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Full Research Article

A systematic approach to understanding and quantifying the EU's bioeconomy

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Abstract. In 2014, approximately 18.6 million people in the European Union (EU) were employed in the bioeconomy, generating annual turnover of around EUR 2.2 trillion. And over the period 2008-2014, almost all sectors of the bioeconomy in the EU experienced labour productivity gains (in terms of turnover per person employed). Agriculture and the manufacture of food, beverages and tobacco accounted for three quarters of the jobs and two thirds of the turnover of the European bioeconomy, while, among different sectors, the highest levels of labour productivity were achieved in the manufacture of bio-based chemicals, pharmaceuticals, plastics and rubber, as well as the production of bioelectricity. This EU bioeconomy overview has been compiled after estimating (using Comext codes) the bio-based content of hundreds of products produced and manufactured in the bioeconomy sectors. Using official statistics, such quantification is easy to replicate and update. It also allows us to highlight similarities and diversities in national bioeconomy patterns within the EU, and to discuss how analysis can support the development of bioeconomy strategies in EU Member States.

Keywords. Bioeconomy, Europe, jobs, turnover, statistics

JEL codes. Q57

1. Introduction

'The Europe 2020 Strategy calls for a bioeconomy as a key element for smart and green growth in Europe' (European Commission, 2012). Monitoring the bioeconomy, a strategic sector in the European Union (EU), presents several challenges (M'barek *et al.*, 2014). In particular, it should address the complex task of dealing with a multisectorial and fast-evolving sector (e.g. the emerging bio-based industries). The European Commission (EC) defines the bioeconomy as encompassing 'the production of renewable biological resources and the conversion of these resources and waste streams into value added

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products, such as food, feed, bio-based products and bioenergy'; the bioeconomy is operated by 'the sectors of agriculture, forestry, fisheries, food and pulp and paper production, as well as parts of chemical, biotechnological and energy industries'. The document presenting the EU's bioeconomy strategy also highlights the social and economic importance of the bioeconomy sectors, which 'are worth EUR 2 trillion in annual turnover and account for more than 22 million jobs and approximately 9 % of the workforce' (EC, 2012).

Based on the EC's definition, the present study defines a methodology for the quantification of the two aforementioned bioeconomy indicators: turnover and number of persons employed (see section 2). Designed to provide bioeconomy monitoring indicators, the methodology has to cope with specific constraints, which are to be transparent and replicable, while providing updatable time series data harmonised across the 28 Member States of the European Union (EU-28). Hence, for the sake of transparency and replicability, this methodology relies on official statistics as a data source, addressing the major challenge of estimating the bio-based part (as opposed to the fossil-based part) of mixed sectors or products. The results of the study are presented in section 3, illustrating the sectorial performances and trends of the European bioeconomy (section 3.1) and the diversity of the bioeconomies at EU Member State level (section 3.2). In section 4, we discuss the caveats of the approach and we propose some steps forwards. Finally, section 5 concludes illustrating how the indicators could be used to support the development of bioeconomic strategies in EU Member States.

2. Methodology

2.1 Defining the scope of the bioeconomy

As a first step, we propose a match between the official definition of the bioeconomy given in EC communication COM(2012) 60 and the latest European classification of activity sectors, i.e. the second revision of the 'Statistical Classification of Economic Activities in the European Community' (NACE Rev. 2) (Eurostat, 2008). Defining the bioeconomy as encompassing the production and manufacture of biomass, 16 NACE sectors can be considered to belong, fully or partially, to the bioeconomy.

- The production of biomass is covered by section A of NACE Rev. 2, comprising the agricultural (A01), forestry (A02) and fishing (A03) sectors.
- The manufacture of biomass is the result of 12 downstream activity sectors listed in section C.

  Six of these exclusively use biomass as a feedstock, in the manufacture of food products (C10), beverages (C11), tobacco products (C12), leather and leather products (C15), wood and products of wood and cork (16) and paper and paper products (C17).

  The other six make use either of biomass feedstock or of carbon fossil-based feedstock. Since official statistics do not distinguish the manufacture of biomass from the manufacture of other kinds of feedstock, it is necessary to estimate their 'bio-based share' (see section 2.3). Those six sectors are the manufacture of textiles (C13), of wearing apparel (C14), chemicals and chemical products (C20), basic pharmaceutical products

and pharmaceutical preparations (C21), rubber and plastic products (C22) and furniture (C31).

- Finally, section D of NACE Rev. 2 comprises the production of electricity (D3511), from which the production of bio-based electricity is estimated.

The NACE Rev. 2 divisions presented in Table 1 (two-digit) are broken down at NACE Rev. 2 classes (four-digit), providing a more detailed description of the activity sectors constituting the bioeconomy. Furthermore, tables of convergence have been established to link NACE sectors with other classifications by product (e.g. the Classification of Products by Activity (CPA) (EC, 2008) and the Combined Nomenclature (CN) used by Eurostat in trade statistics (EC, 2015a)). Hence, the NACE-based definition proposed here is also compatible with a product-based definition of the bioeconomy, and with the use of other indicators measured at product level (e.g. the trade of bio-based products).

