 4.1%. This industry does include such bioeconomic activities as operation and management of recreational parks, beaches, camping grounds, golf courses, sports fields, and skiing facilities such as cross-country skiing tracks and downhill skiing hills and lifts. Therefore, the input-output tables may underestimate the bio-based share of this industry. Of course, it is very challenging to estimate the output side bio-based share of such a diverse industry. For example, does football count as bio-based activity since it is usually played on a grass surface using a leather ball?

Luke's officially statistics are currently calculated using 25% bio-based share for this sector, which seems somewhat exaggerated. If one assumes the output side bio-based share to be equal to 25% following Luke's estimate, and combines it with the input side bio-based share of 4.1%, then the resulting weighted averge is equal to 13.4%. This example illustrates that one does not need to blindly apply the weights of the input-output tables, the proposed framework allows one to complement the objective data of input-output tables with other sources of information, including expert opinions and subjective judgement. However, the GDP share of this industry is only 0.6%, so the adjustment of the output weight has negligible impact on the total size of the bioeconomy. Therefore, in this report we apply the input side bio-based share of 4.1% for this industry without output side adjustment.

6.5 Adjusted bio-based shares

To summarize Section 6, Table 7 reports the bio-based shares of industries for Finland in 2015, with a bio-based share greater than 10%. This table illustrates that the proposed approach covers a larger set of industries than the previous approaches that focus on the output side weights. According to the Input-Output tables, all industries use at least some amount of bio-based inputs. On the other hand, Table 7 illustrates that the primary production is not 100% bio-based when the use of inputs from other industries is taken into account.

We stress that the weights presented in Table 7 illustrate the situation of a single country in a single year. In general, the bio-based shares vary over time and across countries according to the bio-based nature of their industry. For example, in 2015 the output share of the chemical industry was estimated at 10% in the EU-28 vs. 22% in Finland (JRC-nova estimates).

Table 7. Bio-based shares of industries in Finland, according to our study, Luke, and JRC (in percent, industries with a weighted bio-based share > 10%).

Industry	Our study (weighted average of the input- and output-based weights)	Luke	Extended nova-JRC shares (FI, 2015)
A02 Forestry	89	100	100
A03 Fishing	84	100	100
C10_C12 Food industry, etc.	72	100	100
A01 Agriculture and hunting	68	100	100
C16 Woodworking industry	65	100	100
E36 Water collection, treatment and supply	59	100	100
I55_I56 Accommodation and food service activities	57	25	80-100
C17 Paper industry	54	100	100
C18 Printing	48		49-99
C13_C15 Textile, clothing and leather industries	35	72	29-41
C21 Pharmaceutical industry	33	100	44
H53 Postal and courier activities	31		0-100
J58 Publishing activities	21		10-73
C31_C32 Mfr of furniture and other products	20	72	21-43
M74_M75 Other business activities and veterinary activities	19		0-55
G47 Retail trade (excl. motor vehicles, etc.)	19		24-41
D35 Electricity, gas, steam and air conditioning supply	17	45	28
G46 Wholesale trade (excl. motor vehicles, etc.)	17		22-38
C20 Mfr of chemicals and chemical products	14	36	21-22
H52 Warehousing and support activities for transportation	13		23-39
N77 Rental and leasing activities	13		*
E37-E39 Sewerage, waste management, remediation activities	12		18-25
M73 Advertising and market research	12		*
F41_F43 Construction	11	31	*

* Industries marked with * are not covered yet by the “extended nova-JRC methodology”. Therefore, “average input- and output- based weight” of these industries is equal to the input-based weigh.

Source: Own elaboration.

7 Application to the bioeconomy in EU countries in 2015

In this section, we systematically apply the input-output approach by Heijman and our proposed modifications to the input-output data from year 2015 for Finland, Denmark, Italy, Spain, Poland, Romania and EU-28. These countries were selected for representing different areas of Europe: Northern (Finland and Denmark), Central North (Poland), Central South (Romania) and Southern (Italy and Spain).

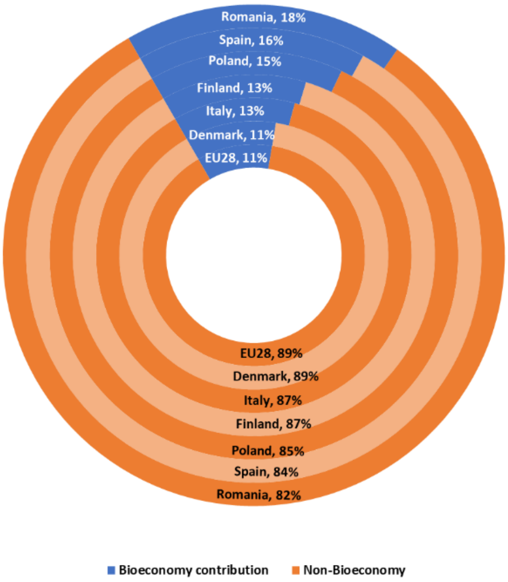
The purpose of this application is to demonstrate empirically the effects of the proposed modifications and shed light on the empirical magnitude of those effects. The input-output tables for year 2015 were obtained from Eurostat.[17]

7.1 Economic indicators: value added

Including all the adjustments proposed in the previous sections, our estimate of the EU-28 bioeconomy in 2015 is €1,460.6 billion, which is 11% of the total GDP. This figure includes €38.3 billion of net subsidies to primary production[18], mainly agriculture. The contribution of tertiary bio-based industries was €872 billion.

The next sequence of charts shows the contribution of the bioeconomy in terms of GDP from different perspectives. Figure 6 illustrates the bio-based share of GDP in the overall GDP, with a comparison between six Member States (Denmark, Finland, Italy, Poland, Romania and Spain) and the EU-28.

Figure 6. Contribution of the bioeconomy to the total GDP in six Member States and EU-28.



Source: own calculations.

The doughnut chart (Figure 6) presents a ranking of the countries according to their bioeconomy share in the overall economy. In this sense, Romania appears to be the country with the highest bio-based share with 18%, followed by Spain (16%) and Poland (15%), while EU-28, which represents a reference value, has the lowest share (11%).

To put our developments into context, recall from the introduction that JRC estimates the size of Finland's bioeconomy to be €13 billion or 7% of the GDP in 2015 (accounting only for production and manufacturing of biomass and production of bio-electricity), whereas the official Luke statistics of Finland that cover more sectors of the bioeconomy than the JRC indicate considerably higher values of €21.3 billion or 12% of the GDP. Applying the constant marginal value product approach by Heijman, the value added of the bioeconomy is €12.3 billion, which is 6.8% of the GDP. By applying this approach, we come relatively close to the JRC estimate and that of the Dutch bioeconomy, but far below the Luke estimate monitored by the Finnish government.

