Assessing the Bioeconomy's Contribution to Evidence-Based Policy:

A Comparative Analysis of Value Added Measurements

Abstract

As the bioeconomy has gained importance in European policy agendas, several European research institutes have elaborated ad hoc methodologies to measure the size of the European bioeconomy and aid in the monitoring of its performance. This paper reviews the main approaches found in the literature for such a quantification by comparing the different methodologies and the corresponding quantitative findings. The various estimations published might be confusing at first sight, reporting a value added of the European bioeconomy within the large range of EUR 881 billion to EUR 2.3 trillion. However, the study concludes that each approach is best suited to measuring a different aspect of the bioeconomy. Using the different approaches, we estimate that the markets of bio-based products and energy generate EUR 730-790 billion of value added, the use of biomass within the European economy generates EUR 670 billion of value added, and the sourcing of core bioeconomy industries with goods and services generates EUR 270 billion of value added. There is no evidence of an increased use of biomass inputs in EU industries in substitution of fossil resources, nor of a decreasing dependence of traditional bioeconomy industries towards fossil resources over the period 2005-2015.

Keywords

Bioeconomy, value added, Europe, input-output tables, bio-based industries, methodologies.

1. Introduction

The bioeconomy promotes the transition to a sustainable economic model derived from the use of biomass and the application of natural sciences, knowledge, and technologies. Its relevance is well acknowledged by international organizations such as the FAO (FAO, 2021; Gomez San Juan et al., 2022) and the OECD (OECD, 2018) and, for example in the case of the European Union, represented by a strategy and action plan (European Commission, 2012, 2018). Together with the development of bioeconomy strategies around the world, the need of tools for quantifying the bioeconomy and monitoring its development has become crucial. However, the bioeconomy is a complex concept, encompassing a broad range of economic activities and their associated workers and consumers, while being dependent on the planet's ecological boundaries. Understanding and analysing such a multidisciplinary phenomenon requires implementing several theoretical and conceptual approaches, using a broad range of methodologies.

From global (FAO, 2021), macro-regional (European Commission, 2022b), to national (Federal Ministry of Food and Agriculture (BMEL), 2014) and regional level (Junta de Andalucía, 2018), guidelines and monitoring systems are being developed and implemented. In the case of the EU, the indicators to measure the progress of the European bioeconomy are very broad and numerous (European Commission, 2022a). However, a smaller number of headline indicators is used by policymakers and stakeholders to analyse and report on the bioeconomy. Most prominently among those indicators features (gross) value added, which is the focus of the present study.

The European Union's statistical directorate general, EUROSTAT, does not (yet) provide statistics of a specific value added indicator for the bioeconomy and all its sectors spanning a broad range from primary production (e.g., agriculture), via processing (e.g., wooden products) to services (e.g., restaurants). Here, a key scientific challenge relates to the separation of fossil and bio-based production to correctly delimit the bioeconomy (Ronzon et al., 2017). Over the last years different methodologies have been developed to fill this gap. These methodologies, although pursuing a similar overall goal (measuring the economic size of the bioeconomy from the value it creates), can be different, as they may focus on a specific policy or research question and use different data sources.

Indeed, scientists from different European research institutes have elaborated sound methodologies for monitoring the development of the bioeconomy's value added over time and across European countries (for example Cingiz et al. (2021b); Iost et al. (2019); Iost et al. (2020); Kuosmanen et al. (2020); M'barek et al. (2014); Porc et al. (2021); Ronzon et al. (2022a, 2022b); Wesseler et al. (2017)). However, these methodologies have not been consistently used in bioeconomy policy making for two reasons: (i) the calculation methods are difficult to understand by non-specialists, and (ii) the different methodologies yield very different estimates of the European bioeconomy's size, which may appear confusing at first sight.

The aim of this paper is to bring clarity on the estimates of the bioeconomy's value added size across different methodologies already published, in order to optimize their use by policy makers and consequently contribute to more evidence-based bioeconomy policies. To do so, the paper clarifies what are the concepts measured by each methodology (section 2) and puts their respective results into perspective (section 3). Emphasis is made on pointing to the different aspects of the bioeconomy measured by the different methodologies and on illustrating how each of them can be mobilised to inform on specific policy questions. Finally, conclusions are remarked in the final section.

2. Presentation of the different methodologies

Different quantitative approaches are proposed in the literature for estimating the value added generated by bioeconomic activities, based on literature analysis and/or statistical databases or on modelling (see an overview in Cingiz et al. (2021b)). Four types of methodologies matching monitoring requirements can be distinguished (i.e., methodologies based on statistical databases that are harmonized across EU Member States and updated over time). In this study, each type of methodology is illustrated by a particular publication that applies to all Member States of the EU (Cingiz et al., 2021a; Cingiz et al., 2021b; Kuosmanen et al., 2020; Ronzon et al., 2022a, 2022b).

All four methodologies are based on industry-level statistics for quantifying the contribution of industry p to the bioeconomy in terms of value added (V_p). The bioeconomy being a cross-sectorial concept, the size of its value added is thus the sum of the contribution of all industries represented by NACE[1] codes in the European System of National Accounts that are indexed by $p = 1,\dots,n$. They comprise the industries that fully fall within the scope of the bioeconomy indexed by $q = 1,\dots,l$, the industries that partly fall within the scope of the bioeconomy indexed by $r = l+1,\dots,m,$ and the industries that do not fall at all within the scope of the bioeconomy indexed by $s = m+1,\dots,n$.[2]

The families of methodologies differ on three main aspects:

[1] NACE is the French acronym for Economic Activities in the European Community.
[2] We denote here the industries by letters *p*, *q*, *r* and s to differentiate with the original studies that use the same subscripts *i*, *j*, *k* with diverging definitions.

(i) The set of industries *q*. All methodologies concur in considering the biomass producing industries fully part of the bioeconomy (i.e., agriculture, forestry and fishing). However, divergences occur on the additional industries that complete the set *q* within the full scope of industries considered (p), see Table 1.