2.2 Data sources

Relying on Eurostat data as a basis for calculation of jobs and turnover in the European bioeconomy is justified by the fact that Eurostat data already comply with our criteria of being regularly updated, available as time series and harmonised across Member States. In particular, the Structural Business Statistics from Eurostat report on the two indicators put forward in COM(2012) 60 – number of people employed and turnover – for the manufacturing sectors (12 sectors out of the 16 bioeconomic sectors listed in sub-section 2.1) and the production of electricity.

The Structural Business Statistics are complemented in this study by other data sources reporting on the primary sectors (i.e. the biomass-producing sectors). Employment data are retrieved from Eurostat's Labour Force Surveys (lfsa_egan22d for the agricultural sector and for_emp_lfs for the forestry sector) and Economic Accounts (aact_eaa01 for the agricultural sector and for_eco_cp for the forestry sector). Since there are no economic accounts for the fishing sector (A03) among Eurostat databases, we used the annual reports of the Scientific, Technical and Economic Committee for Fisheries (STECF) as an alternative source. Fishing related data are released by the STECF in two different documents: (i) aquaculture data are compiled in the report on 'the economic performance of the EU Aquaculture Sector' (STECF, 2014) while (ii) landings data are released in the 'Annual Economic Report on the EU Fishing Fleet' (STECF, 2016).

The data sources and indicators serving as a basis for calculation in this study are listed in Table 1 (see also Eurostat (2016)).

2.3 Estimating the bio-based share by sector of the bioeconomy

As mentioned in section 2.1, nine bioeconomic sectors out of the 16 constituting the bioeconomy are fully bio-based, either because they produce biomass (sectors A01, A02 and A03) or because they exclusively use biomass as a feedstock (sectors C10, C11, C12, C15, C16 and C17). The remaining seven transform biomass among other feedstock (C13, C14, C20, C21, C22, C31 and C3511). Quantifying their contribution to the bioeconomy entails estimating the extent to which they are bio-based (i.e. their bio-based share).

Table 1. Activity sectors covered in this study, with data sources and indicators used.

Sector	NACE code	Data source (code)	Indicator used Label (code)
Agriculture	A01	EUROSTAT – Labour Force Survey (lfsa_egan22d) EUROSTAT - Economic accounts for agriculture (aact_eaa01)	Employment (-) Agricultural goods output (14000), production value at basic prices (PROD_BP)
Forestry	A02	EUROSTAT - Forestry Employment (for_emp_lfs) EUROSTAT - Forestry economic accounts (for_eco_cp)	Employed persons (EMP) Output (P1_TOT)
Fisheries	A03	STECF 2014 STECF 2016	Employees (-) Turnover (TUR) Total employed (totjob) Landings income (totlandinc)
Manufacture of…			
…food products	C10	EUROSTAT - Structural Business Statistic (sbs_na_ind_r2)	Turnover (V12110) Number of persons employed (V16110)
…beverages	C11		
…tobacco products	C12		
…textiles*	C13		
…wearing apparel*	C14		
…leather and leather products	C15		
…wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	C16		
…furniture*	C31		
…paper and paper products	C17		
…chemicals and chemical products (excl. liquid biofuels)*	C20		
…basic pharmaceutical products and pharmaceutical preparations*	C21		
…rubber and plastic products*	C22		
…other organic basic chemicals* (o.w. bioethanol)	C2014		
…other chemical products* n.e.c (o.w. biodiesel)	C2059		
Production of electricity*	D3511	EUROSTAT - Structural Business Statistic (sbs_na_ind_r2)	Turnover (V12110) Number of persons employed (V16110)

*Partly bio-based sectors. A bio-based share has been applied to the original data to estimate the contribution of this sector to the bioeconomy.

Data on sectorial bio-based shares (e.g. the bio-based share of the manufacture of chemicals and chemical products, NACE C20) are currently unavailable, and are extreme-

ly difficult to determine. We propose to infer them from the relative value of bio-based products manufactured by a sector, relative to the total value generated by this sector:

$$\mathrm{BBS}_{i,k,l} = \frac{\sum_{j=1}^{n} \mathrm{bbs}_j \text{ x } \mathrm{Turnover}_{j,k,l}}{\sum_{j=1}^{n} \mathrm{Turnover}_{j,k,l}} \tag{1a}$$

where:

- $\mathrm{BBS}_{i,k,l}$ is the bio-based share of sector i (NACE Rev. 2), in EU Member State k and for year l;
- bbs_j is the bio-based share of product j, given that sector i manufactures $j = n$ products. Bio-based shares vary from 0 for products that do not embed biomass (e.g. Prodcom code 20.12.23.30, Synthetic organic tanning substances) to 1 for those that are made entirely of biomass (e.g. Prodcom code 20.12.22.50, Tanning extracts of vegetable origin);
- $\mathrm{Turnover}_{j,k,l}$ is the turnover of product j, in EU Member State k and for year l.

Before attributing a bio-based share to bio-based products, this approach requires all products manufactured by a given sector to be listed (i.e. n products manufactured by sector i). The more disaggregated the list, the easier it is for experts to estimate the proportion of any particular product that is bio-based. For this reason, we used the Combined Nomenclature (CN, 2015), which is the most detailed product list in use in European official statistics. Correspondence tables allowed us to match the bioeconomic sectors defined in the NACE Rev. 2 classification with the corresponding products in the CN 2015 nomenclature[1]. For this study, the bio-based shares of the bio-based products listed in the CN (eight-digit) nomenclature have been determined by around 15 experts from various European countries, who were interviewed by the nova-Institute between April 2015 and summer 2016. The experts came from various sectors of the bio-based economy, from companies and industrial associations including the chemicals industry (drop-ins, biotechnology, oleochemistry, organic acids, surfactants, paints, etc.) and the wood industry. Other shares were estimated by experts from the nova-Institute.

