Ecological Economics 176 (2020) 106724

Contents lists available at ScienceDirect

Ecological Economics

journal homepage: www.elsevier.com/locate/ecolecon

A New Socio-economic Indicator to Measure the Performance of Bioeconomy Sectors in Europe

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ARTICLE INFO

Keywords:
Bioeconomy
Socio-economic
Europe
Indicators
Multi-criteria

ABSTRACT

The European Commission supports the production of renewable biological resources and their conversion into value added products and bio-energy. A new bioeconomy strategy aimed at promoting a sustainable Europe was launched in October 2018. However, little work has been done to monitor, model and appraise the impacts and developmental trajectories of bioeconomy sectors. To gauge the current sustainability performance of individual European countries, the present study proposes a new indicator – the "socio-economic indicator for the bioeconomy" (SEIB) – to measure the socio-economic performance of bioeconomy sectors. Drawing on Eurostat data and the analytic hierarchy process, multi-criteria decision analysis is employed with the aim of providing a direct comparison between member states (MSs). However, bioeconomy involves a large number of sectors and, therefore, it is useful to propose two versions of this indicator in order also to single out the impact of most innovative sectors: the first version considers all bio-based sectors ("SEIB for overall sectors") while the second version excludes all primary sectors ("SEIB for manufacturing and bio-energy sectors"). The results identify three groups of MSs (virtuous, in-between and laggard) with reference to the European average. Ireland occupies the first position in the ranking, and only three other MSs (Denmark, Portugal and Austria) qualify as "virtuous" countries in both rankings.

1. Introduction

The bioeconomy is attracting increased interest as a conceivable win-win solution for green growth and competitiveness (DeBoer et al., 2019). The European Bioeconomy Strategy supports the production of renewable biological resources and their conversion into vital products and bio-energy in order to satisfy the 2030 Agenda and its Sustainable Development Goals (European Commission, 2018). Biomass resources represent an opportunity for sustainable development in bio-based industries (Morone and D'Amato, 2019), which encompass sectors as diverse as agriculture, food, bio-based chemicals, bio-energy, bio-based textiles and forestry (Morone et al., 2019; Scarlat et al., 2015). Furthermore, development of bioeconomy sectors represents an opportunity to foster innovation and create jobs in rural and industrial areas (Vivien et al., 2019). It also represents an opportunity to revive productivity and growth by improving the competitiveness of domestic industries through new technologies (Purkus et al., 2018) and reducing dependence on imported feedstocks by rehabilitating marginalised lands (Hurmekoski et al., 2019) and exploiting locally sourced wastes and residues in a circular perspective (D'Adamo et al., 2019; Zabaniotou and Kamaterou, 2019) with a fully cascading approach (Corrado and Sala, 2018).

Research on the bioeconomy is clearly fragmented into literature focused on defining terms and literature focused on monitoring (Morone, 2018). Circular economy and bioeconomy are two concepts that tend to overlap being both resource-focused (Loiseau et al., 2016). Circular economy aims to reduce resource use and consumption, to favour reuse and recycling activities and to minimise waste and emissions. Bioeconomy aims to substitute non-renewable resources with bio-based alternatives (D'Amato et al., 2017) emphasizing the introduction of bio-based energy and material to reduce environmental risks (Bugge et al., 2016). A clear point of contact between these two concepts is represented by the industrial symbiosis of productive processes, where an industry by-product is another industry input (D'Amato et al., 2019). Circularity and efficiency not always are embedded in bioeconomy strategies (Bezama, 2016), but some authors introduce the concept of circular bioeconomy to ensure that bioeconomy is a valid support to resource efficiency (Dahiya et al., 2018; Karan et al., 2019). However, little work has been carried out to monitor, model and appraise the impacts and trajectories of particular sectors of the bioeconomy in

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https://doi.org/10.1016/j.ecolecon.2020.106724
Received 28 July 2019; Received in revised form 27 March 2020; Accepted 19 May 2020
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order to establish a sectorial and tailored policy framework (Schütte, 2018). Monitoring is of paramount importance in order to detect and appraise changes concerning environmental, social and economic dimensions (Marchi et al., 2017). Specifically, monitoring enables the efficiency of proposed schemes and environmental and management policies to be appraised and addressed (Wells et al., 2017). A range of stakeholders and/or experts should be involved in the selection of monitoring indicators (Miola and Schiltz, 2019), in order to ensure the contribution of heterogeneous views and insights into the inner dynamics of specific sectors (Monasterolo et al., 2019). Stakeholders tend to differ in their interpretations of the world, as well as in their preferences, strategies and information, and they should therefore be used to provide realistic input into the evaluation and design of public policies (Doyen et al., 2019).

Furthermore, the literature on the bioeconomy reflects a lack of multi-dimensional studies on the socio-economic impacts of the bioeconomy (Sanz-Hernández et al., 2019), the bioeconomy contribution to the current economic and ecological transition (Vivien et al., 2019), the role of primary sectors in the bioeconomy (Asada and Stern, 2018) and the potential of unexplored resources to be used as biofuels and bioproducts (Guo and Song, 2019).

Some authors underlined the necessity for better metrics to monitor the development of the bioeconomy (O'Brien et al., 2017) and following this direction of research, Ronzon and M'Barek (2018) discussed and proposed socio-economic indicators for an analysis and comparison of the bioeconomy of the EU MSs. These indications are confirmed by a systematic review that revealed the need for an in-depth socio and economic analysis in the field of bioeconomy (Sanz-Hernández et al., 2019).

Bearing this in mind, this paper tries to cover a two existing gaps. The first concerns the monitoring of the development of bioeconomy. The second regards the proposition of a more detailed socio-economic analysis of bioeconomy. To this aim, a new indicator, called the "Socio-economic indicator for the bioeconomy" (SEIB), is proposed to measure the socio-economic performance of bioeconomy sectors. It is applied to the European context, following the analysis elaborated by (O'Brien et al., 2017; Ronzon and M'Barek, 2018) and in accordance with the priority challenges identified by the European Commission under Horizon 2020 programme on this relevant theme in the field of sustainability (European Commission, 2019a).

In so doing, the work proposes a multi-criteria decision analysis (MCDA) technique that, drawing on Eurostat data and applying the analytic hierarchy process (AHP), enables the direct comparison of European countries. This approach is in line with Cucchiella et al. (2017), in which an aggregated AHP-MCDA is applied to different sustainable parameters (indicators) useful to compare the performance of European countries. The methodology includes the following steps: i) selecting bioeconomy sectors according to NACE classifications; ii) choosing parameters (on the basis of the literature) to measure socio-economic performance (with heavy reliance on the work of Ronzon and M'Barek (2018) as previously highlighted); iii) assigning values to the parameters in each bioeconomy sector, drawing mainly on Eurostat data; iv) gathering data to prioritise the indicators, in the form of expert pairwise comparisons, following the approach proposed by Saarikoski et al. (2019), in which a MCDA is used in the ecosystem assessment and v) defining weights for the bio-based sectors, drawing mainly on Eurostat data. The new indicator proposed initially is applied to all sectors, and for this motive is called SEIB for overall sectors. However, Ronzon and M'Barek (2018) underlined as the agriculture sector influenced significantly the performance of single countries and consequently, we have calculated another dimension of SEIB, called SEIB for manufacturing and bio-energy sectors, in which the same methodology is applied but all primary sectors are excluded.