Applying the bio-based input shares as described in Section 4, the value added of the bioeconomy is only €9.7 billion or 5.3% of the GDP. The use of input-output tables to track the material flows between industries does not automatically increase the size of the bioeconomy. Applying the industry-level bio-based input shares as described in Section 4.2, the

[17] The Symmetric I-O tables (SIOT) for Denmark, Italy and Romania are published by Eurostat, while the SIOTs for EU-28, Finland, Poland and Spain are obtained with the Supply & Use tables (provided by Eurostat) under the industry technology assumption. In fact, not all the countries publish both “industry by industry” and “product by product” tables, and in this case, they do not provide the information for the “industry by industry” dimension.

[18] Data on subsidies for Bulgaria, Ireland, Luxemburg and Malta are not available.

value added of the bioeconomy further decreases to €8.4 billion or 4.6% of the GDP. This reflects the fact that the marginal value product of bio-based inputs in the secondary bio-based production (e.g., food industry or pulp and paper industry) is lower than that of average marginal value product of all inputs to all sectors. The industry-specific bio-based input shares have been adjusted for the import of bio-based raw materials as follows: we assume that 80% of imports to textile industry and 90% of imported raw materials to food, wood, and paper industries are bio-based inputs. For all other industries, we assume that the imports contain bio-based raw materials in the same proportion as the domestic inputs.

Including the tertiary bio-based production as suggested in Section 4.2.3, the value added of the bioeconomy increases to €16.7 billion or 9.2% of the GDP. The most important industries of tertiary bio-based production include hotel and restaurant services, manufacturing of paper products, construction, and Wholesale and Retail trade industries. Note that construction of wooden houses and wooden furniture uses almost exclusively processed wood from wood industry as input, whereas unprocessed wood from forestry is little used. This example illustrates the need to include tertiary bio-based production to bioeconomy of an increasingly complex economy.

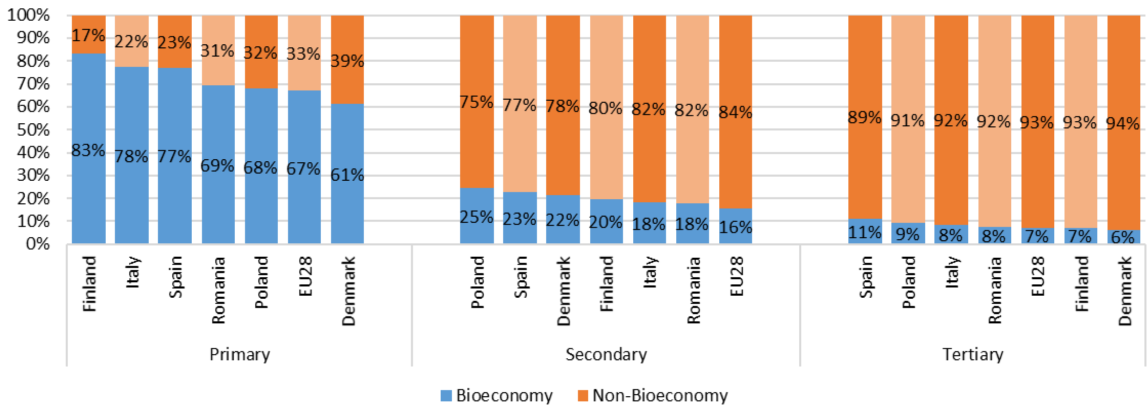
Extending the scope of primary bio-based production by including the inputs of other industries to bioeconomy as discussed in Section 5 further increases the economic size of bioeconomy to €20.1 billion or 11.1% of the GDP. The use of inputs from other sectors in primary bio-based production amounts to €5.5 billion, of which 2.4 billion € was in agriculture. Note that the contributions of industries in Sector 2 to primary production have been subtracted from the gross outputs of those industries to avoid double counting. Finally, including the agricultural subsidies as discussed in Section 6.1 increases the economic size of the bioeconomy to €23.6 billion or 13.1% of the GDP.

Figure 7 displays the distribution of the bioeconomy across primary, secondary and tertiary sectors (clusters). The primary sector includes three industries: "A01 - Crop and animal production, hunting and related service activities", "A02 - Forestry and logging" and "A03 - Fishing and aquaculture". The secondary sector comprises the "B - Mining and quarrying" and all the manufacturing related industries (from "C10-C12 - Manufacturing of food products; beverages and tobacco products" to "C33 - Repair and installation of machinery and equipment"), while the tertiary sector includes all the remaining industries.

This chart presents the dichotomy between Bioeconomy and Non-Bioeconomy, with further detail on the cluster divided by country. The primary sector contribution reaches a difference between the countries of 22 percentage points, in this case Finland shows the highest bio-share (83%) in the primary sector among the countries while Denmark 61%.

A smaller discrepancy between the countries can be observed in the secondary sector where the range (nine percentage points) varies from 25% in Poland to 16% of EU-28. Differences tend to even out in the tertiary cluster (only five percentage points).

Figure 7. Contribution of the bioeconomy to the GDP by cluster in six Member States and EU-28.

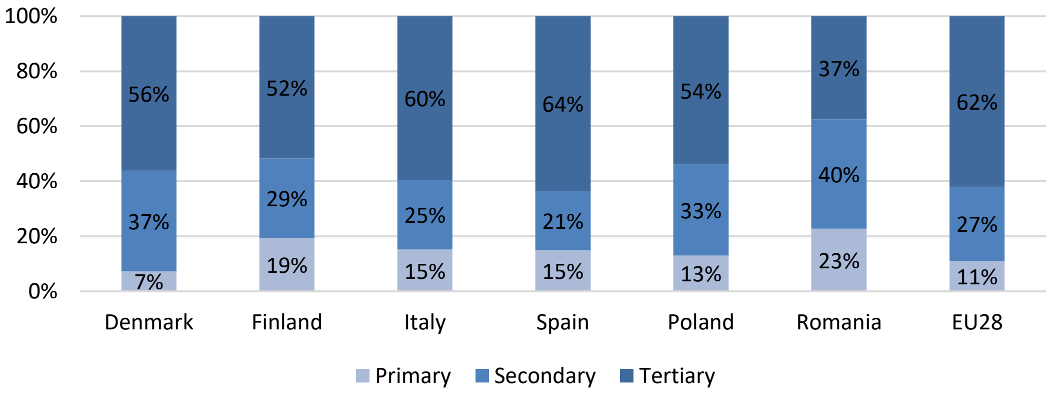


Source: own calculations.