The CN nomenclature is used in the Eurostat-Comext database, which reports only on trade indicators. Hence, we applied the products' bio-based shares (bbs_j) to export data by value, in order to calculate sectorial bio-based share (BBS_i). Indeed, we consider that exports represent the domestic product mix better than imports do. In summary, sectorial bio-based shares ($\mathrm{BBS}_{i,k,l}$; see equation 1a) were approximated as follows:

$$\mathrm{BBS}_{i,k,l} = \frac{\sum_{j=1}^{n} \mathrm{bbs}_j \text{ x } \mathrm{Export}_{j,k,l}}{\sum_{j=1}^{n} \mathrm{Export}_{j,k,l}} \tag{1b}$$

[1] In reality, the correspondence is not direct. A first correspondence was obtained between the NACE Rev. 2 classification of activities (four-digit level) and the Prodcom list of products (eight-digit level), before using the correspondence table Prodom 2015-CN 2015. Note that the Prodcom metadata warns: 'Prodcom statistics relate to products (not to activities) and are therefore not strictly comparable with activity-based statistics such as Structural Business Statistics'.

where $\text{Export}_{j,k,l}$ is the value of the exports of product j, by EU Member State k and for year l.

2.4 Estimates of the number of persons employed, turnover and location quotient

For EU Member State k and for year l, the number of people employed in sector i and the turnover of sector i are calculated as:

$$\text{Number of people employed}_{i,k,l} = \text{BBS}_{i,k,l} \cdot \text{Number of people employed}_{i,k,l} \tag{2}$$

and

$$\text{Turnover}_{i,k,l} = \text{BBS}_{i,k,l} \; x \; \text{Turnover}_{i,k,l} \tag{3}$$

Note that, from a methodological point of view, the calculation of turnover per person in partly bio-based sectors reflects the performance of the sector as a whole (i.e. including the non-bio-based part):

$$\text{Turnover per person employed}_{i,k,l} = \frac{\text{BBS}_{i,k,l} \; x \; \text{Turnover}_{i,k,l}}{\text{BBS}_{i,k,l} \; x \; \text{Number of people employed}_{i,k,l}}$$

$$= \frac{\text{Turnover}_{i,k,l}}{\text{Number of people employed}_{i,k,l}}$$

Thus, in place of the turnover per person of a bio-based sector, we have reported the turnover per person employed in mixed sectors (bio-based and non-bio-based parts) in section 3, as the only point of reference we could obtain for those sectors.

In addition, as proposed by Golden *et al.* (2015) for the USA, the location quotient of the bioeconomy was estimated at Member State and EU-28 level. The location quotient is the indicator usually used to measure how 'concentrated' a sector is in a Member State compared with the European Union overall, i.e. the share of Member States' employment in the bioeconomy (or in a given sector of the bioeconomy) divided by the EU employment share in the bioeconomy (or in the same given sector):

$$\text{LQ}_{i,k,l} = \frac{\text{\% people employed}_{i,k,l}}{\text{\% people employed}_{i,EU28,l}} \tag{4}$$

where:

- $\text{LQ}_{i,k,l}$ is the location quotient of sector i (NACE Rev. 2), in EU Member State k and for year l;
- $\text{\% people employed}_{i,k,l}$ is the proportion of people employed in sector i (the bioeconomy or a NACE Rev. 2 sector), in EU Member State k and for year l; and
- and $\text{\% people employed}_{i,EU\text{-}28,l}$ is the proportion of people employed in sector i (the bioeconomy or a NACE Rev. 2 sector), in the EU-28 and for year l.

If $LQ_{i,k,l} > 1$, the proportion of people employed in sector *i* of EU Member State *k* during year *l* is higher than the proportion of people employed in sector *i* in the EU-28 during year *l*. The labour force of EU Member State *k* is then considered to be more concentrated in sector *i* than on average in the EU-28.

2.5 Data transformation and update

The methodology presented above has been integrated into the DataM management tool. In particular, this tool allowed us to deal with the complexity of estimating the bio-based shares for hundreds of Comext products, and to apply them to data obtained from seven datasets updated at various points during the year.

The resulting database will be made public online at https://datam.jrc.ec.europa.eu/datam/mashup/BIOECONOMICS/index.html, and updated automatically several times a year.

