German Bioeconomy: Economic Importance and Concept of Measurement

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Abstract

In recent literature concept and implications of bio-economy are being discussed extensively and in many cases the term bioeconomy rather serves as a framework for discussion than as an operational basis for estimating size and economic importance. Nevertheless, several of such estimates exist on national and European level. Due to the application of different and sometimes not comprehensible methodology, these estimates cannot be properly compared and evaluated. Therefore, the objective of this article is the development of a transparent method for estimating the economic importance of bioeconomy and the application of this method to provide a comprehensive estimate of the German bioeconomy. Our analysis bases on various official statistics and refers to the year 2014. The size of the bioeconomy is described by the indicators employment, gross value added and turnover. We estimate bioeconomy related employment to range between 3.7-4 million jobs, bio-based gross added value to reach 116-135 bill. EUR and bio-based turnover to range between 451-520 bill. EUR. Challenges in estimating economic importance are data availability and the fact that existing classifications of economic activities do not allow distinguishing fossil-based and bio-based economic activities.

Key Words

bio-based products; monitoring; inputs; outputs; jobs; turnover; gross value added

1 Introduction

In recent literature the bioeconomy concept and its implications are being discussed extensively (VIAGGI, 2016). Among others GOLEMBIEWSKI et al. (2015) give a comprehensive overview on development of the term, definitions, policies as well as different perceptions and aims of bioeconomy. As a conclusion the authors state that "bioeconomy rather serves as a framework for discussion, so that clear definitions of bioeconomy are often missing" (p. 311) and ask for a standard measure "to capture the current size of the bioeconomy as well as to monitor its evolutionary process, i.e. the transition from a fossil to a bio-based economy" (p. 310). Existing approaches to quantify the share of bioeconomy use either the amount of bio-based materials and other inputs that go into production (EFKEN et al., 2012; EFKEN et al., 2016; LUKE, 2018), or the share of bio-based products (i.e. outputs) (PIOTROWSKI et al., 2016), or sectoral (BECHER and WEIMAR, 2016) and empirical estimations (VANDER-MEULEN et al., 2011). Up to date, examples of quantifications of bioeconomy exist for Germany (EFKEN et al., 2012; EFKEN et al., 2016), the EU-28 (PIOTROWSKI et al., 2016; RONZON et al., 2017), Flanders (VANDERMEULEN et al., 2011), Finland (LUKE, 2018), the Netherlands (HEIJMAN, 2016), Canada (PELLERIN and TAYLOR, 2008) and for the US biotech sector as part of the bioeconomy (CARLSON, 2016). In these studies, the quantification of bioeconomy is realized using different economic and structural indicators like employment, turnover or gross value added. These indicators are calculated by using data from European and National Accounts, which are based on existing internationally harmonized classifications, e.g. NACE Rev. 2 (Nomenclature Statistique des Activités Économiques dans la Communauté Européenne Revision 2). Major advantages of using official data are periodic updates, broad availability and possible comparability between countries as the underlying methods and definitions are well established. Basically, indicators for quantification of the bioeconomy derived from such harmonized classifications should be comparable. However, the crucial part is the respective definition of the bioeconomy and how this definition translates into classification categories, e.g. economic activities included in the calculation. Unfortunately, in existing studies, it sometimes remains unclear which economic activities and products are

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included. Furthermore, if partly included, the derivation of a bio-based share remains incomprehensive in some cases. Also the bio-based share itself is not always completely defined and documented. As a consequence, quantification methods are not fully replicable, which impedes comparing and monitoring of the development of bioeconomy of regions, of individual countries or of country groups like the EU.

Our approach to quantify the German Bioeconomy is based on the work of EFKEN et al. (2012). The authors use official statistics on materials and goods (i.e. inputs) supplied to economic activities as classified by NACE Rev. 2. The authors classified all inputs into bio-based and non-bio-based. In a next step, monetary values of all bio-based inputs were summed up and related to the total value of all inputs. This relation constituted the bio-based share of the respective economic activity. The classification of the inputs was done based on expert's opinion and only two classes were applied: non-bio-based and fully bio-based (EFKEN et al., 2012).

The main objective of this article is to develop a more replicable and transparent method for determining the bio-based shares of economic classification units in order to develop a framework for monitoring the development of the bioeconomy at the example of Germany. Consequently, we aim at classifying inputs into economic activities based on official production statistics and not on expert's opinion alone. Secondly, the bio-based share of inputs into economic activities will be quantified in more detail than as proposed by EFKEN et al. (2012). In order to provide a replicable method for calculating bio-based shares and estimating economic importance of the bioeconomy, official data provided by the National Accounts will be the basis of our calculations.

As an additional result and based on our quantification scheme of the bioeconomy, recommendations for additional data collection necessary for a continuous bioeconomy monitoring will be provided.

The remainder of this article is structured as follows: section°2 presents our definition of bioeconomy and the quantification concept, as well as the derivation of bio-based shares of product groups and economic activities and the selection of indicators. Results are presented and discussed in section °3. The paper concludes with a discussion of limitation of our approach and recommendations for a future bioeconomy monitoring.

2 Data Base and Methods

This section starts by giving a comprehensive definition of bioeconomy (2.1) as a necessary basis for assigning economic activities to bioeconomy. Following, the bio-based shares of the respective NACE sections are analysed. Section A (Agriculture, Forestry and Fishing) is considered 100% bio-based, hence, no further estimations are necessary. For those NACE sections that are partly assigned to bioeconomy bio-based shares are calculated from official statistics or derived from other data sources (2.2). Finally, bio-based shares are applied to economic/structural indicators (2.3).