The position of each country varies in every cluster showing different characteristics in contributing to the bioeconomy. For instance, Denmark is in the last position of the primary and tertiary cluster while it appears to be more specialised in the bioeconomy of the secondary sector, where it ranks third. Across clusters, Spain shows the highest share in the tertiary cluster, while it is second in the secondary and third in the primary one.

The next chart helps to describe this comparison by showing the weight of each cluster. Indeed, Figure 8 illustrates the bioeconomy composition from a country perspective.

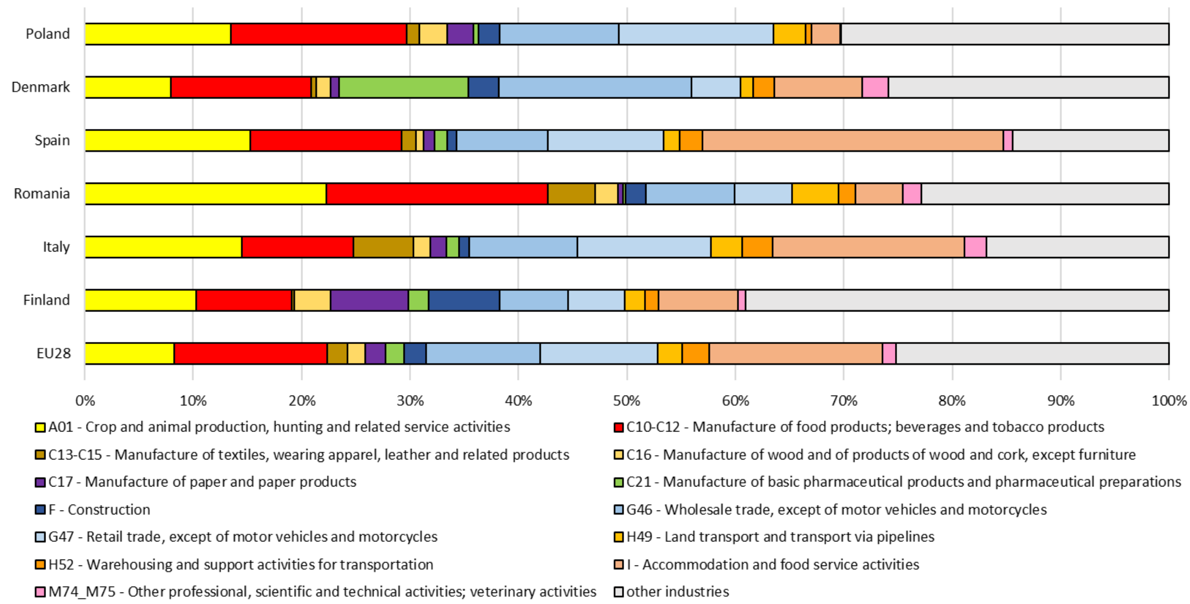
Figure 8. Composition of the bioeconomy's GDP in six Member States and EU-28.



Source: own calculations.

As previously mentioned, Romania shows the highest GDP bio-based share (figure 7) among the countries presented in this section. The 18% share of its bioeconomy in the overall GDP is composed by 23% of primary bio-based production, 40% of secondary production and 37% of tertiary production, as shown in Figure 9. In this case, the share of bioeconomy is distributed more homogeneously across clusters than in other countries, portraying the vocation of this area to the primary and secondary bio-based production.

Figure 9. Contribution of each industry to the bioeconomy's GDP in six Member States and EU-28.



Source: own calculations.

Figure 9 shows a top-14 ranking of the most relevant bio-based industries across the six Member States along with a comparison to EU-28. "A01 - Crop and animal production, hunting and related service activities" is one of the biggest contributors, as well as the only primary production represented[19]. "C10-C12 - Manufacturing of food products; beverages and tobacco products" is the main industry within the secondary sector, and Wholesale (G46) and Retail trade (G47) as well as "I - Accommodation and food service activities" are among the most relevant in the tertiary cluster.

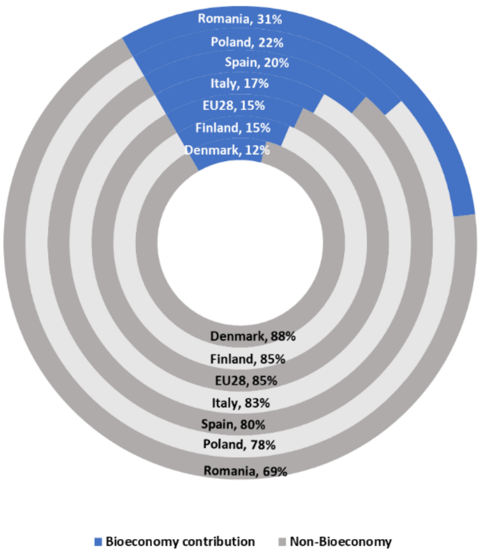
[19] Please note that Finland also includes "A02 – Forestry and logging" among the primary sector industries, which represents 13% of the bioeconomy contribution to the GDP. It is now embodied in the "Other industries" category.

7.2 Social indicators: employment

In this sub-section, we present a similar graphical representation with a focus on the contribution to employment. Our estimate for the EU-28 bioeconomy in 2015 is 33.9 million persons, which is 15.4% of the total employment. The contribution of the primary bio-based industries is 7.15 million persons.

Figure 10 shows the share of the bioeconomy in a country's (or region's) overall employment, with a comparison between six Member States (Denmark, Finland, Italy, Poland, Romania and Spain) and the EU-28. In addition, in this case, Romania appears to be the country with the highest bio-based share with 31%, followed by Poland (22%) and Spain (20%), while Denmark represents the tail end of this chart (12%).

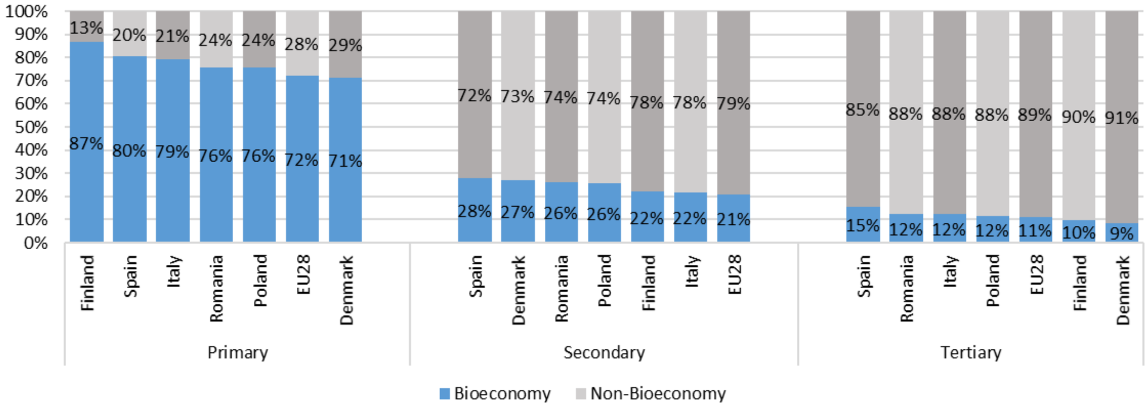
Figure 10. Contribution of the bioeconomy to employment in six Member States and EU-28.