3. Results

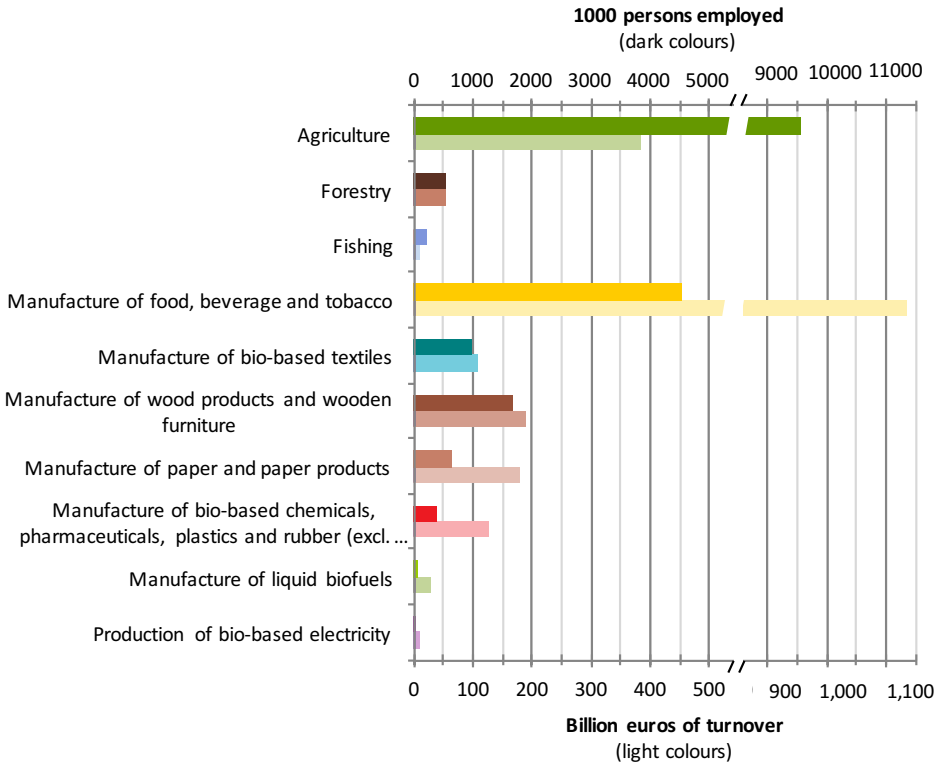
3.1 Main features of the EU bioeconomy

The bioeconomy employed approximately 18.6 million people in the EU-28 in 2014, generating turnover of around EUR 2.2 trillion. Between 2008 and 2014, employment in the European bioeconomy contracted, with the loss of nearly 2 million people employed. Agriculture and the manufacture of food, beverages and tobacco constituted three quarters of the jobs and two thirds of the turnover of the European bioeconomy.

These two sectors are the two main providers of bioeconomy jobs in Europe, employing, respectively, 51% and 24% of the persons employed in the European bioeconomy in 2014 (see Figure 1). The ongoing restructuring of the agricultural sector led to the loss of 1.2 million of persons employed in the EU-28 between 2008 and 2014. Hence, it is the main driver of employment trends in the European bioeconomy. During the same period, employment in the manufacture of wood products and wooden furniture and the manufacture of bio-based textiles also contracted, with the loss of 680,000 of persons employed. This is a significant figure, and contrasts with the modest contribution made by these sectors to total bioeconomy employment (respectively 9% and 5.3% of the total number of persons employed in the EU-28 bioeconomy in 2014). The food, beverages and tobacco manufacturing sector also lost nearly 200,000 jobs. Emerging sectors, such as the manufacture of bio-based chemicals (including liquid biofuels), pharmaceuticals, plastics and rubber, employed nearly 18,000 additional persons in 2014 compared with 2008.

In contrast, the turnover of the European bioeconomy increased by nearly EUR 140 billion between 2008 and 2014. The manufacture of food, beverages and tobacco was the main contributor to the EU-28 bioeconomy turnover in 2014 (51%) (see Figure 1). Its turnover increased by EUR 98 billion over the 2008-2014 period. It is followed by agriculture (17% of the EU-28 bioeconomy turnover), which experienced a turnover increase of EUR 26 billion. Gains are observed in all sectors of the bioeconomy except the manufacture of wood products and wooden furniture (–EUR 20 billion over the period) and the manufacture of bio-based textiles (–EUR 6.5 billion).

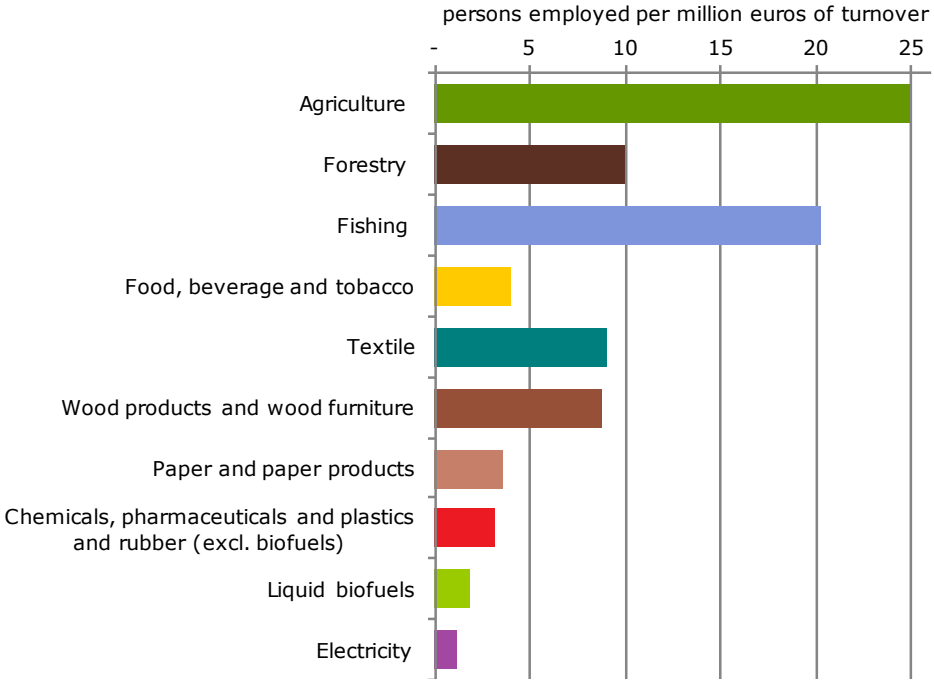
Figure 1. Persons employed and turnover generated in EU-28 bioeconomy sectors (2014).