2.1 Quantification Concept

The German Bioeconomy Strategy aims at supporting the development of an economy that is increasingly based on renewable resources. In such an economy resources are produced sustainably and used efficiently (BMEL, 2014). The strategy defines bioeconomy as connected to natural material cycles and states that it comprises all economic activities that produce, process, use and trade renewable resources (plants, animals, microorganisms and their products). As such, this definition provides the frame for a future monitoring but it is not readily operational in order to quantify the German bioeconomy and, later on, to evaluate if the objectives formulated by the strategy, are achieved. The crucial point is to develop an operational bioeconomy definition that allows for the use of existing official data but is also able to point out, which data is missing in order to quantify and evaluate the bioeconomy with regard to the objectives formulated in the German Bioeconomy Strategy. Consequently, based on this and other existing definitions (COM, 1999; EC, 2012; BMEL, 2014; SEINTSCH, 2013) we developed and applied the following definition of bioeconomy: Bioeconomy includes the production of biomass, bio-based manufacturing along the complete value chains as well as bio-based provision of services, like transport or retail of bio-based products. "Bio-based" refers to products that fully or partially consist of renewable material resources, i.e. biomass. If partially, a minimum input of 10% of bio-based resources is required. The share of 10% was set as a result of review of the data in order to be operational. The use of bio-based products and product-related services encompasses food and feed, material,

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and energetic use. Stimuli for the German bioeconomy are expected especially from material and energetic uses (BMEL, 2014). Besides bio-based material flows, the generation of economic effects through the use of biomass also attributes an economic activity or product to the bioeconomy. On the contrary, durable means of production and capital goods that are necessary for provision of bio-based products are not considered.

Based on that definition, economic activities as classified by NACE Rev. 2 (NACE codes) were assigned to bioeconomy. This assignment is the most important step in operationalizing the bioeconomy definition as it connects bioeconomy definition and aims to available economic data provided by National Accounts. In order to make this assignment replicable we propose the following scheme:

During the assignment process we found it helpful to think along the lines of biomass production and processing and included all economic activities that in some way process or convert biomass. Based on this approach all divisions of NACE section A (agriculture, forestry and fishing) and parts of NACE sections C (manufacturing), D (electricity, gas, steam and air conditioning supply), F (construction) and N (accommodation and food services activities) are defined as biomass producing and processing sectors (Table 1). This "biomass processing" approach allows to consider important challenges of the bioeconomy: efficient and cascading use of resources, substitution of fossil material and energy resources, sustainable resource sourcing as well as the implementation of a circular economy (BIOÖKONOMIERAT, 2015; GAWEL et al., 2016). Possible indicators to be applied in measuring

the achievement of these objectives must refer to material flows and cannot be calculated using monetary information only. Thus, a determination of the material flows is required. This underlines our approach to define bioeconomy along material processing of biomass. We made one exception and partly included NACE sector M (Professional, scientific and technical activities) due to its proposed high relevance within bioeconomy (BMBF, 2018).

2.2 Bio-Based Shares of NACE Sectors

2.2.1 NACE Section C: Manufacturing

Bio-based shares for manufacturing were calculated based on **input** data provided by the Material and Goods received Enquiry (MGrE) and on **output** data from production statistics. For all economic activities of NACE section C (manufacturing), MGrE provides data on acquisition costs of all **inputs**, i.e. materials, consumables and energy that are used in the respective economic activities (STBA, 2017b). The survey is conducted every four years. The data set consists of a random sample of 18 000 companies having 20 or more employees. The randomly selected companies are by law obliged to disclose the information asked for. The MGrE is the only official survey covering the inputs structure of the different industries in Germany (EFKEN et al., 2016). Economic activities are classified according to NACE Rev 2 which corresponds to the German Classification of Economic Activities (WZ 2008). MGrE provides data for two hierarchical levels: divisions (2-digit level) and classes (4-digit level): we used data at the 4-digit level, which is less aggregated and thus provided a higher level of detail.

Inputs into economic activities as listed by MGrE are classified according to German production statistics (Güterverzeichnis für Produktionsstatistiken 2009, GP09), which is based on PRODCOM (Production Communautaire) (EC, 2018) but with a higher level of detail (StBA, 2009). Generally, the survey includes all companies assigned to NACE section C having 20 or more employees whose main business activities take place in Germany. Additionally, for seven economic activities, also companies having 10 or more employees are obliged to disclose their production output. Production statistics provide material and monetary indicators

Figure 1.   Definition scheme of bioeconomy
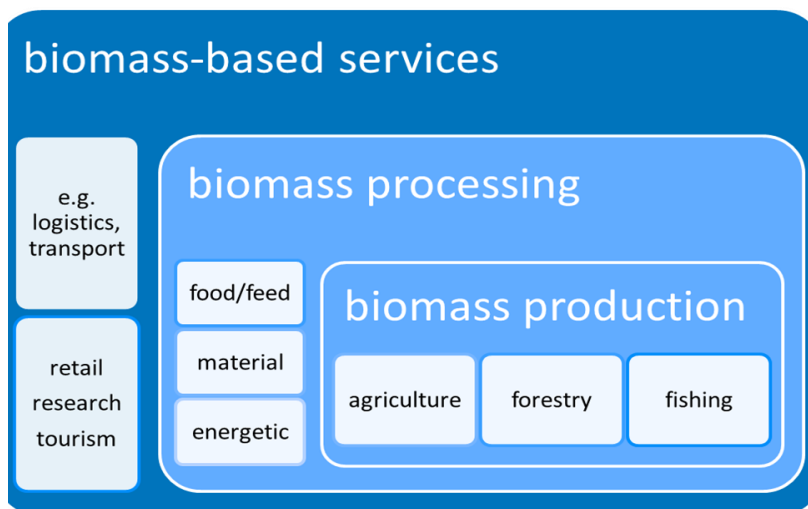
Source: own illustration

on products, i.e. the **output** of economic activities (SтBA, 2016b). Basically, products are identified by a 9-digit code (i.e. product code), which constitutes the lowest level of aggregation. However, MGrE does not cover inputs at the 9-digit level, but registers inputs on aggregation levels ranging from two to five digits.