Source: own calculations.

Figure 11 displays the ratio between bioeconomy and non-bioeconomy across the clusters in each country. The range of the discrepancy in the primary sector reaches 16 percentage points, where Finland shows the highest bio-share value (87%) among the countries while Denmark accounts for the lowest (71%).

Figure 11. Contribution of the bioeconomy to employment by cluster in six Member States and EU-28.

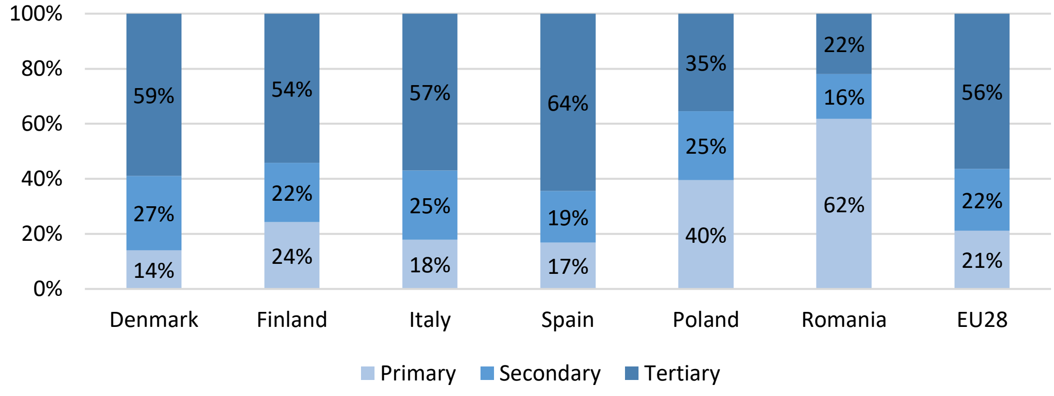


Source: own calculations.

The secondary sector clearly shows a different scenario from the primary one, the share of the bioeconomy in the total economy being much smaller due to the higher number of industries included which have a different specialisation, not purely bio-related. Across countries, the percentage varies from 28% in Spain to 21% of EU-28. The *bioeconomy/total economy ratio* tends to decrease even more in the tertiary cluster, as do the differences between countries (only 6%). In this short ranking, the country comparison again highlights Denmark being last in the primary and tertiary clusters while it appears to be more specialised in the bioeconomy of the secondary sector (as shown in Figure 11 and 12). Across clusters, Spain shows the highest share in the secondary and tertiary clusters, while it is second in the primary one.

Figure 12 underlines the bioeconomy composition from the country perspective. The next chart describes the comparison between the weights of each cluster. As mentioned above, Romania shows the highest bio-based share in employment terms among the countries presented in this sub-section. The 31% of the bioeconomy's employment (Figure 11), is distributed into 62% primary, 16% secondary and 22% tertiary production, as shown in Figure 12. This distribution clearly underlines Romania's primary sector oriented profile (mainly agriculture, as can be seen in Figure 13).

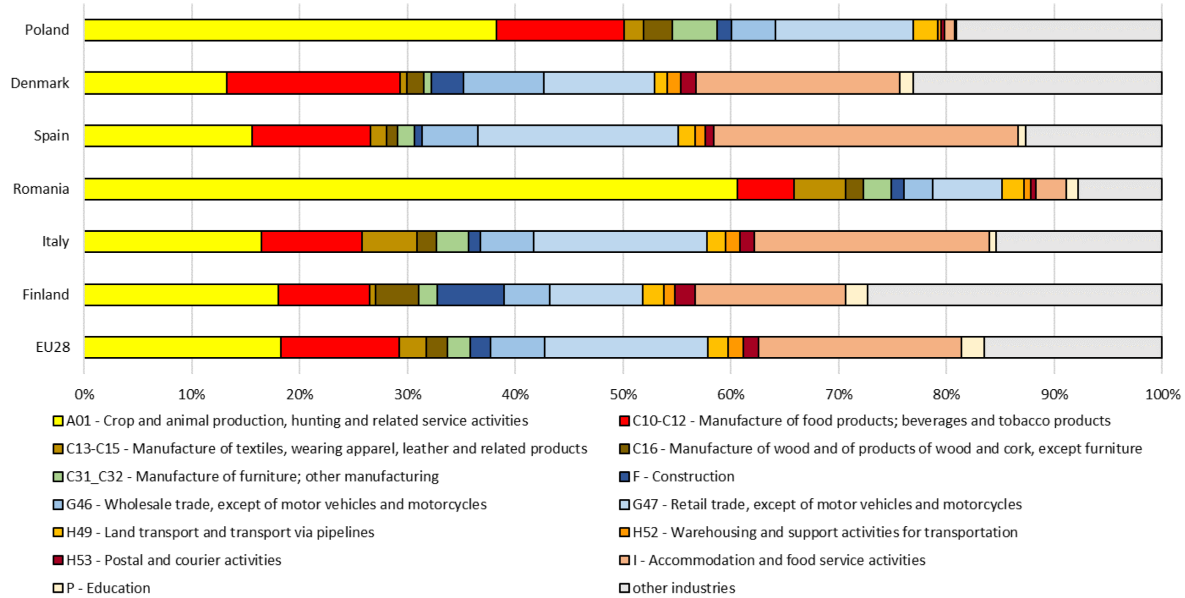
Figure 12. Composition of the bioeconomy's employment in six Member States and EU-28.



Source: own calculations.

From the perspective of the service activities that we can define as *"bio-derived"* share, Spain shows the highest at 64%, followed by Denmark and Italy. The leading countries in the secondary sector are Denmark 27%, Italy and Poland with 25% respectively.

Figure 13. Contribution of each industry to the bioeconomy's employment in six Member States and EU-28.



Source: own calculations.