The biomass-producing sectors, i.e. agriculture, forestry and fisheries, tended to be the most labour-intensive sectors of the European bioeconomy; this was particularly the case with agriculture and the fishing sectors, which employed more than 20 persons per million euros of turnover (see Figure 2). Forestry, the manufacture of bio-based textiles and the manufacture of wood products and wooden furniture were close to the EU average (i.e. 8.3 persons employed per million euros of turnover). The manufacture of food, beverages and tobacco and the manufacture of paper and paper products employed half this average (per million of person employed), while the production of bio-electricity and the manufacture of chemicals (including liquid biofuels), pharmaceuticals and rubber and bio-plastic products employed fewer than 3 persons per million euros of turnover.

A decreasing number of persons employed and an increasing turnover resulted in labour productivity gains in the European bioeconomy during the seven-year period 2008-2014 (in terms of persons employed per turnover). Interestingly, in absolute numbers, highest gains were obtained in the manufacture of chemicals (including biofuels), pharmaceuticals and plastics, in the manufacture of paper and paper products and in the manufacture of food, beverages and tobacco. However, the highest growth of turnover per person employed was registered in the most labour-intensive sectors. These were, in decreasing order, forestry, agriculture and the manufacture of bio-based textiles.

Figure 2. Number of persons employed per million euros of turnover in the bioeconomy sectors.



3.2 Diversity of bioeconomies across EU Member States

The European bioeconomy shows very heterogeneous sectorial contribution at Member State level. Bioeconomy sectors have developed differently according to Member State biomass endowment or Member States access to biomass (e.g. commercial harbours), and also according to prior sectorial development (e.g. maturity of bio-based manufacturing sectors). In this paper, we use two differentiation criteria to portray the diversity of national bioeconomies within the EU (see Figures 3 and 4):

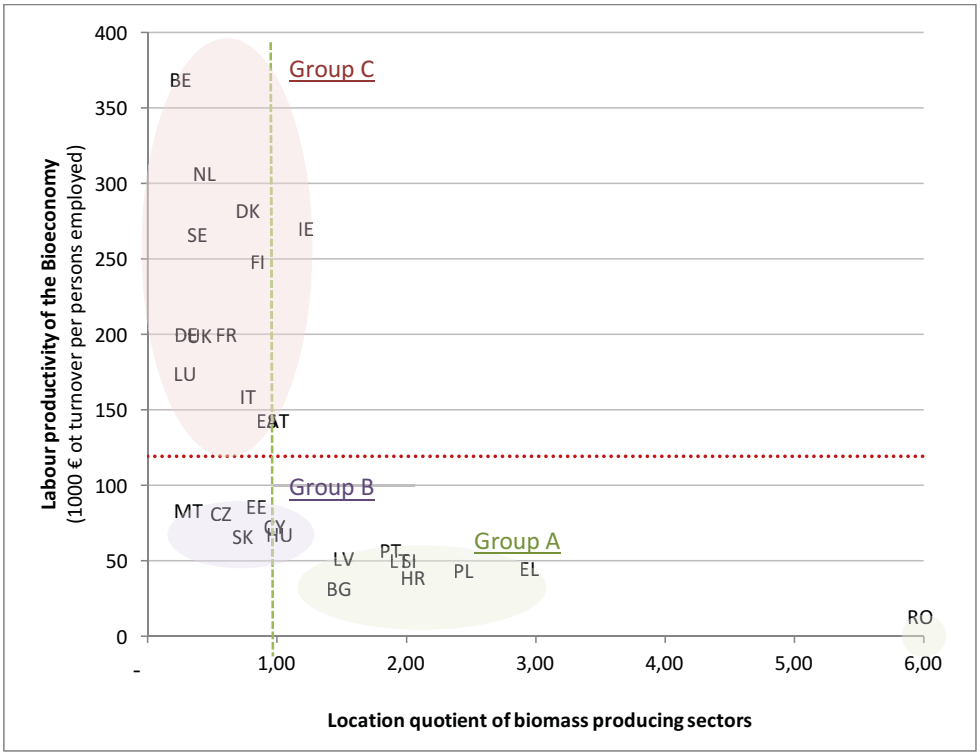
(i) the degree of concentration of the bioeconomy labour force in biomass producing sectors versus that in (partly) biomass manufacturing sectors;

(ii) the average amount of turnover generated by a person employed in the bioeconomy (i.e. turnover per person employed, which is an indicator of labour productivity).

According to these two criteria, three main types of bioeconomy can be identified:

- group A: below EU average labour productivity in the bioeconomy and above EU average employment share in biomass-producing sectors;
- group B: below EU average labour productivity in the bioeconomy and above EU average employment share in (partly) biomass manufacturing sectors;
- group C: above EU average labour productivity in the bioeconomy and above EU average employment share in (partly) biomass manufacturing sectors.