Results of the MGrE 2014 were available by July 2017 (StBA, 2017b), i.e. with a 30-month delay. In the MGrE all received materials and goods are classified into defined categories: raw and auxiliary materials (I), consumables including packaging (II), fuels/combustibles/energy (III). Finally, the sum of all material and goods received is stated (category IV). Following the chosen approach based on material flows all inputs of category I have been classified either as fully, partially or non-bio-based. This classification was done manually by applying existing definitions (COM, 1999), further detail information on GP09 product codes (StBA, 2012) and additional literature research in order to decide, if the respective product contained renewable resources. If an input was considered partially bio-based, we used production statistics of 2014 for the least aggregated product level (9-digit "Güterart") and for the 4-digit level ("Güterklassen"). The production values of bio-based products (at 9-digit level) within a 4-digit-category were summed up and its percentage of the production value at the respective 4-digit level constituted the bio-based share (Eq. 1).

$$bbs = \frac{\sum_i pv9_i}{pv4} \tag{1}$$

bbs bio-based share of input

i number of bio-based products (at 9-digit level) of respective goods class (4 digits)

$pv9$ production value (at 9 digit level) of fully and/or partly bio-based products

$pv4$ total production value (at 4-digit level)

In many cases, the 9-digit code descriptions gave a good indication whether the product is bio-based or not. Furthermore, we used a subject index provided by the German authorities (SтBA, 2018a) to identify products aggregated in a respective 9-digit code. However, the GP09 does not classify products according to their resource base. Thus, many products could not unambiguously be classified as fully bio-based or non-bio-based. Furthermore, a lot of data is not available due to the non-disclosure policy of German official statistics. Therefore, we calculated minimum and maximum bio-based shares for each input (Eq. 2). Minimum was calculated as the sum of fully bio-

based products value. Maximum was derived from summing up fully and partially bio-based product values. If no data was available, we used bio-based percentages from other sources like empirical and market studies.

$$bbs_{min} = \frac{\sum_j pv9_j^{min}}{pv4}; \; bbs_{max} = \frac{\sum_k pv9_k^{max}}{pv4} \tag{2}$$

bbs_{min} minimum bio-based share of a product (at 9-digit-level)

j products (at 9-digit-level) with full bio-based products value

bbs_{max} maximum bio-based share of a product (at 9-digit-level)

k products (at 9-digit-level) with full or partial bio-based products value

As MGrE inputs are registered at different aggregation levels, bio-based inputs were further aggregated if necessary. Bio-based shares of each NACE code were calculated by weighing acquisition costs of each input by its bio-based share and summing up all inputs of the same NACE code (Eq. 3 and 4).

$$bbNACE_{min} = \frac{\sum_p ac\_input_p * bbs_{min}}{total\_inputs} \tag{3}$$

$bbNACE_{min}$ minimum bio-based share of economic activity as expressed by 4-digits NACE code

ac_input acquisition costs of inputs into economic activity in EUR (MGrE)

$total\_inputs$ total acquisition costs of economic activity in EUR (position 990 MGrE)

p inputs

$$bbNACE_{max} = \frac{\sum_p ac\_input_p * bbs_{max}}{total\_inputs} \tag{4}$$

$bbNACE_{max}$ maximum bio-based share of economic activity as expressed by 4-digits NACE code

Bio-based share of the economic indicators, number of jobs (a), gross added value at factor costs (b) and turnover (c) in manufacturing were calculated by multiplying minimum and maximum bio-based shares of NACE codes to a – c, both at 4-digit level:

$$bb_{ind\_min} = bbNACE_{min} * ind_q;$$
$$bb_{ind\_min} = bbNACE_{max} * ind_q \tag{5}$$

bb_{ind_min} minimum bio-based economic indicator a, b, c (4-digit level)

bb_{ind_max} maximum bio-based economic indicator a, b, c (4-digit level)

ind_q economic indicator a, b, c (4-digit level)

For each economic indicator we derived a minimum and a maximum level of bio-based values. In a last step, minimum and maximum bio-based values of economic indicators at 4-digit level were summed up for sector C (manufacturing). When calculating bio-

based turnover, gross added value and jobs, the same bio-based share is applied to each of these economic indicators. The underlying assumption of this approach is that all inputs equally contribute to employment, turnover and gross value added (Efken et al., 2012).

In order to apply the cut-off threshold given in our definition of bioeconomy, we repeated the calculation as described by Eq. (3) and the summing up of bio-based economic indicators and included only those NACE codes having a $bbNACE_i$ of at least 10%.

2.2.2 Other NACE Sections

Bio-based shares of other NACE sections apart from A and C also required a closer examination of data at a lower aggregation level, especially if they are to be assigned fully or partially to bioeconomy. These shares were derived from official data. Table 1 shows all economic activities included and the sources used to calculate shares.

Table 1.   NACE sections other than agriculture, forestry & fisheries and manufacturing attributed to bioeconomy

Section	Description	Bio-based share	Data source
D	Electricity, gas, steam and air conditioning supply	Use of biomass related to all energy sources	Official data from environmental accounting (StBA, 2018b)
F	Construction		
41.20.1 & 41.20.2	Construction of residential and non-residential buildings (except prefabricated constructions) & assembly and erection of prefabricated constructions	Wood construction share	Official data on construction permits (StBA, 2017a)
43.32.0 & 43.91.2	Joinery installation & erection of frames and constructional timber works	100%	(COM, 1999)
I	Accommodation and food service activities		
56.1 - 3	Food and beverage service activities	100%	Own assumption
M	Professional, scientific and technical activities		
72.11.0	Research and experimental development on biotechnology	100%	Own assumption
72.19.0	Other research and experimental development on natural sciences and engineering	Expenses for natural and agricultural sciences	Official data on public sector expenses (StBA, 2016a)

Source: own compilation

The bio-based share of section D was estimated as the energy equivalent of biomass used for the generation of electricity and heat in relation to energy equivalents of all energy sources. The respective data was provided by National Environmental Accounting (StBA, 2018b). Sub-classes 41.20.1 and 41.20.2 of section F (construction) refer to construction of buildings and both of them include construction using different materials. Official German statistics provide data on construction permits with respect to predominantly used building materials. An indicator for the amount of wood used for construction can be derived from total building volume of residential and non-residential buildings predominately built of wood as related to the total building volume of all buildings. For 43.32.0 and 43.91.2 of sector F we followed the German forestry and timber cluster definition (Seintsch, 2013) and included these economic activities completely. From sector I, we included only 56.1-56.3 in our calculations. From sector M, section 72.11.0 was included completely. For section 72.19.0 we used official data on public sector expenses (StBA, 2016a) to calculate the share of natural and agricultural sciences.