The remainder of the paper is organised as follows: Section 2 introduces the materials and methods, whereas Section 3 presents the results, along with a brief picture of the bioeconomy in the European Union. Section 4 discusses the findings, while Section 5 ends with some concluding remarks.

2. Materials and Methods

Multi-criteria decision analysis (MCDA) offers a consistent framework for decision makers evaluating multiple and conflicting goals (Mavrommati et al., 2017). The technique integrates data on the performance of each alternative (i.e. scoring criterion) (Fontana et al., 2013) and the subjective assessment of experts on the relevance of certain criteria (Allain et al., 2017). The present work proposes a new indicator, SEIB, to measure the socio-economic performance of bioeconomy sectors. The bioeconomy involves the production of renewable biological resources and their conversion (together with waste streams) into value added products such as food, feed, bio-based products and bio-energy (European Commission – Joint Research Centre, 2017).

SEIB is a dimensionless indicator derived from the interaction between three variables: i) the value of the socio-economic parameters for each sector (VP), ii) the weight of the socio-economic parameters for each sector (WP) and iii) the weight of the bio-based sectors (WS). It is obtained at two levels:

1. The assessment of the indicator calculated for each bio-based sector ($SEIB_{SK\text{-}(MS)}$) – Eq. (1).
2. The aggregation of $SEIB_{SK\text{-}(MS)}$ across all bio-based sectors, which is then used to obtain an overall value for each MS ($SEIB_{(MS)}$) – Eq. (2).

$$SEIB_{SK-(MS)} = VP_{SK-(MS)-P1} * WP_{SK-P1} * WS_{SK-P1} + VP_{SK-(MS)-P2} * WP_{SK-P2} * WS_{SK-P2} + VP_{SK-(MS)-PX} * WP_{SK-PX} * WS_{SK-PX} \quad (1)$$

$$SEIB_{(MS)} = \sum_{K=1}^{N} SEIB_{SK-(MS)} \quad (2)$$

$VP_{SK-(MS)-PJ}$ is the value of the parameters calculated for the following combinations: i) bio-based sector SK with $K = 1 \ldots N$, in which N is the number of bio-based sectors; ii) country MS, which represents the alternative, in which the total number is equal to 28 (the number of current MSs); and iii) socio-economic parameter with $J = 1 \ldots X$, in which X is the number of socio-economic parameters. Additionally, WP_{SK-PX} is defined according to the following combinations: i) bio-based sector SK with $K = 1 \ldots N$; and ii) socio-economic parameter with $J = 1 \ldots X$. Finally, WS_{SK-PJ} considers the following combinations: i) bio-based sector SK with $K = 1 \ldots N$; and ii) socio-economic parameter with $J = 1 \ldots X$. The value of $VP_{SK-(MS)-PJ}$ is specific for each MS, while the values of both WP_{SK-PJ} and WS_{SK-PJ} are independent. Table 1 shows a list of acronyms of variables, parameters and indices used in the calculation of SEIB.

Table 1
Nomenclature for the SEIB calculation.

Acronym	Description
AV	The absolute value
BBAV	The bio-based absolute value
BBRV	The bio-based relative value
BBS	The bio-based share
J	Specific socio-economic parameter
K	Specific bio-based sector
MS	Member State
N	Number of Bio-based sector
P	Number of citizens
PJ	Generic socio-economic parameters
SK	Generic bio-based sector
VP	The value of the socio-economic parameters for each sector
X	Number of socio-economic parameters
WP	The weight of the socio-economic parameters for each sector
WS	The weight of the bio-based sectors

2.1. Selection of Bio-based Sectors

"The bioeconomy is the production, utilization, and conservation of biological resources, including related knowledge, science, technology, and innovation, to provide information, products, processes, and services across all economic sectors aiming toward a sustainable economy" (Global Bioeconomy Summit, 2018). For this work, 18 micro-sectors were selected according to the official statistical classification of the economic activities of the European Community (NACE rev. 2, (Eurostat, 2008)). These were then grouped into the following 10 macro-sectors (that is, "N"; see eq. (2)) (Ronzon and M'Barek, 2018):

i. Agriculture (A01).
ii. Forestry (A02).
iii. Fishing and aquaculture (A03).
iv. Manufacture of food, beverages and tobacco composed through manufacture of food (C10), manufacture of beverages (C11) and manufacture of tobacco (C12).
v. Manufacture of bio-based textiles composed through manufacture of textiles (C13), manufacture of wearing apparel (C14) and manufacture of leather (C15).
vi. Manufacture of wood products and furniture composed through manufacture of wood products (C16) and manufacture of furniture (C31).
vii. Manufacture of paper (C17).
viii. Manufacture of bio-based chemicals, pharmaceuticals, plastics and rubber (excluding biofuels) composed through manufacture of chemicals (excluding biofuels) (C20), manufacture of pharmaceuticals (C21) and manufacture of bio-based plastics and rubber (C22).
ix. Manufacture of liquid biofuels composed through manufacture of bioethanol (C2014) and manufacture of biodiesel (C2059).
x. Production of bioelectricity (D3511).

The NACE classification does not distinguish between bio-based and non–bio-based activities. Nine of the abovementioned micro-sectors exclusively use biomass as a feedstock (e.g. A01, A02, A03, C10, C11, C12, C15, C16 and C17), while the other nine are hybrid because they use feedstock that is either biomass or carbon fossil–based (e.g. C13, C14, C31, C20, C21, C22, C2014, C2059 and D3511). For this reason, it was necessary to estimate their bio-based share.

2.2. Choice of Socio-Economic Parameters

Section 1 has highlighted how socio-economic indicators are not properly analysed in literature. For this reason, the choice of parameters was purposely based on Ronzon and M'Barek (2018). Specifically, three parameters were selected (that is, "J"; see eq. (1)):

- Turnover (code V12110 in Eurostat – Structural Business Statistics) comprises the market sales of goods or services supplied to third parties, including all duties and taxes on the goods or services (with the exception of VAT) and all other charges (transport, packaging, etc.) to customers.
- Value added (code V12150 in Eurostat – Structural Business Statistics) measures the gross income from operating activities after adjusting for operating subsidies and indirect taxes. Value adjustments (e.g. depreciation) are also considered.
- Workers (code V16110 in Eurostat – Structural Business Statistics) are the total number of persons who work in the observation unit (e.g. unpaid family workers) and who work outside the unit they belong to, but are paid by it (e.g. a maintenance team).

The first two have an economic nature, while the third has a social dimension. The absence of environmental indicators represents a limitation of this work, that will be addressed in future research. At this stage, this choice is justified by a twofold consideration. The first concerns the gap toward socio-economic dimensions showed in the literature; the second concerns the lack of reliable data on the environmental dimension (e.g. the amount of reduction of GHG emissions associated to the bioeconomy sectors, the percentage of natural resources reused/recycled/recovered).