Figure 3. The three main bioeconomy patterns in EU Member States.

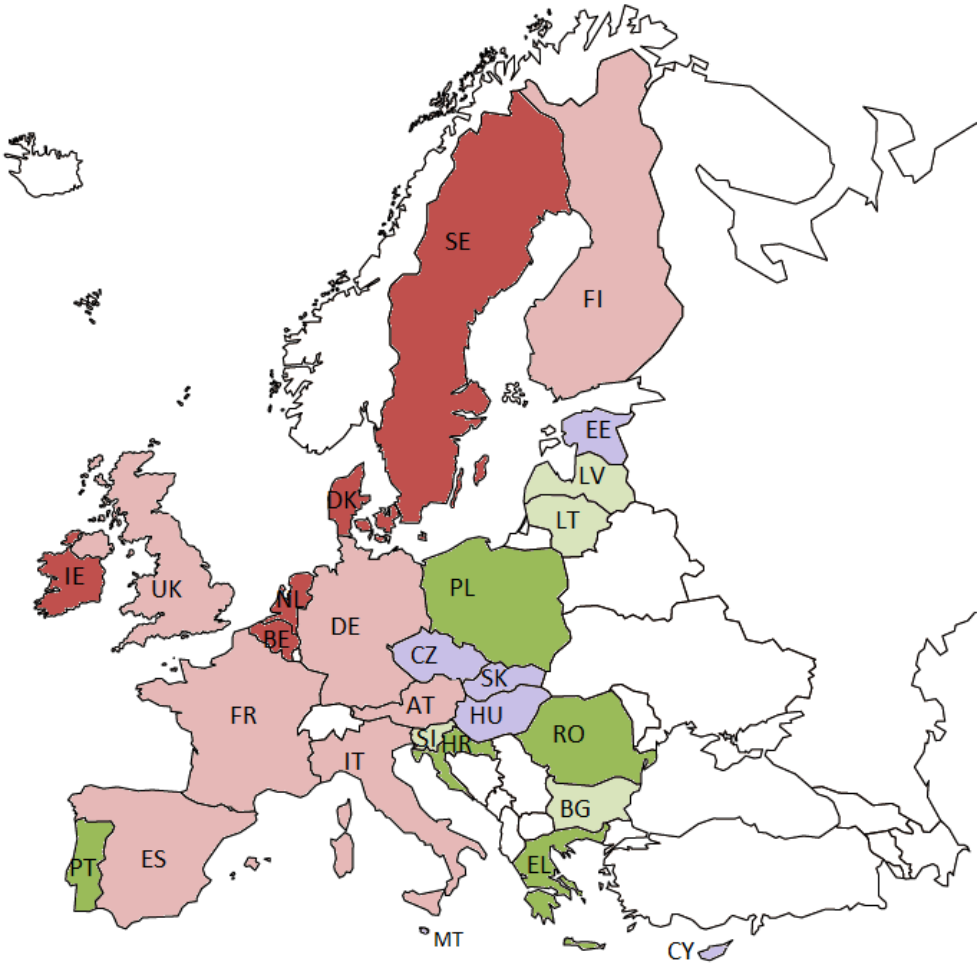


Dotted lines represent the EU average (location quotient of the biomass-producing sectors in green and turnover per person employed in red)

3.2.1 Group A: below EU average turnover per person employed in the bioeconomy and above EU average employment share in biomass-producing sectors

This group comprises Bulgaria, Croatia, Greece, Latvia, Lithuania, Poland, Portugal, Romania, and Slovenia. In all bioeconomy sectors of these countries, the turnover per person employed is lower than the EU average, with only a few exceptions (the fishing sector in Lithuania and the manufacture of paper and paper products in Portugal). Additionally, their domestic labour forces are more concentrated in biomass-producing sectors (i.e. agriculture, forestry and the fishing sector) than in the other EU Member States. This is reflected in a location quotient of biomass-producing sectors greater than 1 (see Figure 3). A closer look at the composition of their bioeconomy labour forces highlights the importance of the agricultural labour force (from 37% of the people employed in the bioeconomy in Latvia to 83% in Romania). It also reveals that in all these countries, a lower proportion of people than the EU average is employed in the manufacture of food, beverages and tobacco, in the manufacture of paper and paper products and in the manufacture of bio-based chemicals, pharmaceuticals, plastics and rubber.

Figure 4. Geographical distribution of Member States belonging to groups A, B and C.



Note: Group A in green, group B in purple and group C in red.

Beyond these common features, the nine Member States in group A show different specialisations of their bioeconomy labour force in the three biomass-producing sectors. As already stated, agriculture is the largest employment sector by far in these nine Member States, but it is particularly developed in Romania, Greece, Poland and Slovenia (≥ 65% of bioeconomy labour force). The fishing labour force is also more developed than the EU average in Greece, Portugal and Croatia, as is the forestry sector in Latvia, Bulgaria, Lithuania, and Croatia. Taking advantage of their forestry resources, Latvia and Lithuania also show a high concentration of their bioeconomy labour force in the manufacture of wood and wooden furniture.