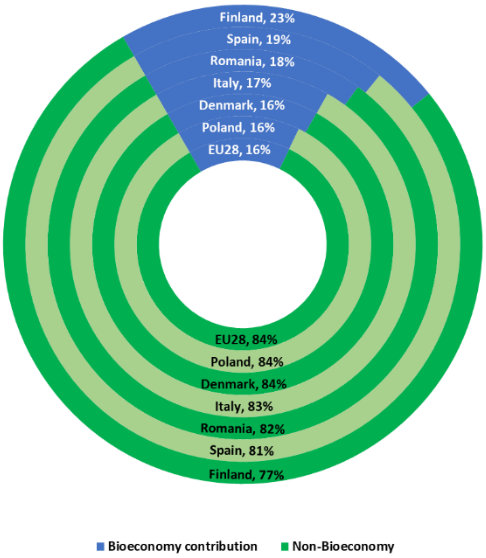
Figure 13 shows the bioeconomy contribution to employment of a top-14 ranking bio-based industries across the six Member States and EU-28. Again, across the main industries implicated, it can be observed the "A01 - Crop and animal production, hunting and related service activities" in the primary cluster, "C10-C12 - Manufacturing. of food products; beverages and tobacco products" for the secondary sector, and Wholesale (G46) and Retail trade (G47) as well as "I - Accommodation and food service activities" among the most relevant in the tertiary cluster except for Poland and Romania.

7.3 Environmental indicators: GHG emissions

Greenhouse gases (GHG) constitute a group of gases contributing to global warming and climate change. The Kyoto Protocol, an environmental agreement adopted by many of the parties to the United Nations Framework Convention on Climate Change in 1997 to curb global warming, nowadays covers seven greenhouse gases classified as non-fluorinated gases (carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O)) and fluorinated gases (hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulphur hexafluoride (SF_6), and nitrogen trifluoride (NF_3)). Converting the different GHG to carbon dioxide (CO_2) equivalents makes it possible to compare them and to determine their individual and total contributions to global warming.

By applying the calculated industry weights to industry level GHG emissions we can compute the bioeconomy contribution to GHG emissions. This, however, implies assuming that the bio-based activities within a certain industry emit the same amount of GHG as their fossil counterpart. For instance, Figure 14 illustrates the bioeconomy contribution to GHG emissions by EU-28.

Figure 14. Contribution of the bioeconomy to GHG emissions in six Member States and EU-28.

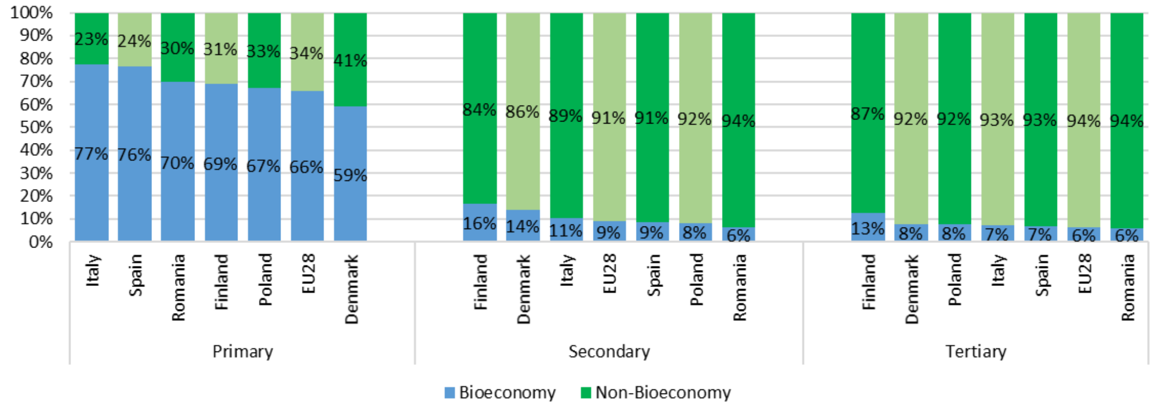


Source: own calculations.

Similar considerations as in Figures 6 and 10 can be made on the contribution of the bioeconomy to GHG emissions. The doughnut chart (Figure 14) compares the shares of GHG emissions of the bioeconomy the rest of the economy in the same six EU countries, as well as in the EU-28. In this case, Finland is the country with the highest share for the bioeconomy, (23% of the country's total), followed closely behind by Spain (19%) and Romania (18%), while EU-28 shows a lower ratio than any of the countries considered (16%).

Figure 15 again illustrates the ratio between bioeconomy and non-bioeconomy across the clusters in each country, this time for GHG emissions. A different picture can be observed when comparing the primary sector contribution, ranging between 77% in Italy and 59% in Denmark, with secondary and tertiary sectors showing similar range of shares across countries.

Figure 15. Contribution of the bioeconomy to GHG emissions by cluster in six Member States and EU-28.

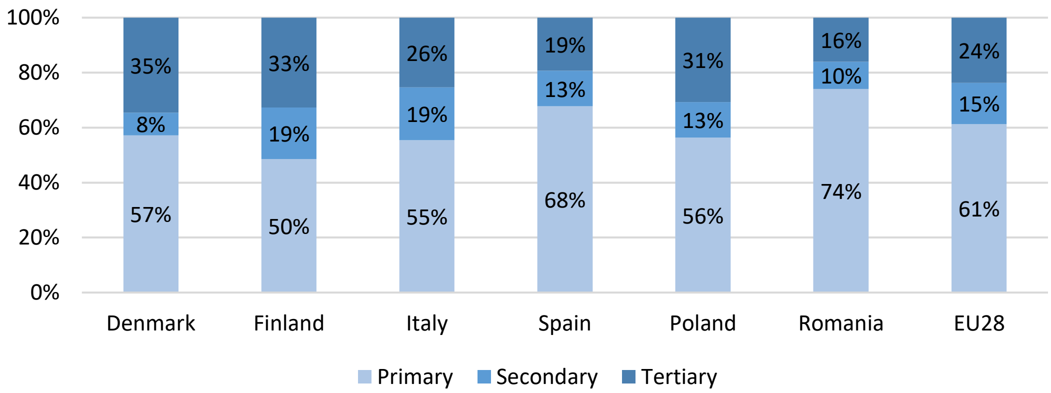


Source: own calculations.

The 18 percentage points range in the primary clusters, as described in the previous sections, indicate a different economic structure and industrial capacity not only between countries but also across the four areas identified (Northern, Central North, Central South and Southern).

As above mentioned, Finland shows the highest GHG bio-based share (Figure 14) among the countries presented in this section. Its 23% of the bioeconomy's GHG emissions is composed by 50% in the primary sector, 19% in the secondary sector and 33% in the tertiary sector, as shown in Figure 16. At this stage, the bioeconomy composition clearly underlines the role of the primary sector in the overall GHG contribution.