(ii) The level of the contribution of industries *r* to the total bioeconomy's value added. Different quantification criteria are considered: the biomass content of products and energy produced or the bioeconomy relevance of the services delivered considering a given policy definition of bioeconomy (see section 2.1.1); the use of biomass; or the provision of inputs to industries *q*.

(iii) The (non-)inclusion into the bioeconomy aggregate of the industries providing inputs to industries *q*.

The different approaches taken regarding points (ii) and (iii) provide distinct measures of the bioeconomy's value added and inform on a variety of aspects of the bioeconomy. Measurement principles are clarified in sections 2.1 to 2.4 while measured aspects are presented in section 3.

2.1. The "output-based" approach

2.1.1. Approach

The "output-based" approach quantifies the value added generated by an industry *p* in proportion to the biomass content of tangible (i.e., merchandise) outputs or to the bioeconomy relevance of intangible (i.e., services) outputs. The biomass content is calculated in dry matter content (Ronzon et al., 2022a). The 'bioeconomy relevance' criterion is derived from a policy definition of the bioeconomy. In the context of the EU Bioeconomy Strategy, it covers the services associated to a bio-based product (e.g., transport, trade, repair), the marketed ecosystem services (e.g., nature tourism), the generation of knowledge in bioeconomy fields (e.g., research and development in life sciences) or support to bio-based markets (e.g., market research, public administration) (Ronzon et al., 2022b).

The output-based approach quantifies the value added of the bioeconomy (V_{BE_O}) at a given point in time and space as:

$$V_{BE\_O} = \sum_q V_q + \sum_r \delta_r . V_r \qquad (1)$$

with δ_r = biomass content share or bioeconomy relevance share of industry *r* (Figure 1). V_q and V_r are the value added of individual industries *q* and *r* (see Annex 1).

Industries *q=1,…,l* comprise the biomass producing industries (A01, A02, A03), the manufacturing of food (C10) and beverage (C11), water supply, sewerage and management[3] (E36-E38) for their full biomass content, as well as food and beverage service activities (I56) and veterinary activities (M75) for their bioeconomy relevance.

Industries *s=m+1,…,n* comprise mining industries (B05-B09), the manufacturing of coke and petroleum products (C19), of mineral or metallic products (C23-C25), of electronic or electrical equipment (C26-C27), of machinery and motor vehicles (C28-C30, C33), the wholesale, retail trade and repair of motor vehicles (G45), the industries of information and communication (J59-J63), of financial, insurance and real estate activities (K64-K66, L68) and of management, employment, human health and social work activities (M70, N78, Q86-Q88).

Industries *r=l+1,…,m* comprise all other NACE industries.

[3] The dry matter content of water is considered 100% biomass (i.e., organic matter and micro-organisms).

2.1.2. Data sources

The output-based approach builds on a variety of data sources. Industry-level data on value added (V_q and V_r) are retrieved from the Eurostat Structural Business statistics (Eurostat, 2022a, 2022b, 2022c) and from Eurostat's national accounts (Eurostat, 2022d) for the industries not represented in the former databases. Other Eurostat databases are mobilised for the computation of the biomass content share or of the bioeconomy relevance share δ_r (Ronzon et al., 2022a, 2022b). In addition to official data, the output-based approach relies on literature, market reports and expert insights for the estimation of the biomass content of the 875 bio-based products listed in the Eurostat database on the production of manufactured goods (Eurostat, 2022e). As δ_r cannot be quantified with precision with available Eurostat data and expert knowledge for all industries *r*, a minimum and maximum threshold value of δ_r is determined that consequently generates a minimum and a maximum value of bio-based value added V_r.

Time series data of V_r are available from 2008 (the latest revision of the NACE classification), up to the most recent common year of data sources used, typically released with a time lag of two years.

2.1.3. Data interpretation

This approach has been coined "policy-driven" in the sense that the bioeconomy relevance of industries in set *p* follows the concept of bioeconomy as defined in the EU bioeconomy strategy. Indeed, by focusing on the bioeconomy nature of industries' outputs, the output-based approach provides lower and upper thresholds of domestic bio-based markets (min V_{BE_O} - max V_{BE_O}). Over time, market developments in the bioeconomy's valued added, or of an individual bio-based industry's value added, give insight on progress towards policy objectives of bio-based market uptake. Also, the difference between an industry's bio-based output share δ_r attained in one country compared with that of another country, or compared with a 100% δ_r share, gives an indication of the remaining potential for bio-based market development.

2.2. The "input-based" approach

2.2.1. Approach

The "input-based" approach quantifies the value added generated by an industry *p* in proportion to its bio-based input cost share. Among the different variants of input-based approaches published in the scientific literature (Efken et al., 2016; Heijman, 2016; Iost et al., 2019; Iost et al., 2020; Kuosmanen et al., 2020; Meesters et al., 2013; Robert et al., 2020), only Kuosmanen et al. (2020) propose quantifications for the EU aggregate. Their methodology, also coined Fundamental Industry Level Model (FILM), is thus proposed here as a benchmark for the families of "input-based" approaches while variations from other input-based approaches are briefly discussed.

The FILM input-based approach relies on the use of monetary flows of input-output tables (IOTs) for quantifying the value added of the bioeconomy (V_{BE_I}) at a given point in time and space, such as:

$$V_{BE\_I} = \sum_q V_q + \sum_r \gamma_r . V_r \qquad (2)$$

with *q* being the biomass producing industries (agriculture, forestry and fishing) and γ_r being the biomass input cost share of industry *r* (Figure 1 and equation 3).

$$\gamma_r = \frac{\sum_r I_{qr} + \sum_r \gamma_{r'} I_{r'r} + \gamma_{Mr} M_r}{\sum_r I_{pr} + M_r} \qquad (3)$$

Thus, I_{qr} is the cost of inputs from the set of biomass producing industries *q* to industry *r*; $I_{r'r}$ is the cost of inputs from industry *r'* to industry *r* with *r'* = *l*+1,…,*m*; $\gamma_{r'}$ is the bio-based input cost share of industry *r'* (equation 4); M_r is the cost of imported inputs to industry *r*; γ_{Mr} is the bio-based input cost share of imported inputs to industry *r;* and I_{pr} is the cost of inputs from all industries to industry *r*. Note that intra-industry trade is captured when *r′* = *r*.

$$\gamma_{r'} = \frac{\sum_{r'} I_{qr'} + \gamma_{Mr'} M_{r'}}{\sum_{r'} I_{pr'} + M_{r'}} \quad (4)$$

2.2.2. Data sources

The FILM approach is systematic across all industries (i.e., does not imply any expert judgement). The data source is the Eurostat IOTs (Eurostat, 2020) released every five years with some Member States also providing annual estimates. This data does not offer a complete coverage of all EU Member States but does provide complete data for the EU28 aggregate.