3.2.2 Group B: below EU average labour productivity in the bioeconomy and above EU average employment share in (partly) biomass manufacture sectors

This group comprises Hungary, Estonia, Cyprus, Malta, the Czech Republic and Slovakia. The bioeconomy in group B shows a level of turnover per person intermediate between groups A and C (see Figure 3). Sectorial turnovers per person are of the same magnitude as those in group A, with the exception of agriculture, which shows higher levels. In contrast to group A, but similarly to group C, the national labour force of group B Member States is more concentrated in (partly) biomass manufacturing sectors than on average in the EU[2]. Although agriculture remains the foremost bioeconomy employment sector, the proportion of bioeconomy labour force employed in agriculture is much lower than in group A. This probably reflects a more advanced restructuring process in agriculture than in group A, also resulting in a higher turnover per person employed.

It is noteworthy that, after agriculture, group B Member States show a concentration of their bioeconomy labour force higher than the EU average in either forestry (Slovakia, Estonia, the Czech Republic and Hungary) or the fishing sector (Malta, Cyprus and Estonia).

Member States with a concentration of their biomass-producing sectors in forestry also have a high proportion of their bioeconomy labour force working in the manufacture of wood and wooden furniture (with the exception of Hungary). Estonia in particular shows the highest proportion among all EU Member States (32%). Slovakia and the Czech Republic employ a higher proportion than the EU average in the manufacture of wood and wooden furniture (more than 15%, compared with 7% on average in the EU-28) and in the manufacture of paper and paper products. Additionally, the manufacture of bio-based textiles employs a higher share than the EU average in Slovakia, the Czech Republic, Hungary and Estonia. The same is true of the manufacture of bio-based chemicals, pharmaceuticals, plastics and rubber in the Czech Republic, Slovakia, Malta and Hungary.

3.2.3 Group C: above EU average labour productivity in the bioeconomy and above EU average employment share in (partly) biomass manufacture sectors

This group includes Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Italy, Luxembourg, the Netherlands, Spain, Sweden and the United Kingdom. The turnover per person employed in the bioeconomy is above the EU average in these countries, which is the result of higher turnover per person employed, in agriculture and all the (partly) biomass manufacturing sectors, than in other EU Member States. In addition, their biomass-producing sectors employ a lower proportion of the labour force than the average in the EU. This is mainly because agriculture accounts for only very small proportion of total employment (less than 4%). Ireland and Austria are the exceptions, with contribution of agriculture to the total labour force still at the EU average level or higher.

There are also additional specificities in the composition of group C's bioeconomy labour force, which is less concentrated in the manufacture of bio-based textiles than on average in the EU (except in Italy, where this sector employs 15% of the bioeconomy labour force). In contrast, the manufacture of paper and paper products concentrates a

[2] Location quotient of the biomass manufacturing sectors higher than one, which is the equivalent of a location quotient of biomass-producing sectors of less than 1 (as shown in Figure 3).

higher proportion of the bioeconomy labour force than in the Member States of groups A and B (except in Ireland). The proportion of the labour force employed in the manufacture of bio-based chemicals, pharmaceuticals, plastics and rubber is of the same order of magnitude as in group B, but is larger than in group A. Those sectors, together with the manufacture of food, beverages and tobacco, are also those displaying the largest labour productivity gap (in terms of turnover per person employed) with groups A and B.

Belgium, the Netherlands, Denmark, Ireland, Sweden and Finland have reached very high levels of bioeconomy turnover per person compared with other group C Member States. Such high levels stem from exceptional performance in one or several bioeconomic sectors. For instance, the highest level of sectorial turnover is reached in the Finnish manufacture of paper and paper products, which generated EUR 854 000[3] of turnover per person employed in 2014. Ireland, the Netherlands and Belgium also rank joint first in terms of turnover per person employed in the manufacture of bio-based chemicals, pharmaceuticals, plastics and rubber (around EUR 500,000 of turnover per person employed or higher). Similarly, the highest levels of turnover per person employed in the manufacture of food, beverages and tobacco were achieved in Ireland, the Netherlands, Belgium and Denmark (more than EUR 400,000 of turnover per person employed). The forestry sector achieved more than EUR 350,000 of turnover per person in Sweden and Ireland. Luxembourg, Finland and Sweden reported the highest levels of turnover per person employed in the manufacture of wood and wooden furniture (> EUR 270,000 per person employed), Denmark and Belgium the highest levels in the fishing sector (> EUR 230,000 of turnover per person employed), and Belgium, Denmark and the Netherlands the highest values in the manufacture of bio-based textiles (> EUR 220,000 of turnover per person employed). Finally, Denmark, Belgium and the Netherlands show the highest turnover per person employed in agriculture.

4. Evaluating the approach

The aim of the present paper and database[4] is to provide a systematic and transparent system for analysing key indicators of the bioeconomy in Europe. The use of official statistics (mainly Eurostat) as a data source offers publicly available and consolidated time series, which are harmonised across EU Member States. The estimation of bio-based shares at eight-digit CN codes for partly bio-based manufactured products gives insights into the performance of emerging, non-traditional bio-based sectors. The integration of different data sources and calculations into an efficient data management tool (DataM) allows for fast data updating as soon as the original data sources are renewed. Finally, the use of advanced visualisation software renders the data more accessible, easier to understand and more attractive to the user.

Throughout the paper, the reader has been informed about specific assumptions taken and/or caveats regarding the chosen approach. In particular, we would like to stress the following points.