2.3. Assignation of Values to the Parameters

Eurostat provides statistical information to EU institutions in support of the harmonisation of statistical methods across MSs. The last available data were published in 2017, and the following parameter values were selected (Eurostat, 2018):

i. C10, C11, C12, C13, C14, C15, C16, C31, C17, C20, C21, C22, C2014, C2059 and D3511 (code [sbs_na_ind_r2]).
ii. A01 (code [aact_eaa01], code [lfsa_egan22d], [nama_10_a64]).
iii. A02 (code [for_eco_cp], code [lfsa_egan22d], code [nama_10_a64]).
iv. A03 (code [lfsa_egan22d], code [nama_10_a64])

When no data were available, the value was assumed equal to that of the previous year; this assumption was particularly verified for the value added parameter. However, as highlighted in Section 2.1, sectors are subdivided in two groups. In fact, in the case of fully bio-based sectors, the value retrieved from the Eurostat dataset was not modified; instead, in the case of the hybrid sectors, a sectoral bio-based share was applied following the approach used by Ronzon et al. (2017). Considering data made available by the European Commission (European Commission, 2019b), this share for each sector and MS was estimated as the average value in 2014–2015 (corresponding to 2016–2017 in temporal terms). Tables A1–A6 present the input data for all 18 micro-sectors and for each European MS (European Commission, 2019b; Eurostat, 2018). These values were also divided by the population (Table A7) to ensure that the data would be comparable across MSs (otherwise the indicator values would always favour larger countries). This choice is in accordance with the existing literature (Barbier and Burgess, 2019; Cucchiella et al., 2017; Szopik-Depczyńska et al., 2018), in which the field of sustainability is investigated. However, also other approaches can be considered suitable (e.g. land area, Gross Domestic Product) - (Martinico-Perez et al., 2018).

$$BBAV_{SK-(MS)-PJ} = AV_{SK-(MS)-PJ} * BBS_{SK-(MS)-PJ} \quad (3)$$

$$BBRV_{SK-(MS)-PJ} = BBAV_{SK-(MS)-PJ}/P_{(MS)} \quad (4)$$

$BBAV_{SK-(MS)-PJ}$ is the bio-based absolute value for sector K, with the socio-economic parameter J applied to each MS; $AV_{SK-(MS)-PJ}$ is the absolute value from the Eurostat database with reference to K and J for each MS; $BBS_{SK-(MS)-PJ}$ is the bio-based share for sector K with the socio-economic parameter J applied to each MS (as reported in Tables A8–A10); $BBRV_{SK-(MS)-PJ}$ is the bio-based relative value for sector K with the socio-economic parameter J applied to each MS; $P_{(MS)}$ is the number of citizens in the MS. BBS is the ratio between the value proposed by Ronzon and M'Barek (2018) and the Eurostat value. C14 is a hybrid sector and, for sectors in this category, BBS ranged from 0 to 1. For example, in Austria, turnover in sector C14 was 830 and 802 million € in 2014 and 2015, respectively, while turnover in the bio-based sector C14 was 335 and 311 million €, respectively. Consequently, the average value of the bio-based sector share for this MS was approximately 40%.

For the other nine full bio-based sectors, BBS was assumed equal to 1. Finally, a normalisation approach was applied to the full list of $BBRV_{SK-(MS)-PJ}$. This was performed in two steps: initially a maximum (MaxV) and minimum value (MinV) were identified for each list; subsequently, the remaining 26 values were defined as intermediate (IntV). It was possible to define the following values:

$$VP_{SK-(MS)-PJ} = 1 \qquad BBRV_{SK-(MS)-PJ} = MaxV \tag{5}$$

$$VP_{SK-(MS)-PJ} = 0 \qquad BBRV_{SK-(MS)-PJ} = MinV \tag{6}$$

$$0 < VP_{SK-(MS)-PJ} < 1 \qquad BBRV_{SK-(MS)-PJ} = IntV \tag{7}$$

A total of 1520 values were defined considering: i) three socio-economic parameters ($J = 3$), ii) 28 MSs and iii) 18 micro-sectors grouped into 10 macro-sectors ($N = 10$).

2.4. Assignation of Weights to the Parameters

The AHP methodology, developed by Saaty (1980), produces a list of priorities through pairwise comparisons based on the judgements of experts. The success of the analysis depends on the interviewees' knowledge and perspectives in the area of investigation. In the present research endeavour, two academic databases (i.e. Scopus and Web of Science) with wide-ranging coverage of English language scientific journals were employed to identify authors who had published scientific works on the bioeconomy. Specifically, a broad keyword search was conducted to retrieve relevant papers that had been published within the timeframe 2017–2019 by pairing the anchor keywords "bio*" with other search strings (i.e., "economy", "indicators," and "based"). This exercise led to the selection of more than 100 studies pertaining to different dimensions of the bioeconomy. Once the corresponding authors were identified as suitable candidates for contact, a mass email was sent to them in March 2019 (Cucchiella et al., 2017). The questionnaire used in the empirical investigation was created using the Qualtrics Research Suite survey software and administered using the CAWI (computer-assisted Web interview) technique (Falcone, 2019). After a two-week period, a reminder email was sent to those who had not yet responded to the questionnaire. After two more weeks, a third reminder was emailed, indicating the final deadline for completing the questionnaire. Ultimately, the questionnaire was completed by 20 experts, encompassing a broad range of academicians and researchers (i.e. research fellows, lecturers, associate professors, full professors) with long-term expertise in the bioeconomy. The years of experience and relative h-indexes of respondents are reported in Table A11. In addition, the questionnaire is presented in the Appendix (see Fig. A1).

AHP assigns a weight for each criterion, according to a decision maker's pairwise comparison of all criteria. The higher the weight, the more important the corresponding criterion (Awasthi et al., 2018). AHP weights are calculated through the use of a judgement scale ranging from 1 to 9 (Table A12) (Saaty, 2008). The AHP comparison matrix can include up to 10 factors (Brudermann et al., 2015); this work considered three factors, according to the number of socio-economic parameters.

In total, the experts made 30 pairwise comparisons: 3 comparisons for each sector, repeated for all 10 macro-sectors (Table 2 gives an example of one sector). This, as well as the percentage distribution of the 10 macro-sectors for each socio-economic parameter (as a point of reference) was sent to the experts "in preview." In the analysis, the judgements were normalised using Belton and Gear's (1983) procedure (Table 3) (Antonopoulos et al., 2014).

A, B and C are the factors (socio-economic parameters) referring to a specific sector K; V_{BA} is the value of factor B less one A; V_{CA} is the value of factor C less one A; V_{CB} is the value of factor C less one B; SC_A is the sum of values in the factor A column; SC_B is the sum of values in the factor B column; SC_C is the sum of values in the factor C column; SR_A is the sum of values in the factor A row; SR_B is the sum of values in the factor B row; SR_C is the sum of values in the factor C row; AR_A is the average value in the factor A row; AR_B is the average value in the factor B row; and AR_C is the average value in the factor C row.

Table 2
Pairwise comparisons per group.

	A	B	C
A	1	$1/V_{BA}$	$1/V_{CA}$
B	V_{BA}	1	$1/V_{CB}$
C	V_{CA}	V_{CB}	1
Sum	SC_A	SC_B	SC_C

Table 3
Normalised pairwise comparisons per group.