Figure 16. Composition of the bioeconomy's GHG emissions in six Member States and EU-28.

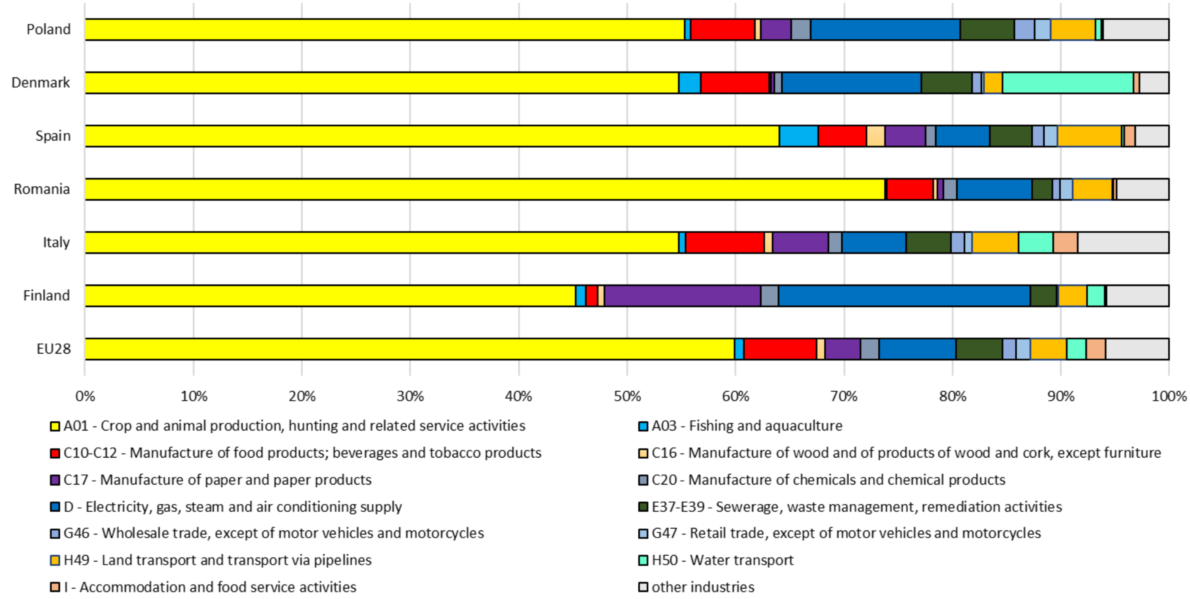


Source: own calculations.

As can be seen in the graphs presented above, the bioeconomy is not self-evidently sustainable. The reader is reminded that carbon sinks in forestry and agriculture are not captured (see also further remarks on the limitations in the conclusions).

The last chart presents a top-14 ranking of the contribution by industry to a country's bioeconomy with a comparison to EU-28. Figure 17 highlights that the primary production sectors (i.e., agriculture) are the major contributor to GHG emissions, recording a maximum value in Romania (74%).

Figure 17. Contribution of each industry to the bioeconomy's GHG emissions in six Member States and EU-28.

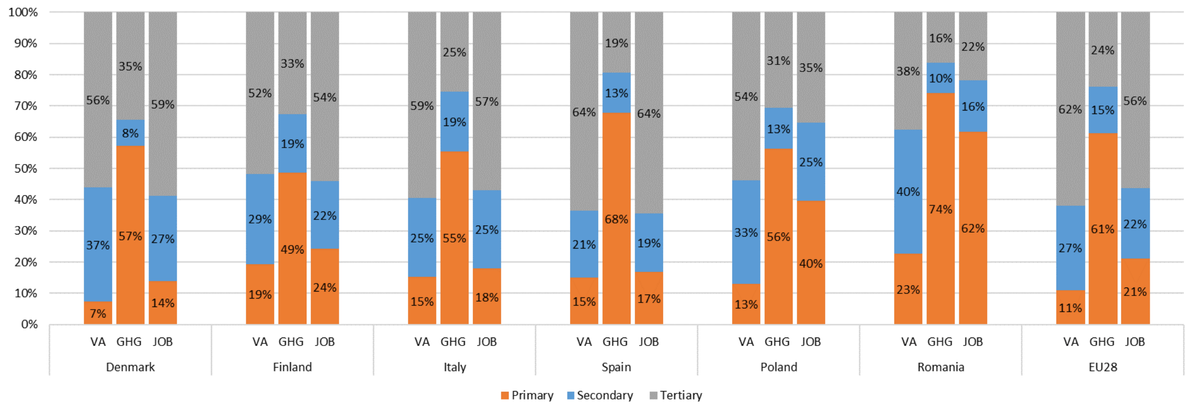


Source: own calculations.

Within the secondary sector "C10-C12 - Manufacturing of food products; beverages and tobacco products" and "C17 – Manufacturing of paper and paper products" are the two most relevant, and "D - Electricity, gas, steam and air conditioning supply" in the tertiary cluster.

Figure 18 completes the set of visualisations proposed across this section, showing all indicators in one chart. The in-depth graph summarises the information with a focus also on the Bioeconomy composition, per country and cluster.

Figure 18. Bioeconomy contribution to GHG emissions by indicator, cluster and country in six Member States and EU-28.



Source: own calculations.

8 Bioeconomic growth: measurement and decomposition

In this section we examine how the growth of the bioeconomy can be decomposed according to different sources, including changes in

1) value added of the bio-based industries
2) bio-based shares of industries
3) transfers to Sector Ib from other sectors

The decomposition is illustrated by examining the growth of the Finnish bioeconomy from year 2010 to 2015.

Let the superscript *t* denote the time period, and recall the adjusted formula for calculating the economic size of the bioeconomy:

(20) $B_b^t = V_{Ib}^t + V_{IIb}^t + V_{IIIb}^t + S_{Ib}^t - \tau^t \sum_{i=m+1}^{n} \theta_i^t T_i^t$.

Firstly, we can break down the change in the size of the bioeconomy from period *t* to period *t*+1to the contributions of different sectors and transfers as:

(21) $B_b^{t+1} - B_b^t = (V_{Ib}^{t+1} - V_{Ib}^t) + (V_{IIb}^{t+1} - V_{IIb}^t) + (V_{IIIb}^{t+1} - V_{IIIb}^t)$

$+ (S_{Ib}^{t+1} - S_{Ib}^t) - (\tau^{t+1} \sum_{i=m+1}^{n} \theta_i^{t+1} T_i^{t+1} - \tau^t \sum_{i=m+1}^{n} \theta_i^t T_i^t)$.