2.3   Economic Indicators

In order to quantify the economic relevance of the bioeconomy in Germany we chose the indicators gross value added at factor cost, turnover and number of jobs (see Eq. 4). These indicators are regularly quantified and published by official statistics according to standardized methods and therefore allow for comparisons across countries and over time. This selection follows other publications on bioeconomy quantification (Efken et al., 2016; Ronzon and M'barek, 2018).

We used EUROSTAT Structural Business statistics (SBS) (EUROSTAT, 2018b) that cover economic activities down to the most detailed activity level. SBS are collected by National Statistical Institutes and submitted to EUROSTAT annually. SBS integrate cost structure statistics and annual structure surveys, i.e. not only enterprises with more than 20 employees are covered. Annual structure surveys also cover enterprises with less than 20 employees (EUROSTAT, 2018b). Structural data for all economic activities that we assigned to the bioeconomy could be used, except for sector A. Here, we used national turnover tax statistics and National Accounting (StBA, 2014, 2018c, 2018d).

3 Results and Discussion

3.1 Sector C: Manufacturing

3.1.1 Bio-Based Shares of Inputs to Economic Activities

Table 2 lists all inputs into sector C (Manufacturing) as covered by the MGrE and their minimum and maximum bio-based shares as estimated from production statistics, i.e. output of economic activity. The index of inputs that is applied by MGrE uses GP09 and includes inputs from primary sectors. The presented shares relate to the monetary value of manufactured goods on the least aggregated level of the production statistics, but allow no conclusion towards actual amounts of material used for production. Bio-based shares of products that constitute material inputs into the economic activities of NACE sector C (Manufac-

turing) range from 0 to 100%. Differences between minimum and maximum bio-based shares of these inputs also range considerably. Large differences are the result of data gaps (undisclosed data) and the way products are classified in production statistics. Textile products for example, are often classified according to the type of fibre that was used, which allows deciding if a product is bio-based or not. For rubber products, we applied a general share of synthetic rubber of 60% (STATISTA, 2018), which resulted in smaller differences. For plastic and pharmaceutical products, sports goods and products from "other manufacturing" minimum and maximum estimates also differ considerably, indicating that the NACE classification is not suitable for differentiating between bio-based and non-bio-based materials, as classification units do not relate to the materials used.

Table 2. **Minimum and maximum bio-based shares of products used as material inputs in economic activities in manufacturing (sector C)**

GP09 code (MGrE)	Description	Bio-based share in %		Annotation
		min	max	
01, 02, 03	Crop and animal production, hunting; forestry and logging; fish and aquaculture products	100	100	
10, 11, 12	Food and feed; beverages; tobacco products	100	100	
13	Textiles	20.27	51.08	
131	Textile fibres	12.92	26.16	
13102	Natural fibres	100	100	
13103	Man-made fibres/filaments	30	30	(STATISTA, 2018)
13104	Silk yarn and yarn spun from silk waste	100	100	
13105	Yarn of wool put up or not put up for retail store; yarn of fine or coarse animal hair or of horse hair	100	100	
13106	Cotton yarn (other than sewing thread)	100	100	
13107	Yarn of flax or jute or of other textile bast fibres; yarn of other vegetable textile fibres; paper yarn	100	100	
13108	Yarn of man-made filaments	20	20	Man-made fibres are partly bio-based; estimated from 132/139
132	Woven textiles	21.52	37.52	
139	Other textiles (without knitted fabrics)	17.39	54.04	
14	Wearing apparel	19.34	72.30	
15	Leather and related products	47.36	47.36	
151	Leather and related products (without apparel and footwear)	27.49	100	No data, estimated from GP09-152
16	Wood, products of wood and cork (except furniture); articles of straw and plainting materials	100	100	
17	Paper and paperboard and its products	100	100	
18	Printed and reproduced recorded media	87	87[)]	
1812	Other printing	96	96	
1813	Pre-press and pre-media services	0	0	
20	Chemicals and chemical products	2.56	13.5	(VCI, 2017)
201	Basic chemicals, fertilisers and nitrogen compounds, plastics in primary forms and synthetic rubber in primary forms	3.73	6.18	
2011	Industrial gases	70.49	100	
2012	Dyes and pigments	1.51	1.51	
2013	Other inorganic basic chemicals	0.29	0.29	
2014	Other organic basic chemicals	1.64	5.76	
2015	Fertilisers and nitrogen compounds	2.33	2.33	
2016	Plastics in primary forms	2.34	2.34	
2017	Synthetic rubber in primary forms*	48.35	69.01	
202	Pesticides and other agrochemical products	0	0	
203	Paints, varnishes and similar coatings, printing ink and mastics	2.56	13.5	(VCI, 2017)

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Table 2. **Minimum and maximum bio-based shares of products used as material inputs in economic activities in manufacturing (sector C) (cont.)**