2.2.3. Data interpretation

By focusing on biomass input cost shares, the FILM methodology reports on the value added (V_{BE_I}) generated from the use of biomass across all industries of an economy. The 5-year time step evolution of V_{BE_I} gives insight on the increasing (decreasing) mobilisation of biomass – measured in value terms - by the economic system considered. The bio-based input cost share γ_r gives an indication of the degree of dependence of industry *r* towards non-renewable biological resources: the smaller γ_r is, the higher the dependence. The development of γ_r over time indicates progress towards the objective of substituting non-renewable (e.g., fossil) resources with bio-based equivalents. Additionally, the FILM approach allows for the incorporation of other adjustments such as subsidies and taxes as well as the possible contribution of other industries to primary production. For an example of its application, see Kuosmanen et al. (2020).

2.2.4. Variation to the FILM approach

While the FILM approach is homogeneous across all NACE industries and employs data from a single source, Iost et al. (2019); and Iost et al. (2020) adapt the input-based approach to reflect the bioeconomy concept as defined in the previous German Bioeconomy Strategy (BMEL, 2014). First, the delineation of the bioeconomy's industrial scope is restricted to a selection of bio-based industries that includes only a few bio-based services (i.e., joinery installation and erection of frames and constructional timber works, food and beverage service activities and research and experimental development on biotechnology). Second, several sources of German statistics are employed. The biomass input cost shares of NACE C industries are derived from the Material and Goods received Enquiry (MGrE), for they offer more precise information than IOTs (DESTATIS, 2017). The bio-based shares of other NACE industries are derived from additional data sources on energy balance and construction permits (AGEB, 2015; DESTATIS, 2018). Third, per policy definition, the bio-based share of research industries (M7219) is not determined according to its biomass input cost share but rather from the share of personnel cost incurred in bioeconomy-related research disciplines on total costs (DESTATIS, 2016). Data on value added are retrieved from EUROSTAT's structural business statistics.

2.3. The "Weighted Input-Output based" approach

The "weighted Input-Output based" approach provides a middle ground quantification of the bioeconomy's value added, taking into account the parameters δ_p and γ_p quantified by the output-based and the input-based approaches (Figure 1). It quantifies the value added of the bioeconomy (V_{BE_W}) at a given point in time and country as:

$$V_{BE\_W} = \sum_p \theta_p . V_p \quad (5)$$

where θ_p is the weighted average of the input-based and output-based coefficients. With that purpose, the output bio-based share δ_p is weighed with the ratio of value added on gross output, and the input bio-based share γ_p is weighed with the ratio of total cost of inputs on gross output:

$\theta_p = (\delta_p.V_p + \gamma_p.I_p) / O_p$ (6)

The data sources used are the same as those employed in the output-based and input-based approaches (see sections 2.1.2 and 2.2.2).

2.4. The "Upstream & Downstream" approach

2.4.1. Approach

The "upstream & downstream" approach quantifies two different aspects of the bioeconomy (Figure 1, Cingiz et al. (2021b)):

- $\sum_r D_r$, the "downstream effect" of the bioeconomy which corresponds to the value added size of the industries *r* that use bio-based inputs in proportion to their respective bio-based input cost share β_r from industries *q*. *q* represents the biomass producing industries, the manufacture of food, beverage, tobacco, wood and paper products, and printing.

- $\sum_r U_r$, the "upstream effect" of the bioeconomy which corresponds to the value added size of the industries *r* that source industries *q* in proportion to their respective output cost share α_r.

In sum, the "upstream & downstream" approach quantifies the value added of the bioeconomy (V_{BE_UD}) at a given point in time and space as[4]:

$V_{BE\_UD} = \sum_q V_q + \sum_r (D_r + U_r)$ (7)

Similarly to equation (2), $D_r = \beta_r .V_r$ (8)

$U_r = \alpha_r (1- \beta_r) V_r$ (9)

where α_r is the output cost share of industry *r* to industries *q*. α_r is multiplied by $(1- \beta_r)$ to avoid double counting with the downstream effect.

$$\alpha_r = \frac{\sum_q I_{rq}}{\sum_p I_{rp} + F_r + E_r} \quad (10)$$

where F_r denotes the final demand for industry *r* and E_r denotes the exports of industry *r*.

2.4.2. Data sources

Similarly to the FILM approach, the "upstream & downstream" approach is systematic across all industries and does not imply any expert judgement. The two effects are computed from the OECD's IOTs with annual data series from 2005 to 2015 for the 28 pre-Brexit EU Member States (OECD, 2021). EU28 data are calculated as an aggregate of the former 28 countries.

2.4.3. Data interpretation

Compared to the other three approaches, the "upstream & downstream" method adds information on how much the bioeconomy is integrated with the rest of the economy, in particular to non-bioeconomy sourcing industries.

The downstream component $\sum_r D_r$ provides similar information as the input-based approach (see section 2.2.3). Additionally, the output cost share α_r used for the quantification of the upstream component U_r illustrates the interconnection between industry *r* and the core bioeconomy industries *q*. The higher α_r is, the larger is the sourcing role of industry *r*. Moreover, the development of the total upstream and downstream effects over time ($\sum_r U_r$ and $\sum_r D_r$) informs whether an increasing

[4] Notations have been changed compared to Cingiz et al. (2021b) for the sake of harmonization across the various methodologies presented in the paper.