	A	B	C	Sum	Avg
A	$1/SC_A$	$1/(V_{BA}/SC_A)$	$1/(V_{CA}/SC_A)$	SR_A	AR_A
B	V_{BA}/SC_A	$1/SC_B$	$1/(V_{CB}/SC_B)$	SR_B	AR_B
C	V_{CA}/SC_A	V_{CB}/SC_B	$1/SC_C$	SR_C	AR_C
Sum	1	1	1	3	1

Finally, the consistency ratio (CR) was used to calculate the consistency of the pairwise comparison matrix (Diaz-Sarachaga et al., 2017). Within AHP methodology, CR represents the statistical analysis tool able to give solidity to the assessments provided by experts. In fact, the presence of a constraint determines the reliability level of provided judgements. When a CR is lower than 0.10 (or 10%), judgements can be considered trustworthy (Saaty, 2008). The CR calculation was included in the Excel file that was provided to the experts. To determine the CR, interviews were carried out using the CAWI technique, enabling the experts to check their results.

$$\lambda_{max} = SC_A * AR_A + SC_B * AR_B + SC_C * AR_C \tag{8}$$

$$CI = (\lambda_{max} - n)/(n - 1) \tag{9}$$

$$CR = CI/RI \tag{10}$$

λ_{max} is the largest Eigen value, CI is the consistency index, n is the number of factors and RI is the random inconsistency value (Table A13).

Finally, all 20 interview data were collected and the related geometric mean was calculated (Subramoniam et al., 2013), assuming that the relevance among all experts was consistent. In the calculation of geometric mean, WP_{SK-PJ} measured the weight of J socio-economic parameter for each sector K, varying from 0 to 1, and the sum of WP_{SK-P1}, WP_{SK-P2} and WP_{SK-P3} was equal to 1.

2.5. Assignation of Weights to the Bio-Based Sectors

While the distribution of weights among the socio-economic parameters was performed in accordance with the AHP based on the experts' knowledge, the distribution of weights among the bio-based sectors was generated using statistical data, with reference to the average value of the EU 28 in 2017. In this calculation, WS_{SK-PJ} measured the weight of K sector for each J socio-economic parameter varying from 0 to 1, and the sum WS_{S1-PJ}, WS_{S2-PJ}, WS_{S3-PJ}, WS_{S4-PJ}, WS_{S5-PJ}, WS_{S6-PJ}, WS_{S7-PJ}, WS_{S8-PJ}, WS_{S9-PJ} and WS_{S10-PJ} was equal to 1.

3. Results

3.1. Values of the Socio-Economic Parameters

Section 2.3 defined the methodology used to calculate values for the three socio-economic parameters. The values referred to historical data and, consequently, they objectively reflected the picture of European MSs at that time (2017). In this way, the work is aligned with the European Commission approach of monitoring the performance of countries year by year (European Commission, 2018). Here, an example calculation is reported in order to support the replicability of the methodology. With respect to sector A01 ($K = 1$) and the parameter of turnover ($J = 1$), it is not possible to register the maximum value in Table A3. In fact, the maximum value can only be defined by

Table 4
List of bio-based sectors.

Bio-based sectors	NACE rev. 2
Agriculture (K = 1)	A01
Forestry (K = 2)	A02
Fishing and aquaculture (K = 3)	A03
Manufacture of food, beverages and tobacco (K = 4)	C10, C11, C12
Manufacture of bio-based textiles (K = 5)	C13, C14, C15
Manufacture of wood products and furniture (K = 6)	C16, C31
Manufacture of paper (K = 7)	C17
Manufacture of bio-based chemicals, pharmaceuticals, plastics and rubber (K = 8)	C20, C21, C22
Manufacture of liquid biofuels (K = 9)	C2014, C2059
Production of bioelectricity (K = 10)	D3511

calculating the ratio between the values reported in Table A3 and those proposed in Table A7. In doing so, it can be noted that Ireland has a value of 1.685 thousand € per capita and $VP_{S1-(IE)-P1}$ equal to 1. In contrast, Austria has an intermediate value (0.763 thousand € per capita) and $VP_{S1-(AT)-P1}$ equal to 0.36. When a similar procedure is repeated for the two other parameters, Ireland loses its first rank position in both cases. In fact, considering the value added parameter, (J = 2) Ireland has a value of 0.681 thousand € per capita while Austria's is 0.368 thousand € per capita (the first position is achieved by the Netherlands, with 0.771 thousand € per capita); consequently, $VP_{S1-(IE)-P2}$ is equal to 0.86 and $VP_{S1-(AT)-P2}$ is equal to 0.37. With respect to the workers parameter (J = 3), Ireland and Austria have a value of 0.020 and 0.017 cap/cap, respectively, and the best performing country is Romania (0.098 cap/cap). Thus, $VP_{S1-(IE)-P3}$ is equal to 0.18 and $VP_{S1-(AT)-P3}$ is equal to 0.15. In the study, this same procedure was repeated for all 10 bio-based macro-sectors (Table 4, see Section 2.1) to evaluate the three socio-economic parameters proposed by Ronzon and M'Barek (2018): workers (Table A14), turnover (Table A15) and value added (Table A16).

Five of the 10 macro-sectors had maximum values equal to 1 because they were characterised by only one micro-sector, while the other 5 macro-sectors had two or more micro-sectors and, when the first position was not attained by the same MS, the maximum value was lower than 1. The normalisation of input data enabled a direct comparison of values, irrespective of their unit of measure or size. At the same time, it limited the analysis in the sense that any decrease/increase in the normalised value was not linked to a decrease/increase in absolute value. In fact, this attribute depended also on the reference value represented by the maximum value. Table 5 shows the list of MSs occupying the first position for each macro-sector and socio-economic parameter. The aggregation of all data was complex and normalisation was a necessary step to elaborate the final SEIB value. For the sake of comparison, best performing MSs for each socio-economic parameter in absolute terms are reported in Fig. A2. Germany occupies the first position in both turnover and value added followed by France and Italy. Instead, Poland and Romania show the highest number of workers followed by Germany.

Table 5
Top position of European MSs.

Bio-based sectors	Workers	Turnover	Value added
Agriculture (K = 1)	Romania	Ireland	Netherlands
Forestry (K = 2)	Latvia	Finland	Finland
Fishing and aquaculture (K = 3)	Malta	Malta	Denmark
Manufacture of food, beverages and tobacco (K = 4)	Bulgaria	Ireland	Ireland
Manufacture of bio-based textiles (K = 5)	Portugal	Italy	Italy
Manufacture of wood products and furniture (K = 6)	Estonia	Estonia	Estonia
Manufacture of paper (K = 7)	Finland	Finland	Finland
Manufacture of bio-based chemicals, pharmaceuticals, plastics and rubber (K = 8)	Denmark	Ireland	Denmark
Manufacture of liquid biofuels (K = 9)	Sweden	Belgium	Belgium
Production of bioelectricity (K = 10)	Finland	Finland	Denmark

3.2. Weights of the Socio-Economic Parameters

Section 2.4 described the methodology used to calculate weights for the three socio-economic parameters. The pairwise comparisons of the experts were collected and all interview data are reported in Tables A17–A36. The experts proposed V_{BA}, V_{CA} and V_{CB} for each sector (see Table 2), and these values were normalised following the approach described for Table 3. The final goal was to calculate AR_A, AR_B and AR_C.