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[3] The data source, Eurostat Structural Business Statistics, points out a break in time series. Nevertheless, even before the break, the turnover per person employed in the manufacture of paper and paper products in Finland reached EUR 590,000 per person, which remains the highest level reached in that sector among EU Member States.

[4] Database available at https://datam.jrc.ec.europa.eu/datam/mashup/BIOECONOMICS/index.html.

The proposed indicators, jobs and turnover, are compiled in accordance with current policy and analytical needs. In particular, turnover as an economic indicator has advantages and disadvantages. On the one hand, it is a measure of overall economic dynamics of a particular sector, as it includes all totals invoiced during the reference period. On the other hand, it might lead to some double counting and does not provide the real value added of that sector.

Apart from the number of jobs, we also propose the calculation of the location quotient as a relative measure indicating the concentration of countries in a specific bioeconomy sector. The aggregate numbers for the location quotient are particularly high in some countries because of the enormous numbers of jobs in the agricultural sector. Therefore, when using aggregates, the reader should be aware of the important weight of this 'traditional' sector in transition, which could disguise the expanding nature of smaller, emergent sectors.

An important effort has been made to determine sectorial bio-based shares, e.g. the bio-based share of the manufacture of chemicals and chemical products (NACE C20). We propose to infer them from the relative value of bio-based products manufactured by a sector relative to the total value generated by this sector. Over time, we expect these numbers to be refined by experts in the field.

Based on turnover and jobs, we also calculate derived indicators, such as turnover per person. Because of the methodological limitation mentioned in section 2.4, the calculation of turnover per person in partly bio-based sectors reflects the performance of the sector as a whole (i.e. including their non-bio-based part).

To further analyse the state and potential of the bioeconomy, additional indicators are under development. We propose to complement 'Turnover' with 'Value added at factor costs' derived from Eurostat Structural Business Statistics, in order to capture more precisely the contribution of individual sectors to the overall economy (without double counting).

Other indicators are being prepared, derived mainly from Eurostat-Prodcom (e.g. volume and value of bio-based production, including bio-based chemicals and plastics), or from Eurostat Structural Business Statistics (the number of enterprises, investments, wages and salaries).

The integration of similar indicators in model-based forward-looking analysis (e.g. van Meijl *et al.*, 2016; Philippidis *et al.*, 2016) is an important step to link past developments with future pathways.

5. Conclusions

The results presented in section 3 are one piece of a broader research program aimed at supporting the development of bioeconomy strategies in the EU in the context of the Bioeconomy strategy review and of the Circular economy package[5] (EC, 2015b). Supported by data on biomass availability and additional information on bioeconomy companies and plants, a more detailed analysis could be undertaken, with the aim of identifying opportunities for the development of Member States' bioeconomies.

[5] The Commission will examine the contribution of its 2012 a Bioeconomy Strategy to the circular economy and consider updating it if necessary (EC, 2015b pp17).

On the basis of the three broad clusters of national bioeconomies proposed in this paper, one could differentiate policy targets related to the strengthening of (partly) manufacturing sectors versus biomass-producing sectors, and the improvement of labour productivity in general. This would have to take into account biomass endowment and previous sectorial developments (infrastructures).

Several Member States have already proposed strategies (German Bioeconomy Council, 2015); in this article we name only a few.

Countries with sufficient biomass endowment and well-developed primary sectors have certainly many opportunities to develop downstream value chains. For example, thanks to Finland's abundant resources, its forestry industry is the core element of the Finnish (group C) bioeconomy strategy (Finnish Ministry of Employment and the Economy, 2014). Key elements are timber, diversification of wood products and bioenergy including wood-based transports, but also biotechnologies for health and pharmaceutical applications. The high turnover per person and location quotient in the specific sectors highlights Finland's exemplary role among northern European countries.

Examples of Member States where potential of value chains in the blue economy is partly untapped are Portugal (group A) and Ireland (group C). Each equipped with important marine resources, they have defined national strategies to develop the blue economy, planning the development of aquaculture, blue energy and blue biotechnologies for the manufacture of pharmaceutical, medical and cosmetic products (Irish Department for Agriculture, 2012; Government of Portugal, 2013).

Obviously, previous sectorial developments and industrial clusters often provide the basis to foster the transition from traditional, originally non-bio-based sectors to a higher bio-based share. For example the long-standing experience of The Netherlands (group C) in the biotechnology, chemicals and agri-food sectors, combined with excellent logistics and biomass supplies in harbours, opens many options for establishing biorefineries (SER, 2010; DGBI-PDBBE, 2013).

Several countries in groups A and B, starting from a much lower labour productivity level but endowed with abundant primary production and a sound manufacturing base, could add value through bio-based methods of production.

The use of the existing indicators for broad analysis of individual Member States has to be accompanied by more in-depth investigation at sector level and including the breakdown of information on regional (NUTS2) level.

The presented indicators and database are further steps in the provision of more information on the European bioeconomy by the Joint Research Centre of the European Commission[6] and its research partners. The availability and easy access of the full dataset at https://datam.jrc.ec.europa.eu/datam/mashup/BIOECONOMICS/index.html is in accordance with the open data policy and should trigger feedback from all stakeholders, with the overall aim of improving the existing methodologies and datasets.

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[6] The establishment of a Bioeconomy Knowledge Centre is planned for 2017.

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Disclaimer

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