(decreasing) value creation from the use of renewable biological resources ($\sum_r D_r$) is concomitant or not with a growth of the economic size of bioeconomy sourcing industries ($\sum_r U_r$). Finally, the ratio of bioeconomy value added on GDP (V_{BE_UD}/GDP) describes how much the bioeconomy is integrated into the whole economy.

As a summary, Figure 1 graphically illustrates the concepts or flows quantified in the four approaches and their related equations and Table 1 compares the main parameters of the four approaches.

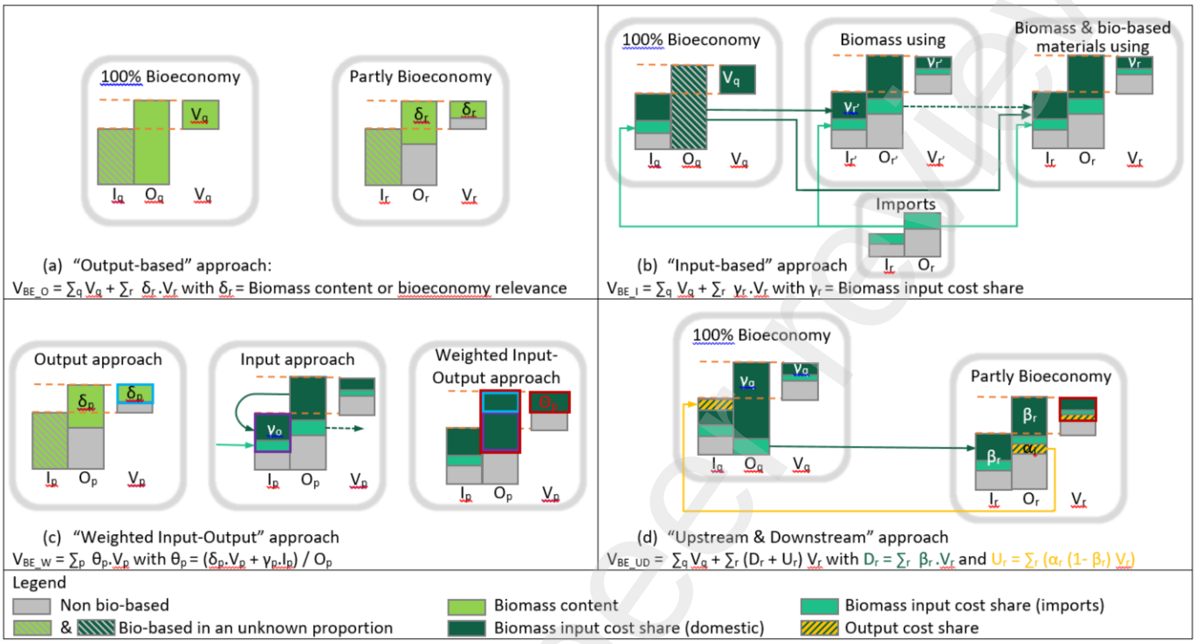

Figure 1. Four methodological approaches for determining the bio-based share of industry p.

Note: I stands for Input, O for Output and V for Value added, all three are measured in monetary terms.

Table 1. Summary comparison of the four approaches introduced at sections 2.1 to 2.4 .

Approach	**"output-based"**	**"input-based" (FILM)**	**"weighted Input-Output"**	**"upstream & downstream"**
Quantification criteria	Biomass content of tangible outputs, bioeconomy relevance of intangible outputs	Biomass inputs (biomass input cost share)	See the two previous columns	Biomass inputs (biomass input cost share) and sourcing of industries *q* (output cost share)
Equations	$V_{BE\_O} = \sum_q V_q + \sum_r \delta_r V_r$ *Equation (1)*	$V_{BE\_I} = \sum_q V_q + \sum_r \gamma_r V_r$ *Equation (2)*	$V_{BE\_W} = \sum_p \theta_p V_p$ with $\theta_p = (\delta_p V_p + \gamma_p I_p) / O_p$ *Equations (5) and (6)*	$V_{BE\_UD} = \sum_q V_q + \sum_r (D_r + U_r)$ *Equation (7)*
Industries *q* (NACE codes)	A01-A03, C10-C12, E36, I56, M75	A01-A03	A01-A03	A01-A03, C10-C12, C16-C18

Industries *s* (NACE codes)	B05-B09, C19, C23-C30, C33, G45, K64-K66, L68, M70, N78, Q86-Q88.	None	None	None
Data sources	Expert knowledge and many Eurostat sources	Eurostat's IOTs	See the two previous columns	OECD's IOTs
Interpretation of the results	Bio-based market size	Use of biomass	Middle ground perspective between the previous two columns	Use of bio-based inputs and integration to the wider economy

3. Results and discussion

The four methodologies presented above yield very different estimates of the value added size of the EU bioeconomy in 2015, ranging from EUR 881 billion to EUR 2.3 trillion (Figure 2). Such a large range may be puzzling at first sight or may even confuse policy makers. In fact, differences in numbers reflect the different aspects of the bioeconomy captured by each approach. This section summarises the main results, sheds light on the specific aspects of each methodology and illustrates how the diversity of quantitative evidence produced can be mobilised to answer relevant policy questions.

3.1. Aggregated results and complementary information on differences

In order to provide an overview of main results, we focus hereafter on the comparison of the aggregates of primary, secondary and tertiary economic sectors[5] as illustrated by Figure 2. For each of these aggregates, we highlight the reasons leading to differences in value added estimates and give sectoral examples to aid the understanding of the result differences. The weighted input-output approach is not commented though, as it always provides an intermediate quantification between the input-based and the output-based approaches. All quantifications from the "upstream and downstream" approach are taken from the online database published by Cingiz et al. (2021a)[6].

[5] The primary sector refers to NACE sections A and B (biomass production and mining and carrying), the secondary sector to NACE C to F (manufacturing), and the tertiary sector to NACE G to T (services).
[6] Although the methodological comments exposed in section 2.4 were derived from Cingiz et al. (2021b).