The five differences in the parentheses on the left-hand side of the equation represent the changes in the value added of Sectors Ib, IIb, and IIIb, and the change in the net subsidies to Sector Ib from the other sectors, respectively. This decomposition can help to shed light on which broad sectors of the bioeconomy are driving the growth, and what is the contribution of transfers through subsidies and taxes.

Secondly, the change in the size of each sector *h* = Ib, IIb, IIIb can be further decomposed as:

(22) $V_h^{t+1} - V_h^t = \sum_{i\epsilon h} \theta_i^{t+1} V_i^{t+1} - \sum_{i\epsilon h} \theta_i^{t+1} V_i^{t+1}$

$= ½ [\sum_{i\epsilon h} \theta_i^{t+1}(V_i^{t+1} - V_i^t) + \sum_{i\epsilon h} \theta_i^t (V_i^{t+1} - V_i^t)]$

$+ ½ [\sum_{i\epsilon h} V_i^{t+1}(\theta_i^{t+1} - \theta_i^t) + \sum_{i\epsilon h} V_i^t (\theta_i^{t+1} - \theta_i^t)]$.

The first expression in the square brackets measures the change in the value added of the bio-based industries of sector *h*, applying the bio-based shares in periods *t*+1 and *t*, and taking the average. The second expression brackets measures the contribution of the change in the bio-based shares of the industries, calculated using the value added in periods *t*+1 and *t*, and taking the average. Therefore, the first component can be interpreted as the growth of the bio-based industries based on the average bio-based share, whereas the second component measures the "greening" of the bio-based industries themselves, which can occur through increased share of bio-based inputs and/or increased share of bio-based material in the output.

Thirdly, note that the change in the size of the sector *h* can be further broken down to the industry level. For industry *i*, the decomposition can be stated as:

(23) $\theta_i^{t+1} V_i^{t+1} - \theta_i^{t+1} V_i^{t+1}$

$= ½ [\theta_i^{t+1}(V_i^{t+1} - V_i^t) + \theta_i^t (V_i^{t+1} - V_i^t)]$

$+ ½ [V_i^{t+1}(\theta_i^{t+1} - \theta_i^t) + V_i^t (\theta_i^{t+1} - \theta_i^t)]$.

The industry-specific decomposition can shed further light on which industries are contributing positively or negatively to the growth of the bioeconomy, and whether the changes are due to the growth of the industry *per se* or greening of the industry.

We next illustrate the decomposition by comparing the Finnish bioeconomy in years 2010 and 2015. Table 8 compares the size of the bioeconomy in years 2010 and 2015 in terms of the value added, subsidies to Sector Ib, and taxes from Sectors IIb and IIIb. All figures in the table are presented in million € at the prices of 2015, deflated using the producer price index. We see that the Finnish bioeconomy increased by €0.9 billion. The growth was entirely due to increase in value added, whereas the decreasing subsidies to primary bio-based production and transfers from Sectors IIb and IIIb had a negative effect on the growth of the bioeconomy.

Table 8. Change in the size of the Finnish bioeconomy from year 2015 compared to 2010 (million €, prices of 2015).

Industry	2015	2010	Change
Value added	22 280	20 865	1 415
Subsidies to Sector Ib	1 608	1 950	-342
Transfers from Sectors IIb, IIIb	-240	-90	-150
Total bioeconomy	23 648	22 726	923

Source: own calculations.

Table 9 illustrates that the growth of the Finnish bioeconomy between the years illustrated was mainly driven by the strong GDP growth of Sector IIIb. Interestingly, the bio-based shares of all three sectors coontributed to the growth (see the θ effect), especially in Sector IIb. Note that the increased bio-based share of Sector IIb more than offset the decreasing value added of that sector. Again, the subsidies and transfers had a negative contribution to the growth of bioeconomy.

Table 9. Decomposition of the changes in the Finnish bioeconomy from 2010 to 2015 (million €, prices of 2015).

	V change	θ effect
Sector Ib	188	32
Sector IIb	-29	143
Sector IIIb	1030	52
Subsidies	-342	
Transfers from Sectors IIb, IIIb	-150	
Total bioeconomy	923	

Source: own calculations.

Table 10 sheds further light on which specific industries had greatest positive and negative contributions to the decline of the Finnish bioeconomy by ranking the top-five and bottom-five industries according to the two-digit NACE classification. The five industries that contributed positively to the growth of the bioeconomy were forestry, accommodation and food service activities, wholesale trade, electronics industry, and the rental and leasing activities. In all these five sectors, the bio-based share (θ effect) increased notably, particularly in the electronics industry.

Table 10. Industries with the largest positive and negative contributions to the Finnish bioeconomy (million €, prices of 2015).

Industry	*V* change	θ effect	Contribution
02 Forestry	503	10	513
55-56 Accommodation and food service activities	200	83	283
46 Wholesale trade (excl. motor vehicles, etc.)	190	37	227
26 Electronics industry	-75	229	154
77 Rental and leasing activities	5	143	148

13-15 Textile, clothing and leather industries	-34	-41	-75
18 Printing	-72	-20	-90
84 Public administration and social security	27	-229	-202
01 Agriculture and hunting	-313	26	-286
85 Education	51	-367	-316

Source: own calculations.

Analogously, the five industries with the greatest negative contribution to the decline of the bioeconomy in the six-sector model were the textile and clothing industries, printing, public administration, agriculture, and education. Except for agriculture, the bio-based shares of these industries decreased, particularly in public administration and education. Note that while the public expenditure on industries 84 and 85 increased (as indicated by the positive V change), the decreased bio-based share (θ effect) of these two industries amounts to €0.6 billion decreasing effect to the Finnish bioeconomy from 2010 to 2015.

While the Finnish government was launching an ambitious bioeconomy strategy (published in 2014), at the same time, the bio-based shares of the two key public services decreased. To give a more specific example based on the input-output tables, in education (85), the inputs from agriculture decreased by €10.5 million from year 2010 to 2015, inputs from the food industry decreased by €54.0 million, and the inputs from the wholesale and retail trade together decreased by €82.1 million (of which a significant share must be food).

9 Conclusions

The purpose of this report was to advance more objective and rigorous measurement and analysis of the bioeconomy. Yet, we must recognize that the size of the bioeconomy is always to a certain extent in the eye of the beholder and determined by the methodological approach and assumptions chosen.

First of all, the scope of the bioeconomy differs between countries. Even within the EU, which not least has a common European Bioeconomy Strategy, Member States include different economic sectors in their bioeconomy measurements, motivated by the specific structure of the individual economies.