| GP09 code (MGrE)	Description	Bio-based share in %		Annotation
		min	max	
204	Soap and detergents, cleaning and polishing preparations; perfumes and toilet preparations	2.56	13.5	(VCI, 2017)
206	Man-made fibres	0	13.5	(VCI, 2017)
21	Basic pharmaceutical products and pharmaceutical preparations	8.73	31	higher bio-based percentage; further data undisclosed
211	Basic pharmaceutical products	7.67	40.0	
212	Basic pharmaceutical preparations	8.95	30.75	
22	Rubber and plastic products	7.87	39.42	
221	Rubber products	36.57	40.0	
2211	Rubber tyres and tubes; retreading and rebuilding of rubber tyres	32.56	40.0	
2219	Other rubber products	38.31	40.0	
222	Plastic products	1.63	40.84 [7]	(IFBB, 2016)
2221	Plastic plates, sheets, tubes and profiles	3.99	23.50 [7]	(IFBB, 2016)
2222	Plastic packing goods	0.00	47.59 [7]	(IFBB, 2016)
2223	Builders' ware of plastic	0.00	65.85 [7]	(IFBB, 2016)
2229	Other plastic products	0.63	46.53 [7]	(IFBB, 2016)
31	Furniture	66	71	
32	Other manufacturing	1	6	
321	Coins, jewellery and related articles	0	0	
322	Musical instruments	55.60	75.79	
323	Sports goods	0	79.40	
324	Games and toys	0	9.58	
325	Medical and dental instruments and supplies	0	0	
329	Other manufacturing	1.78	24.94	
3299	Other manufacturing n.e.c.	2.35	19.81	
32992	Umbrellas and sun umbrellas: walking-sticks, seat-sticks, whips and the like	0	0	
32995	Other manufacturing n.e.c.	0	0	

(n.e.c. – not elsewhere classified; *includes products containing natural rubber and vegetable oils)
Source: own calculations; if bio-based share could not be calculated due to missing data, other sources were used (see Annotations)

3.1.2 Bio-Based Shares of Economic Activities in Manufacturing

Figure 2 shows the distribution of minimum and maximum bio-based shares of economic activities (4-digit level) that belong to NACE sections displayed at the x-axis. For better clarity, sections with less than 10% bio-based inputs on the 4-digit level, were excluded, according to our definition of bioeconomy. The number of aggregated subsections ranges from 2 to 31, depending on how many subsections were covered by the MGrE. For example, for section 16 (wood and product of wood and cork, except furniture) bio-base shares of six economic activities (4-digit level) ranged from 26% (1629: manufacture of other products of wood) to 91% (1610: sawmilling and planning of wood). The resulting median bio-based share of the section is estimated between 63 and 65%. Traditionally, section 16 and all its subsections are considered to be 100% bio-based (COM, 1999; SEINTSCH, 2013; BÖSCH et al., 2015). However, our results do not reflect this assumption. One explanation lies in the method we used: bio-based shares were calculated as a ratio of bio-based **material** inputs value to **total** inputs received as surveyed by MGrE. Material inputs constitute between 42 and 98% of the total value of all received materials, goods, consumables and energy. Second, the composition of inputs into a certain economic activity: e.g. material inputs into 1610 involve, besides round wood also chemical, plastic and metallic products (STBA, 2017b, see table "Table2.1 WZ 4-Steller"). Consequently, even economic activities that have been evaluated as "fully bio-based" by other authors (EFKEN et al., 2012; EFKEN et al., 2016; PIOTROWSKI et al., 2016) might receive non-bio-based inputs. The presented bio-based shares of economic activities (see Figure 2) have to be put in context of missing data and the MGrE position "other material input". High respective shares of total material inputs received would lead to an underestimation of bio-based shares as it cannot be determined if "other material input" might also be bio-based. However, shares of "other material input" of total material input ranged between 0 and 3.3% only. We, therefore, consider the calculated results to be consistent.

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Figure 2. **Distribution of bio-based shares of relevant NACE sectors at 4-digit-level**
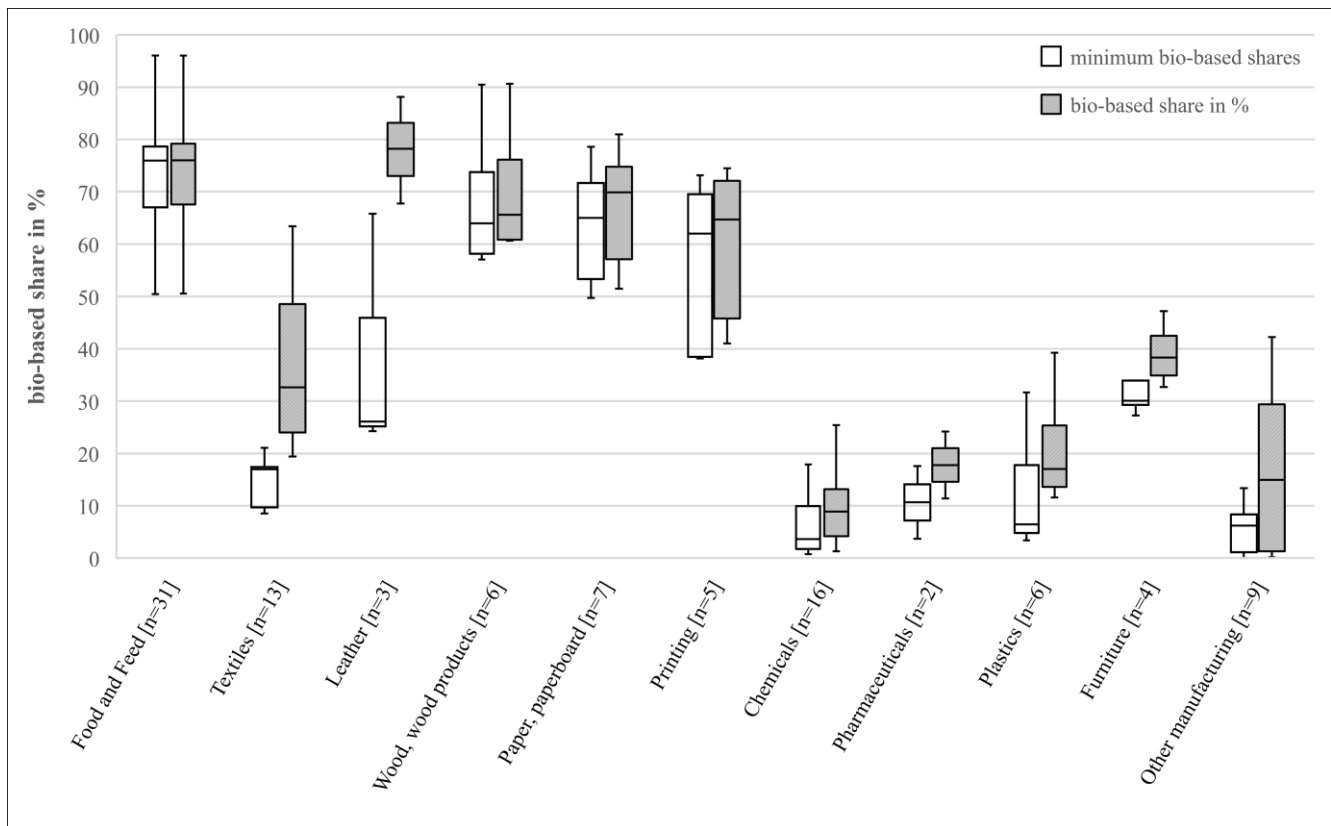
Source: own calculations: n refers to the number of subsections included, see chapter 3.1.2