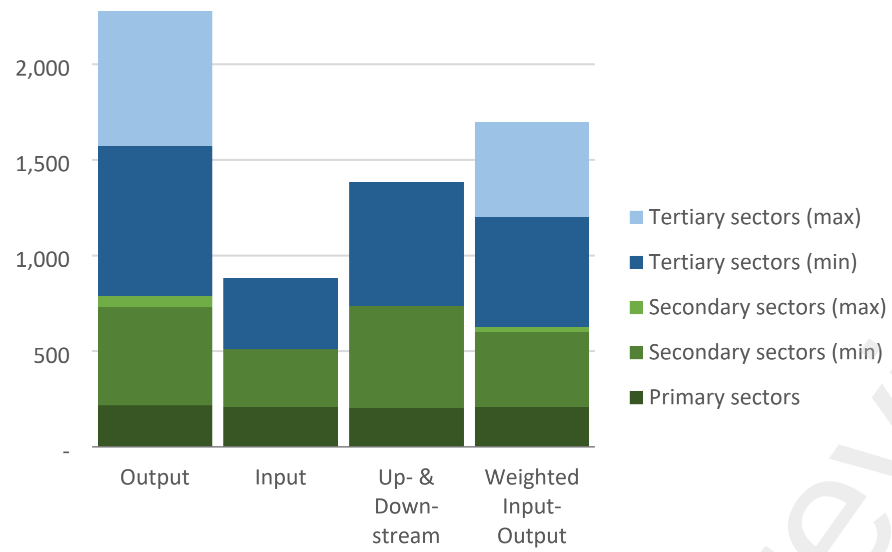

Figure 2. Estimation of the value added size of primary, secondary and tertiary activities of the EU28 bioeconomy according to the four quantitative approaches presented in the study

Estimations of value added for the bioeconomy industries of the **primary sector** are convergent (EUR 207 to 216 billion) in spite of methodological differences and slight variations from the different data sources employed by each approach. The output-based approach only considers those industries that produce biomass (EUR 216 billion) while the other three approaches also consider a proportion of the bioeconomy value added coming from the mining industries. From an input-based perspective, EUR 1 billion of value added is generated from the use of renewable biological material in mining activities such as for bioleaching. Moreover, the upstream effect U_r calculated in the "upstream and downstream" approach reveals that EUR 1.2 billion of value added are generated from the sourcing of core bioeconomy industries *q* by mining industries.

The value added of the bioeconomy industries operating in the **secondary sector** differs more from one approach to the other than in the case of primary sector industries: EUR 299 billion (input-based approach) to EUR 573 billion (output-based approach). The biomass input cost share γ_r (input-based approach) is systematically smaller than the biomass content δ_r of the outputs of the manufacturing industries (output-based approach), except for those industries *s* considered non bio-based in the output-based approach (γ_r ranging between 0.6% and 2.5%, Table 2). As a matter of example, only 55% of the inputs of the manufacturing of food, beverage and tobacco are bio-based inputs while that industry generates fully bio-based outputs (i.e., γ_r = 55% and V_r = 152 EUR billion in the input-based approach while δ_r = 100% and V_r = EUR 237 billion in the output-based approach). The proportion (α_r (1- β_r)) of outputs that secondary sector's industries sell to bioeconomy industries *q* ranges from 0.3% to 5.3%.

Table 2. Output bio-based shares (a), biomass input cost shares (b), combined upstream and downstream shares (c) and weighted Input-Output shares (d) at the sectorial level and for the EU28 in 2015

nace		(a) min – max		(b)	(c)	(d) min– max	
A01_A03	Agriculture, forestry, fishing	100%	100%	100%	100.0%	100%	100%
B05_B09	Mining and quarrying	0.0%	0.0%	1.4%	3.0%	0.6%	0.6%
C10_C12	Food, beverages and tobacco products	100%	100%	54.8%	100.0%	66.4%	66.4%

C13_C15	Textiles, wearing apparel and leather products	35.6%	46.5%	40.9%	6.0%	38.4%	42.8%
C16	Products of wood and cork	99.7%	99.7%	45.7%	100.0%	61.7%	61.7%
C17_C18	Paper products and printing	60.8%	98.9%	30.7%	100.0%	37.3%	53.2%
C19	Coke and refined petroleum products	0.0%	0.0%	0.6%	3.7%	0.5%	0.5%
C20_C21	Chemicals and pharmaceuticals	25.6%	27.1%	4.3%	8.4%	12.1%	12.6%
C22	Rubber and plastics products	3.3%	3.9%	4.6%	9.1%	4.1%	4.4%
C23	Other non-metallic mineral products	0.0%	0.8%	2.5%	5.5%	1.6%	1.9%
C24	Basic metals	0.0%	0.0%	0.9%	1.5%	0.7%	0.7%
C25	Fabricated metal products	0.0%	0.0%	1.5%	4.4%	0.9%	0.9%
C26	Computer, electronic and optical equipment	0.0%	0.0%	1.4%	1.7%	0.9%	0.9%
C27	Electrical equipment	0.0%	0.0%	1.6%	2.1%	1.0%	1.0%
C28	Machinery and equipment, nec	0.0%	0.0%	1.1%	2.7%	0.7%	0.7%
C29	Motor vehicles, trailers and semi-trailers	0.0%	0.0%	1.5%	1.2%	1.1%	1.1%
C30	Other transport equipment	0.0%	0.0%	1.5%	1.4%	1.1%	1.1%
C31_C33	Manufacturing nec; repair and installation of machinery and equipment	8.8%	17.8%	8.3%	9.8%	8.4%	11.3%
D35_E39	Electricity, gas, water supply, sewerage, waste and remediation services	24.0%	25.4%	1.3%	5.6%	10.2%	10.6%
F	Construction	5.3%	5.6%	3.4%	4.4%	3.9%	4.0%
G45_G47	Wholesale and retail trade; repair of motor vehicles	24.8%	39.8%	3.7%	11.0%	15.0%	23.0%
H49_H53	Transportation and storage	20.1%	32.2%	0.9%	3.9%	8.9%	14.0%
I55_I56	Accommodation and food service activities	76.5%	76.5%	34.7%	34.3%	57.7%	56.4%
J58_J60	Publishing, audiovisual and broadcasting activities	0.0%	32.1%	4.6%	12.3%	2.4%	19.1%
J61	Telecommunications	0.0%	0.0%	0.9%	2.1%	0.5%	0.5%
J62_J63	IT and other information services	0.0%	0.0%	0.9%	2.7%	0.5%	0.5%
K64_K66	Financial and insurance activities	0.0%	0.0%	0.6%	3.3%	0.3%	0.3%
L68A	Real estate activities	0.0%	0.0%	0.9%	2.2%	0.2%	0.2%
M69_N82	Professional, scientific and technical activities, administrative and support services	4.0%	11.8%	2.1%	4.9%	2.0%	9.8%
O84	Public administration and defence; compulsory social security	10.5%	15.9%	2.6%	4.7%	0.9%	11.5%
P85	Education	2.2%	4.9%	4.3%	6.7%	0.9%	3.5%
Q86_Q88	Human health and social work activities	0.0%	0.0%	5.4%	5.6%	1.8%	1.8%
R90_S96	Arts, entertainment and recreation and other service activities	0.2%	47.1%	3.8%	6.9%	1.6%	27.1%