For example, Expert 2 (Table A18) defined that the weight of both turnover and value added should be double that of workers; additionally, the expert considered value added "equally to moderately preferred" over turnover in sector A01. In this way, the distribution of weights was as follows: 49% value added, 31% turnover and 20% workers. After aggregating the judgement of all experts, turnover emerged as the most important parameter for eight experts, value added was the most important for seven experts and workers were the most important for five experts. However, as the numerical value of the weights differed, a mean was calculated to define an exact priority level according to the AHP. Regarding sector A01 (K = 1), the weight of turnover (J = 1), value added (J = 2) and workers (J = 3) was, respectively: WP_{S1-P1} = 0.368, WP_{S1-P2} = 0.343 and WP_{S1-P3} = 0.289. The same process was repeated for all 10 macro-sectors (Table 6).

Turnover was considered the main socio-economic parameter capable of measuring MS performance in terms of developing the bioeconomy. In all sectors, turnover held the most significant weight, ranging from 0.337 (WP_{S5-P1}) to 0.368 (WP_{S1-P1}). Value added was the second position in 9 out of 10 sectors (with K = 5 the exception), ranging from 0.327 (WP_{S2-P2}) to 0.343 (WP_{S1-P2}). Finally, the weight of workers ranged from 0.289 (WP_{S1-P3}) to 0.332 (WP_{S5-P3}). The normalised weights of the socio-economic parameters did not change as a function of specific MSs. The last step for the AHP analysis was the evaluation of CR (Table A37), which was always lower than 0.10. This result was expected because all experts checked this value before returning their judgements.

3.3. Weights of the Bio-based Sectors

The third SEIB component involved assigning weights to the bio-based sectors. As discussed in Section 2.5, both WS_{SK-PJ} and WP_{SK-PJ} represented a distribution of weights, but the former was calculated from historical statistical data while the latter was based on the experts' judgement. Both WS_{SK-PJ} and $VP_{SK-(MS)-PJ}$ measured the performance of socio-economic parameters; in this case, the former did not require input data normalisation, but the latter required this additional step. In fact, the reference value was represented by the EU 28 (see $AV_{SK-(EU\,28)-PJ}$). Table 7 shows the overall value of the three socio-economic parameters and Fig. 1 presents the percentage distribution. For example, the number of workers (J = 3) in Agriculture, 8,261,400, was equivalent to 48.9% of the overall bioeconomy sector (17,638,261) in agriculture (K = 1). Thus, WS_{S1-P3} was assumed equal to 0.489.

In comparison with the values reported in the literature (Ronzon and M'Barek, 2018), the present data show an increase of 118,910 million € and 39,299 million € for turnover and value added, respectively, in 2017 relative to 2015. However, the numbers also show a decrease of 429,837 in the number of workers. The analysis of single bio-based sectors defined the key role played by agriculture (K = 1) and the manufacture of food, beverages and tobacco (K = 4):

- Sector S1 occupied the first position for number of workers (J = 3), with WS_{S1-P3} = 0.489, and the second position in terms of turnover

Table 6
Normalised weights of the socio-economic parameters.

Bio-based sectors	Workers	Turnover	Value added
Agriculture (K = 1)	0.289	0.368	0.343
Forestry (K = 2)	0.321	0.352	0.327
Fishing and aquaculture (K = 3)	0.323	0.347	0.330
Manufacture of food, beverages and tobacco (K = 4)	0.318	0.347	0.335
Manufacture of bio-based textiles K = 5)	0.332	0.337	0.330
Manufacture of wood products and furniture (K = 6)	0.321	0.345	0.334
Manufacture of paper (K = 7)	0.305	0.359	0.336
Manufacture of bio-based chemicals, pharmaceuticals, plastics and rubber (K = 8)	0.307	0.355	0.338
Manufacture of liquid biofuels (K = 9)	0.315	0.356	0.329
Production of bioelectricity (K = 10)	0.319	0.353	0.328

(J = 1), with $WS_{S1-P1} = 0.168$, and value added (J = 2), with $WS_{S1-P2} = 0.291$.

- Sector S4 occupied the first position for both turnover, with $WS_{S4-P1} = 0.516$, and value added, with $WS_{S4-P2} = 0.368$, and the second position in terms of workers, with $WS_{S4-P3} = 0.270$.
- 9 out of 10 bio-based sectors increased both turnover and value added in 2017, relative to 2015 values (with a single exception represented by the production of bioelectricity). Regarding turnover, the most significant increase was registered in sector S4 to the value of 74,721 million €, followed by sector S1 to the value of 18,217 million €. Concerning value added, the opposite situation arose. The most relevant increase was in sector S1 to the value of 18,585 million €, followed by sector S4 to the value of 9410 million €. Finally, five bio-based sectors increased the number of workers (sector S4, by 211,794 units) and the same number of bio-based sectors presented a decrease (sector S1, with 605,800 units).

3.4. SEIB in the European Countries

SEIB was derived from the product of three variables: i) $VP_{SK-(MS)-PJ}$ (see Tables A14–A16), ii) WP_{SK-PJ} (see Table 6) and iii) WS_{SK-PJ} (see Fig. 1). According to eqs. (1)–(2), SEIB was calculated in two distinct steps. The first step evaluated bioeconomy performance in each bio-based sector - $SEIB_{SK-(MS)}$ (Table 8). The second step integrated both socio-economic parameters and bio-based sectors - $SEIB_{(MS)}$ (Fig. 2).

The European average was used as a reference; for example, Eq. (11) reports the value for the agriculture sector (K = 1). The same operation was repeated for the other nine sectors and, finally, the SEIB of the EU 28 was calculated as per Eq. (12).

$$SEIB_{S1-(EU\ 28)} = 0.146 * 0.29 * 0.489 + 0.369 * 0.37 * 0.168 + 0.381 * 0.34 * 0.291 = 0.081 \tag{11}$$

$$SEIB_{(EU\ 28)} = 0.081 + 0.003 + 0.002 + 0.116 + 0.011 + 0.017 + 0.010 + 0.011 + 0.000 + 0.000 = 0.252 \tag{12}$$

The definition of indicators was useful for mapping the entire sector in aggregate. The results clearly demonstrate how all sectors performed. Overall, the final SEIB value was strictly linked to two bio-based sectors: agriculture (K = 1) and the manufacture of food, beverages and tobacco (K = 4). This result does not indicate that less attention was being paid to other sectors; but the quantitative approach used to evaluate socio-economic parameters defined these sectors as priorities. Another relevant result was the initial subdivision of European MSs into two groups: i) 12 MSs with an overall SEIB value higher than the European average and ii) 16 MSs with an overall SEIB value lower than the European average. The weight of sectors (K = 1 and K = 4) for the first group was as follows: Greece (92%; first in K = 3), the Netherlands (89%), Ireland (87%; first in K = 4 and second in K = 1), France and Spain (86%), Romania (84%; first in K = 1), Belgium (80%; first in K = 9), Denmark (79%; first in K = 8 and second in K = 4), Germany (76%), Austria (72%), Portugal (70%; first in K = 5) and Lithuania (64%).