The MGrE categories "consumables including packaging and fuels/combustibles/energy" may also have bio-based inputs, e.g. packaging involves paper and cardboard and the energy used for manufacturing, which might also be partially bio-based. In order to give a more detailed estimate of bio-based shares of economic activities covered by the MGrE, general bio-based shares of packaging and energy use should be applied. As MGrE does not differentiate these categories further for the different economic activities, the resulting share would be the same for every economic activity, which is not considered to give a realistic estimation. Thus, bio-based shares of economic activities refer to material inputs only.

Wide boxes and whiskers in Figure 2 indicate high variations of bio-based shares of subsections (4-digit level) within a 2-digit NACE-section. This is the case for the majority of sections included in our analysis. Chemicals, pharmaceuticals and furniture show the smallest variation of bio-based shares. Large differences between minimum and maximum indicate that the bio-based shares of the material inputs into the respective economic activities cannot

be estimated unambiguously. This is particularly true for textiles (13, 14) and leather products (15). Even though a lot of product codes can be fully considered as bio-based (e.g. GP09-1310 25 000: cotton, carded or combed), a considerable number of other product codes describe only partially bio-based activities. Large differences in estimated minimum and maximum shares can also be explained by comparatively high production values of these activities. Leather does not only involve pure leather itself (1511), but also luggage, handbags and the like (1512) as well as footwear (1520), that use considerable shares of non-bio-based materials like chemicals, plastics, metals (STBA, 2017b, see table "Table2.1 WZ 4-Steller").

Highest bio-based shares occur in food and feed (including beverages and tobacco: NACE 10, 11 and 12). For this section the differences between minimum and maximum bio-based shares are smallest, as the inputs into these economic activities are largely from the primary sector and thus 100% bio-based. For only a few inputs, like chemicals, minimum and maximum shares differed.

Table 3. **Range of bio-based employment, gross value added and turnover in sector C (manufacturing)**

	Jobs	Gross added value (factor costs)	Turnover
	mill.	bill. EUR	bill. EUR
Min (no cut-off)	1.091	53.471	243.77
Max (no cut-off)	1.283	66.819	289.15
Min 10%	1.012	47.227	220.79
Max 10%	1.067	50.309	231.87

Source: own calculations

3.1.3 Economic Indicators

In section C (Manufacturing), bio-based employment ranges between 1.09 and 1.3 million jobs. Gross added value at factor costs is estimated at a range between 53.5 and 66.8 bill. EUR and about 244 to 289 bill. EUR turnover can be assigned to the German bio-economy (Table 3). According to our definition of bioeconomy (see 2.1), we applied a cut-off threshold and excluded all economic activities with less than 10% bio-based input at 4-digit level. Applying the cut-off has a strong impact on the estimated bioeconomy indicators of manufacturing: bio-based employment is reduced by about 80,000 to 215,000 jobs, gross added value by 6 to 16 billion EUR and turnover by 23 to 57 billion EUR. Excluding all inputs with a bio-based share less than 10% results in a reduction of estimated bio-based employment of 8-17%, a decline in gross added value of 12-25% and a decrease in turnover of 10 to 20%.

The applied 10% cut-off was initially specified in order to have an operational basis for data analysis. A cut-off is supposed to allow neglecting minor biomass flows, especially if these cannot be quantified reliably. The large impact of the chosen cut-off leads to the conclusion that the application of 10% might lead to an underestimation of the bioeconomy. Consequently, smaller cut-off percentages should be tested and possibly applied in order to define a more specific cut-off that includes relevant biomass flows but excludes biomass flows of lesser importance with respect to the applied indicators. Specifying a possible cut-off must take into consideration that small biomass flows may generate high turnover and value added and vice versa.

3.2 Other Sectors

Bio-based shares of other sectors covered in our analysis ranged from 9.1 to 100% (Table 4). With regard to jobs and gross value added, food and beverage service activities constitute the most relevant economic activities. One may argue, that these sections are strongly service based and therefore should not be assigned to bioeconomy. However, these services are characterized by the processing of agricultural products, analogous to NACE section 10, 11 and 12, and they would not exists without biomass inputs. Thus, they fit into our definition of bioeconomy. Consequently, we included these economic activities in our estimate. It might be debatable, if these activities should be fully included into a bioeconomy estimate, as to our

Table 4. **Bio-based jobs, gross value added and turnover of sectors D, F, I and M**

Code	Description	Bio-based share	Jobs	Gross value added	Turnover
		%	number	mill. EUR	mill. EUR
D 35.1/3	Electric power generation, transmission and distribution	9.1	18,478	3,153	4,439
D 35.2	Manufacture of gas; distribution of gaseous fuels through mains	94.3	13,373	3,806	51,321
D 35.3	Steam and air conditioning supply	9.1	992	162	605
F 41.20	Construction of residential and non-residential buildings (except prefabricated constructions) & assembly and erection of prefabricated constructions	7.81	21,779	1,012	3,316
F 43.32.0	Joinery installation	100	146,429	4,287	11,332
F 43.91.2	Erection of frames and constructional timber works	100	186,886	7,792	18,389
I 56.1 - 3	Food and beverage service activities	100	1,542,445	23,036	51,013
M 72.11.0	Research and experimental development on biotechnology	100	12,454	740	1,248
M 72.19.0	Other research and experimental development on natural sciences and engineering	57.3	82,849	4,946	6,857