Investigating concrete examples, the choice of the bio-based share in so-called hybrid sectors explains to a large extent the differences between for instance the economic indicators for Finland calculated by the JRC from those of the Finnish statistical office. There might be good reasons why different bio-based shares, mainly based on expert opinion, are chosen. However, with a view of creating a European bioeconomy monitoring framework and the drive towards a greener, circular economy with cascading use of resources, reflections about a more systematic and rigorous methodology seem adequate.

As a first step, we propose, analogous to the classical three-sector classification of the economy, to distinguish between bio-based and non-bio-based primary, secondary, and tertiary sectors, hence extending the number of sectors to six. Following the deifintion of the updated Bioeconomy Strategy we thus can include the service sectors.

In the overview of existing approaches to measure the bioeconomy we analyse the output-based approaches by JRC-Nova and LUKE (FI) and the material flow approaches by the Statistic Netherlands-CBS and Thünen institute. Then we revisit the input-based approach by Heijman (based on input-output tables) and propose some improvements regarding the heterogeneity of industries, the imports of bio-based inputs, and the tertiary bio-based production.

As the main conclusion of the report, we propose a synthesis of input- and output-based approaches. This is motivated by the fact, that determining the bio-based weights based on the input-output tables implicitly assumes that the bio-based share of outputs is the same as that of inputs. Clearly, this is not the case for the primary bio-based production sectors – agriculture, forestry, and aquaculture – where the outputs are completely bio-based whereas the inputs are far from 100% bio-based. Indeed, the bio-based shares of the inputs and outputs of an industry can differ considerably. On the other hand, relying exclusively on the bio-based content of the output would ignore the use of bio-based inputs in the production process. To take into account the bio-based content in both the inputs and the outputs, we propose to form the industry weights as the weighted average.

Before applying the new methodology, certain adjustments for some specific industries are needed. For subsidized primary sectors, e.g. the agriculture or fishing sectors, we adjust the value added of the bioeconomy by adding the net subsidies paid to the primary bio-based production in sector, and subtract the share of taxes allocated to subsidies of this sector from the secondary and tertiary bio-based sectors. While acknowledging remaining flaws of this solution, this adjustment seems necessary, taking into account that e.g. the net subsidies to agriculture in Finland in 2015 amounted to €1.58 billion, compared to the value added of the sector of only €1.23 billion.

Further adjustments are performed with regard to the bio-based shares of the wholesale and retail trade industries, the water supply, sewerage and recycling, as well as sports and recreation sectors.

Applying the methodology with the adjustments proposed, our estimate for the EU-28 bioeconomy in 2015 reaches €1,460.6 billion value added, which is 11% of the GDP. The nova-JRC methodology calculates €621 billion value added for the same year. This difference is mainly explained by the contribution of the tertiary bioeconomy sectors of €872 billion by the proposed methodology. It is noteworthy to mention the €38.3 billion of net subsidies to primary production[20], mainly agriculture, now included in the assessment.

For the EU-28, the most important sector becomes "Accommodation and food service activities" (16%), followed by "Manufacturing of food products; beverages and tobacco products" (14%), (bio-based) "Retail trade" (11%), (bio-based) "Wholesale trade" (10%) and "Crop and animal production" (8%). The classification in three production sectors results for the EU-28 value added into 11% for the Primary, 27% for the Secondary and 62% for the Tertiary production sector.

Turning to the social indicator of employment, we can observe the strongly increased share of "Crop and animal production" to 18% of the total bioeconomy employment of 33.2 million (compared to 18.1 million in the Nova-JRC methodology). The classification in three production sectors results for the EU-28 employment into 21% for the Primary, 22% for the Secondary and 57% for the Tertiary production sector.

Throughout the report, a specific focus has been placed on Finland for illustration purposes and because of in-depth country knowledge. The bioeconomy strategy of the Finnish government's from year 2014 aims to increase the output of bioeconomy sector to €100 billion by year 2025 and create 100,000 new jobs. In this report we have shed light on these numerical targets. First, the gross output is a debatable measure for the bioeconomy, because the outputs of primary production are double counted in the outputs of bio-based processing. Secondly, the measurement of bioeconomy is still at an incipient stage, which leads to the omission of some sectors of the bioeconomy, whereas other sectors are overproportionally represented. Thirdly, some bioeconomy sectors rely on government subsidies (particularly the agricultural production), with labour productivity of bioeconomy being low compared to other sectors. While ensuring the supply of renewable materials and recompensing primary producers for their nature services, is clearly desirable, the goal of creation of jobs with lower productivity has to be seen in a whole-economy context.

[20] EU-28 does not include data on subsidies for Bulgaria, Ireland, Luxemburg and Malta.

The updated Bioeconomy Strategy (European Commission, 2018) stresses the need of "addressing the systemic challenges that cut across the different sectors, including synergies and tradeoffs, to enable and speed up the deployment of circular economy models". Disentangling the economic system and depicting the value flow along the productive sectors, including the service sector, opens new avenues for analysis and eventually, monitoring of the bioeconomy. While the approach does not (yet) include ecosystem services to give a monetary value to nature's provisions, it does provide a broad overview of bioeconomy's value share between primary producers, manufacturers and the service sectors. This might be helpful to observe the process of a socially fair transition to a climate-neutral economy, thus touching upon a main request from primary producers' representatives to participate in the wealth generation throughout the value chain. As a novelty, we also include the transfers from and to sectors, which is in particular of importance for the primary bio-based production, subsidized all around the world.

The proposed approach allows in principle also calculating the bioeconomy contribution to GHG emissions. However, it implies the debatable assumption that bio-based activities in hybrid sectors emit the same amount of GHG as their fossil counterpart. Another shortcoming is the non-inclusion of carbon-sinks such as forestry. Primary production (i.e., agriculture) appears as the major contributor to GHG emissions. Furthermore, the assessment of the environmental dimension requires a much more detailed sector disaggregation, if not on product-level. Though still imperfect, the inclusion of the environmental dimension is motivated by the need to cover all sustainability dimensions in a coherent approach.

The proposed methodology addresses different challenges for measuring the size and eventually providing a basis for evaluating the contribution of the bioeconomy to a sustainable transition. The approach allows for yearly updates following the calendar of Eurostat I-O tables, probably with a 3 to 4 years delay. It relies on a thorough estimation of the bio-based shares of the inputs and outputs of the various sectors. The authors believe that these are fundamental elements to ensure that "The next era of industry will be one where the physical, digital and biological worlds are coming together" (European Commission 2020a). Taking account of the diversity of EU's bioeconomies and sectors, this report broadens the ongoing discussion on how to measure and determine the contribution of the bioeconomy to a sustainable and circular economy.

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