The second observation is that the weights of the socio-economic parameters had less influence than the values of the parameters, themselves. For example, the weight of turnover (J = 1) was 35%, compared to 34% for value added (J = 2) in sector K = 4; while the difference was more significant in sector K = 1 (37% vs 34%). Nonetheless, in the first two countries in the ranking – Ireland ($SEIB_{(IE)} = 0.456$) and Denmark ($SEIB_{(DK)} = 0.400$) – the contribution of $SEIB_{S1-(IE)-P1}$ was 0.062, which is lower than $SEIB_{S1-(IE)-P2}$ of 0.086; the same was verified for $SEIB_{S1-(DK)-P1}$ and $SEIB_{S1-(DK)-P2}$ (0.059 < 0.074). This result must have been determined by $VP_{SK-(MS)-PX}$. However, in sector K = 4, the impact of $SEIB_{S4-(MS)-PJ}$ was more significant than $SEIB_{S1-(MS)-PJ}$; in this case, the values were consistent with the weight preference order. However, the final difference between two socio-economic parameters was particularly significant in the case of Denmark: $SEIB_{S4-(IE)-P2}$

Table 7
Socio-economic parameters of the European bioeconomy in 2017 (European Commission, 2019b; Eurostat, 2018). Workers expressed as number of persons employed; turnover and value added measured in million €.

Bio-based sectors	Workers	Turnover	Value added
Agriculture (K = 1)	8,621,400	398,381	192,182
Forestry (K = 2)	554,300	51,644	27,468
Fishing and aquaculture (K = 3)	165,900	11,650	8104
Manufacture of food, beverages and tobacco (K = 4)	4,756,246	1,227,727	242,818
Manufacture of bio-based textiles (K = 5)	990,248	104,108	28,943
Manufacture of wood products and furniture (K = 6)	1,408,401	181,485	48,809
Manufacture of paper (K = 7)	660,000	200,000	45,961
Manufacture of bio-based chemicals, pharmaceuticals, plastics and rubber (K = 8)	441,336	180,517	60,069
Manufacture of liquid biofuels (K = 9)	27,453	13,086	2957
Production of bioelectricity (K = 10)	12,976	9141	2892
Bioeconomy	**17,638,261**	**2,377,737**	**660,202**

Fig. 1. Percentage distribution of the European bioeconomy sectors in 2017 (European Commission, 2019b; Eurostat, 2018).
Legend: agriculture (K = 1); forestry (K = 2); fishing and aquaculture (K = 3); manufacture of food, beverages and tobacco (K = 4); manufacture of bio-based textiles (K = 5); manufacture of wood products and furniture (K = 6); manufacture of paper (K = 7); manufacture of bio-based chemicals, pharmaceuticals, plastics and rubber (K = 8); manufacture of liquid biofuels (K = 9); production of bioelectricity (K = 10).

(0.082) < $SEIB_{S4-(IE)-P1}$ (0.119); and $SEIB_{S4-(DK)-P2}$ (0.038) < $SEIB_{S4-(DK)-P1}$ (0.116).

3.5. Comparison of SEIB, Turnover/Workers and Value Added/Workers

The proposed indicator does not guarantee a comprehensive and detailed vision of the sector considering that the environmental dimension is not directly considered. However, the main advantage of SEIB is its ability to integrate three socio-economic indicators (evaluating both value and weight) for each bio-based sector with the relative weight of each sector. The main limitation of SEIB is linked to the normalisation practice used to maximise performance (assigning a value of 1, irrespective of the effective value), with all data compared to this maximum value. However, as discussed previously, normalisation is necessary to de-couple the performance of MSs from the size of their population.

Some authors (Ronzon et al., 2017; Ronzon and M'Barek, 2018) have defined the socio-economic dimension of bioeconomy using historical data. In particular, two indicators were proposed: the apparent labour productivity, which is the ratio of value added to employment; and the location quotient, which is the proportion of MS sectoral levels of employment with respect to the corresponding European average levels. The three socio-economic parameters selected in this work (see Section 2.2) can be compared in several ways. On the one hand, it is possible to follow the same approach proposed by Ronzon et al. (2017) and Ronzon and M'Barek (2018) considering the ratio between value added and workers, as well as the ratio between turnover and workers. On the other hand, however, the new indicator proposed in this

Table 8
SEIB for bio-based sectors in 2017.

	K = 1	K = 2	K = 3	K = 4	K = 5	K = 6	K = 7	K = 8	K = 9	K = 10
AT	0.080	0.007	0.000	0.144	0.010	0.038	0.019	0.010	0.000	0.001
BE	0.036	0.001	0.000	0.167	0.004	0.016	0.010	0.016	0.002	0.001
BG	0.068	0.008	0.000	0.117	0.017	0.009	0.006	0.004	0.000	0.000
HR	0.061	0.007	0.005	0.117	0.011	0.013	0.005	0.002	0.000	0.000
CY	0.070	0.002	0.004	0.071	0.000	0.004	0.003	0.000	0.000	0.000
CZ	0.043	0.008	0.000	0.069	0.009	0.014	0.011	0.024	0.000	0.000
DK	0.144	0.002	0.006	0.173	0.003	0.028	0.007	0.034	0.000	0.003
EE	0.038	0.014	0.004	0.058	0.009	0.066	0.006	0.002	0.000	0.001
EU 28	0.081	0.003	0.002	0.116	0.011	0.017	0.010	0.011	0.000	0.000
FI	0.049	0.027	0.001	0.048	0.005	0.031	0.065	0.014	0.002	0.003
FR	0.089	0.002	0.002	0.136	0.008	0.008	0.008	0.010	0.000	0.000
DE	0.031	0.002	0.000	0.166	0.006	0.021	0.014	0.018	0.000	0.000
EE	0.150	0.001	0.006	0.098	0.005	0.003	0.004	0.001	0.000	0.000
HU	0.100	0.004	0.000	0.085	0.006	0.008	0.007	0.015	0.000	0.000
IE	0.174	0.002	0.003	0.223	0.002	0.015	0.004	0.032	0.000	0.000
IT	0.093	0.002	0.002	0.071	0.036	0.022	0.010	0.009	0.000	0.001
LV	0.058	0.018	0.003	0.046	0.010	0.042	0.003	0.003	0.000	0.001
LT	0.102	0.012	0.001	0.060	0.016	0.052	0.008	0.003	0.001	0.000
LU	0.036	0.001	0.000	0.067	0.000	0.005	0.000	0.000	0.000	0.000
MT	0.006	0.000	0.006	0.057	0.000	0.000	0.002	0.000	0.000	0.000
NL	0.163	0.000	0.002	0.132	0.002	0.014	0.010	0.009	0.000	0.000
PL	0.089	0.005	0.001	0.097	0.004	0.025	0.009	0.008	0.001	0.000
PT	0.064	0.005	0.004	0.145	0.042	0.019	0.009	0.013	0.001	0.001
RO	0.206	0.005	0.001	0.041	0.014	0.015	0.003	0.008	0.000	0.000
SK	0.047	0.010	0.000	0.020	0.009	0.016	0.008	0.008	0.000	0.001
SI	0.059	0.007	0.001	0.026	0.007	0.022	0.012	0.003	0.000	0.000
ES	0.130	0.002	0.005	0.102	0.009	0.009	0.008	0.007	0.000	0.000
SE	0.018	0.015	0.001	0.039	0.001	0.029	0.036	0.016	0.002	0.001
UK	0.018	0.001	0.001	0.153	0.004	0.014	0.007	0.006	0.000	0.001

Legend: agriculture (K = 1); forestry (K = 2); fishing and aquaculture (K = 3); manufacture of food, beverages and tobacco (K = 4); manufacture of bio-based textiles (K = 5); manufacture of wood products and furniture (K = 6); manufacture of paper (K = 7); manufacture of bio-based chemicals, pharmaceuticals, plastics and rubber (K = 8); manufacture of liquid biofuels (K = 9); production of bioelectricity (K = 10).