Source: own calculations

knowledge it has not yet been studied to what extent material inputs other than biomass from agricultural production go into food and beverage service activities. MGrE does not cover these sections and other official statistics are not available. Still, from a material input point of view, we consider these sections very important for the bioeconomy. EFKEN et al. (2016) also fully included these sections in their estimation of bioeconomy as reliable data of the bio-based was missing. Furthermore, BROSOWSKI et al. (2016) define biomass residue streams like "biodegradable waste from kitchens and canteens", "commercial food waste (not waste management)" and "used cooking oil from municipal waste", that are at least in part generated by food and beverage service activities. Contrary to our definition, AARNE and HAUTAKANGAS (2018) included food and beverage service activities with a bio-based share of 25%. However, this share also is an estimation based on the expertise of the Natural Resources Institute Finland (LUKE). The construction sector provides about 355,000 bio-based jobs and generates about 13 billion EUR bio-based gross added value. The energetic use of biomass also considerably contributes to the German bioeconomy: about 33,000 jobs are bio-based and a gross added value of about 7 billion is generated.

Table 5.   Range of bio-based employment, gross value added and turnover in all sectors

	Jobs	Gross added value (factor costs)	Turnover
	number	bill. EUR	bill. EUR
Min (no cut-off)	3.766	122.63	474.80
Max (no cut-off)	3.958	135.98	520.16
Min 10%	3.687	116.39	451.82
Max 10%	3.742	119.47	462.90

Source: own calculations

3.3 Total Size of the Bioeconomy

In total, between 3.77-3.96 mill. jobs can be assigned to the German bioeconomy. This relates to a gross added value at factor costs between 123-135 bill. EUR and a turnover that ranges between 475-520 bill. EUR. If a 10% cut-off is applied, the numbers are reduced to 3.69-3.74 mill. jobs (2-5% less), a gross added value between 116 and 119 bill. EUR (5-13 % less) and a turnover between 452 and 463 bill. EUR (5-12% less), respectively.

Our results differ considerably from former estimates of the German bioeconomy. EFKEN et al. (2012) attributed about 5 mill. jobs, 165 bill. EUR

gross value added to bioeconomy in 2007. For 2010 EFKEN et al. (2016) considered slightly more jobs (5.1 mill.) but less gross added value (140 bill. EUR) to be generated by bio-based economic activities as compared to 2007. These differences are partially explained by the revision of NACE classification. For 2007 EFKEN et al. (2012) used the German classification of economic activities edition 2003 (WZ 2003), which was based on NACE Rev. 1.1. EFKEN et al. (2016) used NACE Rev. 2 and WZ 2008. Compared to WZ 2003 the structure of WZ 2008 was changed considerably. The coverage of economic activities was extended and economic activities were aggregated or, in other cases, split. Furthermore, differences can be explained by a different definition of bioeconomy. EFKEN et al. (2012) and EFKEN et al. (2016) also included certain services as economically important for bioeconomy, like grocery retail. Our approach, however, covers economic activities that are directly related to the material flow of agricultural, forestry and fish-based biomass. These different approach explain differences in results. EFKEN et al. (2012) applied different approaches for agricultural and forest biomass and determined bio-based shares of inputs into economic activities (according to MGrE) differently. In our approach, the bio-based shares of all inputs, independently of biomass origin, were determined applying a consistent methodology using production statistics. Thus, the derivation of bio-based shares of inputs and of economic activities is consistent and can be replicated which constitutes an important element of a future bioeconomy monitoring in Germany. A strong advantage of our approach is the determination of bio-based shares of products on the most detailed level of classification (9-digit level = product code). Changes in the material use of biomass can be detected more easily and derivation of bio-based shares becomes therefore more transparent than in existing studies.

Recent studies at EU level estimate German bio-based employment up to 1.92 million jobs and bio-based turnover up to 396 bill. EUR (JRC, 2018). This ranges considerably below our estimations. One reason is the application of a different definition of bioeconomy in the EU estimations. Economic activities like, printing, construction, food and beverage service activities and biotechnology research were excluded. Furthermore, bio-based shares were based on experts' knowledge or estimates. However, the underlying classification also was NACE Rev. 2 and they also used EUROSTAT structural business statistics data for their estimations (JRC, 2018).

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4 Conclusion and Recommendations

Existing estimations of the size of bioeconomy differ considerably. Main reasons are different definitions of the term "bioeconomy" and which economic activities should be included in the quantification, based on the chosen definition. For future bioeconomy monitoring standards and estimation of comparable results, the development of a generally accepted and operational definition is of major importance. This includes the question if all partially bio-based economic activities and products should be included and, if not, which cut-off percentage should be applied. Concluding from the large impact of a 10% cut-off, the impact of smaller percentages should be discussed and tested on the available data.

Another reason for deviant bioeconomy estimates is the derivation method for bio-based shares of economic activities. Up to now, mostly expert estimates, often without transparent referencing of sources, have been used or derivation of bio-based shares was not explained sufficiently. In terms of transparency and replicability an approach mainly based on expert knowledge and opinion approach is not sufficient for a future bioeconomy monitoring at national or European level. In this article, we determined bio-based shares by classifying products on the least aggregated level of production statistics as bio-based and then weighing their production value. In the case of missing data, we used secondary statistics or empirical data. However, even as our approach is more transparent than approaches based on expert's opinion alone, the classification of product as bio-based is not completely unambiguous and depends on data and literature availability. We draw the conclusion that a future bioeconomy monitoring must include constant market observation and consultation of experts in order to take developments and innovations regarding material uses of renewable resources into account. This is especially true for so-called drop-in solutions, were product characteristics remain the same but fossil resources in the production process are substituted by renewable ones. So, expert opinions and their estimates are an important source of information but in our opinion should be communicated transparently and combined with available official data and economic classifications.