T97_T98	Activities of households as employers	0.0%	100.0 %		0.0%	0.0%	0.0%

Sources: Cingiz et al. (2021a); Kuosmanen et al. (2020); Ronzon et al. (2022a, 2022b)

The **tertiary sector** shows a high divergence in terms of value added size estimates from one approach to the other: EUR 370 billion (input-based approach) to EUR 1,488 billion (output-based approach). The four-fold difference is due to relatively small biomass input cost shares (γ_r = 1-5%, except for accommodation and food services where γ_r = 35%) compared with high biomass content or bioeconomy relevance of tertiary outputs (maximum δr = 12-100% in eight out of fourteen tertiary industries, Table 2). While the approaches based on IOTs (input and "up and downstream" approaches) are systematic and precise, the output-based approach suffers from both a lack of clarity about the definition of a bioeconomy service and a lack of informative data for the quantification of their bioeconomy relevance. In two extreme cases, the bioeconomy relevance of the industries of sport, amusement and recreation activities and the activities of household employers could not be quantified with available data, leading to the very broad assumption of minimum and maximum bioeconomy relevance shares of 0% and 100% (for a discussion of the output-based approach, see Ronzon et al. (2022b)). Finally, the industries of telecommunication and information technologies, finance, insurance, real estate, human health[7] and social work are excluded from the sectorial scope of the bioeconomy in the output-based approach (δ_r = 0%). Nevertheless, they use biomass (γ_r ranging between 0.6% and 5.4%) and source core bioeconomy industries *q* with their outputs (α_r (1- β_r) ranging between 0.4% and 2.0%). Consequently, they are worth EUR 75 billion according to the input-based approach and EUR 123 billion in the "upstream & downstream" approach.

3.2. Tailoring the right approach to specific policy requirements

Taken separately, the different approaches provide insight on fundamental policy questions:

(i) What is the size of bio-based markets? What is their potential for development?
(ii) What is the size of the economic activities that rely on the use of biomass?
(iii) How does the bioeconomy and the rest of the economy interlink?
(iv) Is the substitution of non-renewable resources by renewable biological resources happening?

Moreover, sectorial data can also be used to inform on more specific policy questions related with the bioeconomy such as the dependence of the EU economy to fossil resources, the size of the knowledge-based bioeconomy (KBBE) and many others.

3.2.1. Size and development of bio-based markets

The development of bio-based markets is pivotal in the EU bioeconomy strategies, which have been conceived as engines of green growth.

The output-based approach precisely offers the means for monitoring the economic wealth created from the production and selling of bio-based products and bioenergy and from waste treatment (NACE sectors A to F). Taking the year 2015 as a reference for comparison with the other approaches, the value added size of the EU bio-based markets is estimated between EUR 730-790 billion. It has increased by 30-31% in the decade 2009-2019, which has permitted to maintain their contribution to the EU's total value added at approximately 5.5-5.9%. The output-based approach also allows country level and sectorial level analysis. Keeping the EU28 as a geographical scope, bio-based markets are dominated by food and agricultural commodities (respectively EUR 189 billion and EUR 183 billion in

[7] Human health is explicitly excluded from the bioeconomy in the European bioeconomy strategy (European Commission, 2018).

value added size 2015, Table 3 (a)). If we follow a stricter definition of "bio-based products" that excludes food and feed products, then the largest markets for bio-based products are the ones of paper products and of bio-based pharmaceuticals, with a value added size of EUR 45 billion each (Table 3 (a)). Interestingly, the four industries responsible for the biggest biomass-derived markets – agriculture, food, paper and bio-based pharmaceuticals – were also identified as the main motors of productivity growth in the EU over the last decade by Ronzon et al. (2022a), either because these industries have modernised their production processes (agriculture, the manufacture of paper), or because they have attracted workers from less intensive bio-based industries (manufacture of bio-based pharmaceuticals and food products) or both phenomena. Their market size has grown by 37-43% over the period 2009-2019, except for the food industry (30% growth).

The secondary sector of the EU28 (NACE C to F) is 19-21% bio-based in 2015 ($\delta_{NACE\ C\text{-}F}$). That proportion remains stable over the decade 2009-2019. It is certainly impossible to achieve a fully bio-based secondary sector as some metal, mineral and other non bio-based components of manufactured goods cannot be substituted with biomass. Notwithstanding, a 20% share seems low enough to expect some feasible progress. Output bio-based shares of 35-40% have been achieved by the secondary sectors of Latvia and Lithuania in 2015, thanks to an important manufacture of wood products and food and beverages (both countries), of wooden furniture (Lithuania) and bioenergy industry (Latvia). The Irish case illustrates a bioeconomy less oriented towards wooden biomass, where the manufacture of bio-based chemicals (δ_r=31%) together with a strong food and beverage industry drives a 32-33% bio-based secondary sector.