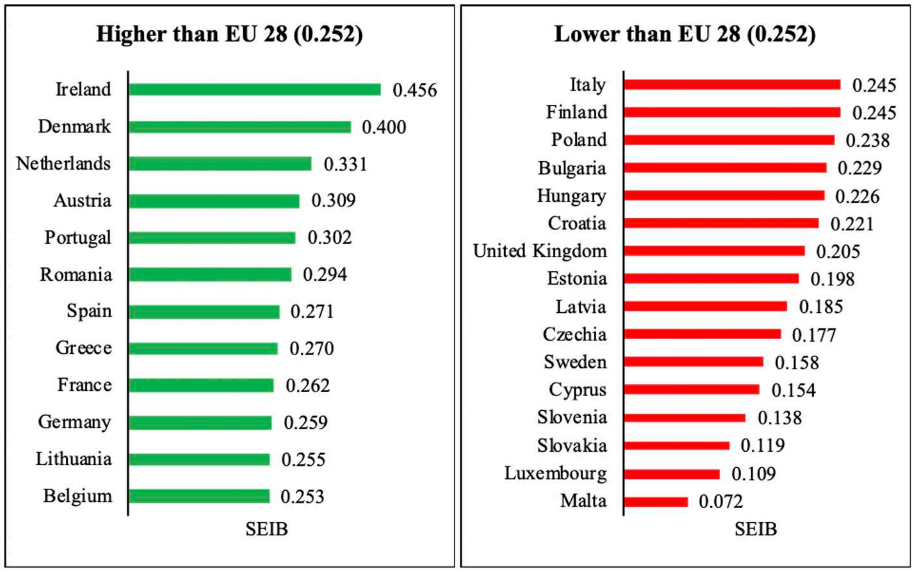

Fig. 2. Higher and lower SEIB value for overall sectors in European MSs, relative to EU 28 in 2017.

Table 9
Three indicators of the bioeconomy, 2017.

SEIB (dimensionless)		Turnover/workers (thousand € per worker)		Value added/workers (thousand € per worker)	
Ireland	0.456	Belgium	421	Ireland	111
Denmark	0.400	Denmark	347	Denmark	97
Netherlands	0.331	Ireland	344	Belgium	93
Austria	0.309	Netherlands	335	Netherlands	85
Portugal	0.302	Finland	293	Sweden	78
Romania	0.294	Sweden	255	Finland	74
Spain	0.271	France	244	United Kingdom	64
Greece	0.270	Germany	205	France	56
France	0.262	United Kingdom	203	Germany	52
Germany	0.259	Austria	169	Austria	52
Lithuania	0.255	Luxembourg	167	Luxembourg	51
Belgium	0.253	Italy	164	Italy	47
EU 28	0.252	Spain	150	Spain	43
Italy	0.245	EU 28	135	EU 28	37
Finland	0.245	Malta	108	Cyprus	31
Poland	0.238	Cyprus	100	Slovakia	26
Bulgaria	0.229	Estonia	97	Czech Republic	25
Hungary	0.226	Czech Republic	83	Estonia	25
Croatia	0.221	Portugal	79	Malta	23
United Kingdom	0.205	Slovenia	73	Hungary	21
Estonia	0.198	Slovakia	73	Portugal	21
Latvia	0.185	Hungary	70	Slovenia	20
Czech Republic	0.177	Lithuania	59	Greece	18
Sweden	0.158	Latvia	57	Croatia	16
Cyprus	0.154	Poland	52	Latvia	16
Slovenia	0.138	Croatia	50	Lithuania	15
Slovakia	0.119	Greece	50	Poland	11
Luxembourg	0.109	Bulgaria	33	Bulgaria	10
Malta	0.072	Romania	18	Romania	5

manuscript, SEIB, aggregates the three parameters through the analytic hierarchy process (AHP) hence allowing for comparison among European Countries – see Table 9.

In the present research, both indicators (turnover/workers and value added/workers) identified the same 13 countries as over-performing against the European average. Belgium was the most efficient in thousand € per worker in terms of turnover (421 thousand €), followed by Denmark and Ireland. Ireland was the most efficient in thousand € per worker in terms of value added (111 thousand €), followed by Denmark and Belgium. In this analysis, the distribution of countries with a value greater or lower than the European average differed from that obtained by SEIB. The main motivation behind optimising these ratios hinged on the role of workers. The final value of SEIB increased in line with the number of persons employed and decreased in line with the value of the above-cited ratios. Hence, Romania, which demonstrated a high SEIB due to its large number of workers in the agriculture sector, presented the worst performance in terms of the ratio of turnover/workers and value added/workers. Conversely, Finland and Sweden showed good performance in terms of both turnover and value added, but an insignificant number of workers. Accordingly, the present research used a new approach, using the number of workers in comparison to both turnover and value added and an expert survey to define the weight of three socio-economic indicators. The results highlight the relevance of this weight, which was found to range from 28.9–33.2% across several bioeconomy sectors (see Table 6). A comparison with existing literature (Ronzon and M'Barek, 2018) is possible only for the per capita value added indicator. Basically, the performance of MSs is not changed in comparison to the European average. On the one hand, among MSs positioned above the average Denmark shows a relevant increase which places it above Belgium; the same occurs for the Netherlands in comparison to Sweden. On the other hand, Poland, Bulgaria and Romania occupy always the last positions.

Ireland, Denmark and the Netherlands occupied the first position in all of the proposed indicators; consequently, these MSs could be seen to play an important role in the development of bioeconomy sectors. Concerning the most populous countries, only three out of these five MSs (France, Germany and Spain) consistently outperformed the European average. The positive performance of Belgium was motivated by the following numerical consideration: it achieved the 17th position in terms of workers, but 8th and 9th in terms of turnover and value added, respectively. Portugal shows, instead, an opposite situation. This country contributes to 1.7% of the overall value-added and to 1.8% of the turnover, while the value associated to workers is equal to 3%. As a result, this determines a lower value with respect to turnover per capita and value added per capita, being the weight of numerator less significant than the one of denominator for the indicators calculation (i.e. turnover/workers and value added/workers).