Internationally and EU-wide harmonized economic classifications constitute the basis for a future bioeconomy monitoring. These classifications have been developed and updated to reflect present international and national economic reality. Apart from primary production and traditional uses of agricultural, forest and fish resources, economic activities are still predominantly based on fossil resources. Consequently, classifications are not designed to differentiate between the uses of fossil- and bio-based resources. This becomes even more relevant the more bio-based resources are processed to produce end products. As economic activities and products become increasingly bio-based, classifications should be updated in order to reflect this transition and to include evolving new, innovative technologies and the respective products in statistical accounts as soon as they gain momentum in real-life economy. Understanding that such updates need considerable effort, we suggest using the outcomes of the article to prioritize economic activities and products, as defined in existing classifications like NACE, PRODCOM, and also the Combined Nomenclature for traded goods, for updating. High ranges of bio-based shares indicate highest uncertainties with respect to the use of bio-based resources. In our study, plastic products are characterised by highly uncertain bio-based shares, but as SCARLAT et al. (2015) point out, a significant expansion of bio-based plastics is under way. If uncertainties in these and other products could be reduced by updating classifications, overall bioeconomy estimates could efficiently be improved. PRODCOM and Combined Nomenclature are annually updated (EUROSTAT, 2018a). Future update could include the consideration, if products are bio-based or not. An alternative approach to reduce uncertainty is the complementation of existing statistical questionnaire that enterprises are obliged to answer. The declaration of the bio-based share of each reported product code would allow for the calculation of bio-based shares of higher aggregated classification units and, eventually, of the total bioeconomy.

Further aspects of data quality, and as such a general drawback of our calculation approach, are cut-off thresholds applied by official statistics. Often, statistics do not cover small and medium enterprises (SME) and thus do not provide the full picture of economic activities. Besides the possible quantitative underestimation (e.g. JOCHEM et al., 2015), in the transition process from fossil- to bio-based, SME may also be of high importance due to their innovative capacity (HANSEN, 2016). Especially the categories of innovative and digital entrepreneurs having a high affinity to new technologies, are prone to disrupt established markets or to create new markets and conse-

quently push structural change (KFW RESEARCH, 2018). Even though, it is still discussed in literature what type of innovation prevail in SMEs as compared to large firms (OKE et al., 2007; BJERKE and JOHANSSON, 2015; HERVAS-OLIVER et al., 2016), they are an important part of the economy and must not be excluded from estimations. However, several aspects of how SME and bioeconomy relate to each other go beyond the scope of this article but need clarification and should be object of further research: what official data on SME is available on a regular basis, how can SME efficiently be included in statistical or empirical surveys and how are SME distributed across economic activities?

The transition from a fossil-based to a bio-based economy is characterized by path dependencies and lock-in effects (PANNICKE et al., 2015). The authors point out, that currently the dominant bioeconomy policy approach regarding innovations and new technologies is financial support of research and development. However, the authors also argue, that complementary policies should directly support niche formation in the bioeconomy and "reduce the use of fossil resources". In that sense, in a future bioeconomy monitoring, policy tools with regard to bioeconomy should also be monitored as they could hint towards innovations and the development of new technologies.

As described by EFKEN et al. (2012), in Germany firms are assigned to economic activities according to the activity within the firm that generates the highest share of added value. Consequently, a certain part of firm economic activity is falsely attributed to bioeconomy or falsely omitted. Up to now, it cannot be determined if this causes an over- or underestimation of bioeconomy. Last but not least, if data firms are reporting to National Statistics allow inferences on individual firms, they are not disclosed in the statistics. The resulting data gaps enhance the uncertainty of bioeconomy estimates. We suggest that for scientific and monitoring purposes existing data should be made available under strict obligations. Another methodological aspect that needs further consideration is the assumption, that all inputs of the same economic activity equally contribute to employment, turnover and gross value added. We calculated bio-based shares using monetary data. Consequently, size of material flows cannot be deduced from these shares. We suggest two general alternatives in order to be able to calculate material flows from official statistics: either official statistics need to be extended to consistent reporting of material and not only monetary in- and output, or the establishment of official and con-

sistent prize indices of relevant materials. The second alternative would also require a continuous monitoring of product properties and the respective shares of renewable and bio-based materials that are used in production.

In the presented study, we estimated the size of German bioeconomy using economic indicators under the assumption that "all inputs equally contribute to employment, turnover and gross value added" (Chapter 2.2.1). This approach may of course lead to over- or underestimation as the use of renewable resources might contribute differently to the chosen indicators depending on the economic activity or sector. Also, it may neglect possible substitution effects and the fact that some economic activities are more labour- and/or capital-intensive than others. However, similar methodology for example is used in in Life Cycle Assessments (LCA) for the allocation of ecological indicators (WEIDEMA and SCHMIDT, 2010; WEIDEMA, 2014). Furthermore, up to date, the major part of official statistics refers to monetary indicators alone. Other data that could help to develop more realistic calculation approaches are missing. From our point of view, quantification of biomass flows could help solving this problem. Inputs into economic activities in form of material amounts instead of acquisition costs as covered by the MGrE in its current form, would allow for a better understanding of the contribution of resources to economic indicators of the respective economic activities. Also, information on biomass flows is needed to evaluate not only economic, but also social and environmental sustainability aspects of the bioeconomy. In order to assess objectives of the German bioeconomy, like resource efficiency, cascade use, recycling and sustainable production and processing of biomass, reliable estimates of how much biomass is used are needed. Unfortunately, such information is only partially provided by official statistics. MGrE already provides an excellent basis by surveying the production value of inputs into economic activities. We suggest to further developing the standards of the MGrE by additionally surveying amounts of these inputs. In order to better estimate bio-based shares of economic activities, inputs should be surveyed at a less aggregated level.

With our study we aim to lay the foundation for defining the "buzzword" bioeconomy (STAFFAS et al., 2013) in order to establish an operational understanding of the term which we consider necessary to be able to quantify bio-based economies and, in a second step, to quantify and evaluate sustainability comprehensively.

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