Table 3. Top 5 markets according to the different criteria discussed in the text (EU28, 2015)

(a) Top 5 markets of bio-based products and energy by value added size*				
	Industry (nace sector)		Value added size (V_p in million euros)	Output bio-based share (δ_p in %)
1	Manuf. of food products	C10	189,000	100%
2	Agriculture	A01	183,441	100%
3	Manuf. of paper and paper products	C17	45,257 - 45,625	99% - 100%
4	Manuf. of bio-based pharmaceuticals	C21	44,827	49%
5	Manuf. of beverages	C11	40,890	100%
(b) Top 5 market industries by value added generated from biomass use				
	Industry (nace sector)		Value added size (V_r in million euros)	Biomass input cost share (γ_r in %)
1	Manuf. of food products, beverage and tobacco products	C10_C12	152,458	55%
2	Accommodation and food service activ.	I55_I56	130,084	35%
3	Human health activities	Q86	29,762	4%
4	Education	P85	29,226	4%
5	Manuf. of textiles, wearing apparel and leather products	C13_C15	28,521	41%
(c) Top 5 industries relying on biomass and bio-based product resources in proportion to their inputs				
	Industry (nace sector)		Value added size (V_r in million euros)	Biomass input cost share (γ_r in %)
1	Manuf. of food products, beverage and tobacco products	C10_C12	152,458	55%

2	Manuf. of products of wood and cork	C16	17,363	46%
3	Manuf. of textiles, wearing apparel and leather products	C13_C15	28,521	41%
4	Manuf. of paper and paper products	C17	17,484	37%
5	Accommodation and food service activ.	I55_I56	130,084	35%
(d) Top 5 sourcing industries to core bioeconomy industries *q*, by value added size				
	Industry (nace sector)		Value added size (V_r in million euros)	Output cost share ($\alpha_r.(1-\beta_r)$ in %)
1	Wholesale and retail trade; repair of motor vehicles	G45_G47	112,945	8%
2	Professional, scientific and technical activities, administrative and support services	M69_N82	34,750	2%
3	Transportation and storage	H49_H53	19,425	3%
4	Electricity, gas, water supply, sewerage, waste and remediation services	D35_E39	15,221	4%
5	Financial and insurance activities	K64_K66	14,152	2%

** sorted on the maximum estimation of value added size.*

Note: the level of disaggregation varies from one methodology to the other (e.g. the aggregate C10-C12 in (b) is broken down into C10, C11 and C12 in (a)).

3.2.2. Use of biomass and value added creation

Side-by-side with market objectives, the two consecutive EU bioeconomy strategies promote the sustainable use of biomass – in particular for industrial purposes – to achieve a bioeconomy transition in Europe. A sustainability assessment is out of the scope of the present study. However, the input-based approach developed by Kuosmanen et al. (2020) and the downstream component quantified by Cingiz et al. (2021a) do provide evidence on the extent to which biomass is used in the different economic sectors of the EU28, and on the ability of each industry to create value added from it.

According to Kuosmanen et al. (2020), the use of biomass and bio-based products generates EUR 670 billion of value added in the EU28 economy, excluding the biomass producing activities[8] (2015 data). The primary sector, mining and quarrying activities depend on the use of biomass for 1.4% of their input costs, from which they produce EUR 1 billion of value added). The secondary sector is more dependent on biomass inputs than the tertiary sector but less efficient at generating value added from it: with a 9% biomass input cost share, the secondary sector generates EUR 299 billion compared to a 4% share in the tertiary sector, generating EUR 370 billion.

The manufacturing of food, beverage and tobacco and accommodation in rural areas and food services create the largest amounts of value added from biomass usage in the EU28 (EUR 152 and 130 billion each, Table 3 (b). More surprisingly, they are followed by human health activities and education (EUR 29-30 billion each). Human health is excluded from the EU definition of the bioeconomy but it is preponderant in more process-based definitions (e.g., USA, Brazil). Education uses biomass in the form

[8] The industries that produce biomass – i.e., agriculture, forestry and fishing – are fully accounted part of the bioeconomy by Kuosmanen et al. (2020) (industries *q*). As a result, no biomass cost share γ_r is calculated for those industries and we cannot report here on their use of biomass.

of paper, wooden desks and furniture and in the form of breakfasts served at school in some Member States.

The industries that depend more on biomass usages are traditional industrial activities (again excluding biomass producing activities[8]), see the top four industries at Table 3 (c). Their sourcing in biomass and bio-based products reaches 37% to 55% of total input costs (γ_r). Tertiary activities come only at the fifth position in the form of accommodation in rural areas and food services (γ_r = 35%).

3.2.3. The degree of inclusivity of the Bioeconomy within the macroeconomy

The scope of the bioeconomy and its penetration into the rest of the economy is another topic of policy interest. The chronological evolution of bioeconomy-related policy initiatives indeed shows different perceptions of bioeconomy activities. The first policy concept of KBBE put the focus on those scientific and knowledge-productive activities in the domain of life sciences (Patermann et al., 2018). In contrast, the first bioeconomy strategy of the EU turned the spotlight onto primary and secondary bio-based production while the second strategy broadened the scope to all types of activities that use biomass, tertiary activities included.

The work from Cingiz et al. (2021a) applies to all three perceptions and quantifies the interlinkages between the bioeconomy and the rest of the economy. At the EU28 level, the production of biomass contributes 1.6% of the total value added in 2015, which rises to 4.6% if we add the other fully bio-based industries *q* (food, beverage, tobacco, wood products and paper, see Table 1). The trickling down of industries *q*'s output to partly bio-based manufacturing and service activities permits the generation of an additional 3.9% of the EU28 total value added (EUR 511 billion).

In addition, Cingiz et al. (2021a) claim that the input provision to a variety of industries is not the only way the bioeconomy penetrates the economy. Bioeconomy industries also depend on the rest of the economy for input provision. That economic link is quantified in the form of a so-called 'upstream effect' (equation 9) and is worth 2% of the EU28 total value added. The largest upstream effects are observed from tertiary activities (Table 3 (d)), nearly half of the upstream effect being the fact of trade activities[9] (42%) and transportation and storage (7%). In sum, the authors estimate that fully bio-based industries *q* and the downstream and upstream effect of other industries account for a significant 10.4% of the EU28 value added.

Regarding the size of the KBBE, the results from Cingiz et al. (2021a) are unfortunately not disaggregated enough to inform on the value added generated by the knowledge-productive activities used by the set of industries *q* (upstream effect of NACE M71-M75 and P85). The estimation could be computed with further research though. Another approximation could be provided from an output-based perspective, i.e., the value added created by the production of knowledge in bioeconomy fields from the above quoted NACE activities. Unfortunately, available data sources cannot permit a more precise quantification than EUR 35-121 billion for the EU28 in 2015.

3.2.4. Substitution effect and dependence of the EU bioeconomy to fossil resources

The substitution of non-renewable resources in industrial and energy processes is central in the EU bioeconomy strategy for addressing the two objectives of lowering the EU dependence to non-renewable feedstocks and of contributing to climate change mitigation (European Commission, 2012 page 5; 2018 page 9). Such a substitution effect could be observable from the monitoring of sectorial biomass input cost shares (γ_r and β_r) over time in the form of increasing usage of biomass input in

[9] Wholesale, retail trade and repair of motor vehicles (NACE G45, G46, G47).

proportion to total inputs (in value terms). Time series are only offered for the biomass input cost shares β_r by Cingiz et al. (2021a)[10].

Contrary to the expected upward trend, Cingiz et al. (2021a) indicate a reduction of biomass input cost shares from 2.7% to 2.5% in the secondary sector (excluding the set of sectors *q*) and from 5.1% to 4.4% in the tertiary sector between 2005 and 2015. The authors note, however, that the biomass input cost share of the secondary sector is stabilising since 2010. At the EU28 level, the reduction trend is particularly noticeable in the manufacture of furniture and repair and installation of machinery and equipment (NACE C31-33) and in the industry of publishing, audiovisual and broadcasting (NACE J58-60) but trends differ across countries. A note of caution has to be introduced here on the monitoring of biomass inputs in value terms. Due to differentials in the relative value of biomass compared to other inputs, a decreasing proportion of biomass inputs in value does not always correlate with a decreasing proportion in quantity.

Beyond the capacity of a whole economy to use biologically renewable resources in industrial processes and services, some observers question the capacity of the bioeconomy to source itself with less fossil inputs. In that sense, the upstream component of mining and fossil-based industries provides evidence on the link between industries *q* and fossil resources. Cingiz et al. (2021a) estimate that 1.1% of the output of the mining and carrying sector and 3.2% of the output of the manufacturing of coke and refined petroleum products source the core bioeconomy industries *q*. These proportions have remained fairly steady over the 2008-2015 time period but they vary across EU Member States: from 0.3% to 4.4% in the case of mining and carrying activities and from 0.5% to 8.1% regarding the manufacture of coke and petroleum products in 2015.

The same logic could apply to examine the use of plastics by industries *q* although the data source used for the quantification of the upstream component does not disentangle fossil-based from bio-based plastic inputs.

4. Conclusion

The scientific community has responded well to the challenge of quantifying the economic performance of the EU bioeconomy. As this study demonstrates, a variety of sound methodologies are now implementable to inform on various aspects of value creation in bioeconomy sectors. Nevertheless, the communication of scientific outcomes to policy makers could be improved, avoiding the general term "value added of the bioeconomy" and clarifying instead the source of value added quantified. As a few examples, for the EU in 2015:

- EUR 730-790 billion of value added were created *from the aggregated domestic production of biomass, bio-based products and bioenergy* (output approach), that is 5.5-5.9% of the total EU value added. The agro-food industry is responsible for half of the EU bio-based market, followed by the paper and bio-based pharmaceuticals industries. Services are not yet well captured in the output-based approach.

- EUR 670 billion of value added were created *from the use of biomass in all economic sectors (input-based approach),* that is 5% of the total EU value added. The secondary sector is more dependent on

[10] At a less disaggregate sectorial breakdown than the one points in time γ_r from Kuosmanen et al. (2020) and with different data source and calculation method. γ_r and β_r are therefore not directly comparable.

biomass inputs than the tertiary sector but less efficient at generating value added from it (EUR 299 billion vs. EUR 371 billion).

- EUR 270 billion of value added were created *from the use of products and services in the production of biomass and food, wood and paper products* (upstream component of the bioeconomy), that is 2% of the total EU value added.

In addition, contrary to the EU bioeconomy strategy's expectations, our results do not conclude on a clear trend towards an increase of biomass input use in EU industries nor towards a decreasing dependence of traditional bioeconomy industries towards mining, coke and petroleum products over the period 2005-2015.

Pursuing a growing value added from bio-based markets, bio-based feedstock, or bioeconomy inputs should not be the only objective of a functioning bioeconomy. The sustainability of production and consumption within the bioeconomy, the health of natural ecosystems and a fair distribution of bioeconomy's benefits are also central in the policy narrative. The methodologies presented here have been tested in the literature on other indicators such as the number of persons employed (Kuosmanen et al., 2020; M'barek et al., 2014; Ronzon et al., 2022b; Ronzon et al., 2017) or greenhouse gas emissions (Kuosmanen et al., 2020). However, monitoring sustainability aspects surely requires a much more comprehensive set of indicators and scientific methods.

Finally and beyond the overview given in this paper, the different methodologies could be mobilised for further research on areas closely related to the bioeconomy, such as the size of the knowledge-based bioeconomy, of the circular economy or of paid recreational services. Monitoring the use of biomass and the bio-based substitution of strategic sectors could also provide additional evidence to the debate on the classification of economic activities into green or brown sectors that has become topical in the context of the publication of a Green Taxonomy by the EU (Bohnenberger, 2022).

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