3.6. SEIB for Manufacturing and Bio-energy Sectors

The bioeconomy involves the agriculture, forestry, fisheries and aquaculture sectors (primary sectors), as well as sectors producing processed food, chemicals, materials and energy (see Table 4). In

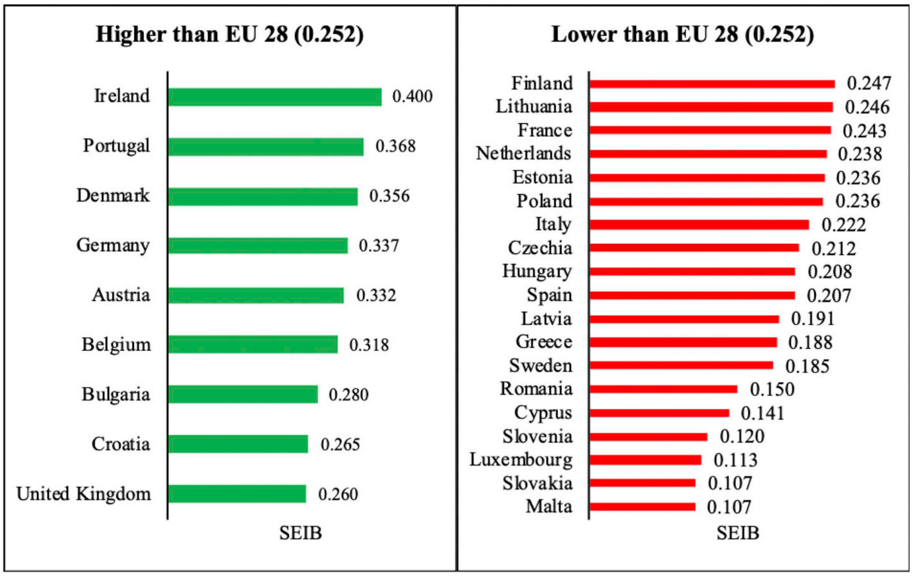

Fig. 3. Higher and lower values of SEIB for manufacturing and bio-energy sectors in European MSs, relative to EU 28 in 2017.

particular, in the present research, the agriculture sector was found to significantly influence the final SEIB value (Fig. 1). To strengthen the findings, a complete analysis was conducted on the performance of the bioeconomy in Europe through an alternative SEIB that excluded primary sectors from the analysis ("SEIB for manufacturing and bio-energy sectors). Consequently, $SEIB_{(MS)}$ (see Eq. (2)) was obtained from seven sectors, excluding K = 1, K = 2 and K = 3. According to this formula, $VP_{S1\text{-}(MS)\text{-}PJ}$, $VP_{S2\text{-}(MS)\text{-}PJ}$ and $VP_{S3\text{-}(MS)\text{-}PJ}$ were 0 and $WS_{SK\text{-}PJ}$ required recalculation. For example, in analysing the manufacture of food, beverages and tobacco (K = 4) the following new weights were obtained: $WS_{S4\text{-}P1}$ = 0.641, $WS_{S4\text{-}P2}$ = 0.561 and $WS_{S4\text{-}P1}$ = 0.573.

Fig. 3 shows the subdivision of MSs with respect to the European average. Six out of the 12 countries presented in Fig. 2 (Ireland, Portugal, Denmark, Germany, Austria and Belgium) achieved a value greater than the EU 28, in addition to Bulgaria, Croatia and United Kingdom. These results confirm that the role of primary sectors is particularly significant in some countries. Fig. 4 shows the variations in MS performance moving from SEIB for overall sectors to SEIB for manufacturing and bio-energy sectors. In particular, the decrease of SEIB for manufacturing and bio-energy sectors was extremely significant in Romania, at 0.144 (0.150 vs. 0.294), followed by that of the Netherlands, Greece and Spain. Conversely, the primary sectors were less relevant in Germany, which showed an increase of only 0.078 (0.337 vs 0.259), followed by Portugal and Belgium. The variation of SEIB in its two dimensions is typically explained by the following observation: SEIB for overall sectors is largely influenced by agriculture (K = 1) and food, beverage and tobacco (K = 4). While the latter is still present in SEIB for manufacturing and bio-energy sectors, agriculture is excluded. Analysing the performance of the best performing countries in terms of $SEIB_{S4\text{-}(MS)}$, some MSs as Germany, Portugal and Belgium display a value of $SEIB_{S1\text{-}(MS)}$ that is smaller than that of $SEIB_{S4\text{-}(MS)}$. This occurrence is due to the fact that for these countries the increase in the value associated to the manufacture of food, beverage and tobacco (K = 4) is significantly larger in magnitude than the reduction of value deriving by the exclusion of agriculture (K = 1). The opposite is true for other countries (like Ireland and Denmark), which show a value of $SEIB_{S4\text{-}(MS)}$ that is greater than $SEIB_{S1\text{-}(MS)}$ (i.e. analysing SEIB for manufacturing and bio-energy sectors the increase of the value associated to the sector K = 4 is not balanced by the reduction of value linked to the sector K = 1).

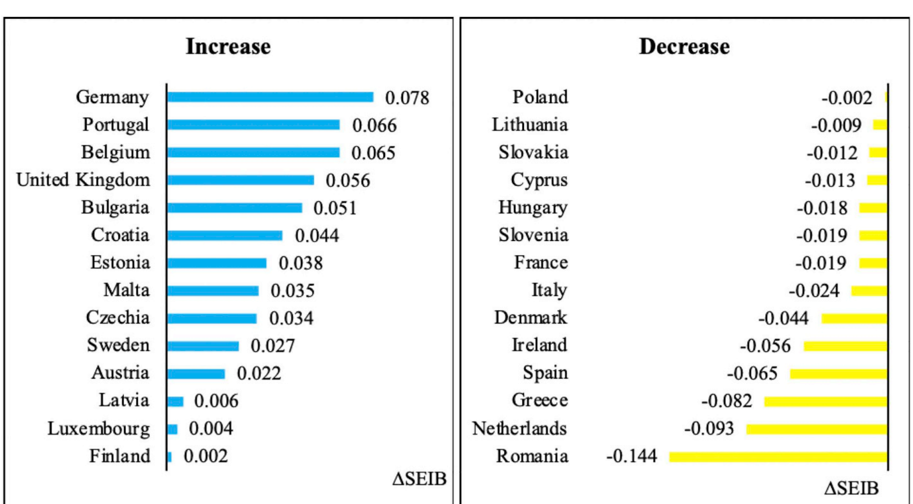

Fig. 4. Delta variation between SEIB for manufacturing and bio-energy sectors and SEIB for overall sectors.

4. Discussion

Monitoring of the European bioeconomy has been hindered by a lack of data capable of covering all bioeconomy sectors, as well as the absence of relevant standardised indicators. However, recently, several aspects of the sustainability of the bioeconomy have been examined, including: residual biomass potential (Hamelin et al., 2019), technological innovation policy (Schütte, 2018), food security (von Braun, 2018) and social assessments (Rafiaani et al., 2018). Of particular interest, Ronzon and M'Barek (2018) sought to provide an overall picture of the development of the bioeconomy in the EU by first estimating a set of socio-economic indicators, also considering hybrid sectors. The present research sought to contribute to the literature by providing a tool to consider and compare socio-economic aspects of the bioeconomy (i.e. value added, turnover and workers) in order to rank European countries' performance and direct and support strategic choices.

Figs. 2 and 3 showed the MSs performance with respect to the European average. Within these two groups (higher and lower than the European average), the SEIB performance of many MSs showed great variation. For example, Ireland had a SEIB for overall sectors that was 0.204 greater than the EU average, while Belgium's was greater by only 0.001. Likewise, Italy displayed a SEIB of only 0.007 lower than the EU average, while Malta's was lower by 0.180. Therefore, it was deemed appropriate to define a range as a reference to provide consistency to the analysis. A hypothetical interval surrounding the EU average (i.e. from - 5% to +5%) was considered for this specific work and allows identifying the composition of three groups of MSs (virtuous, in-between and laggard) with reference to the European average and for both SEIBs.

Looking at the SEIB for overall sectors, MSs were subdivided into the following groups with respect to the EU average value:

- "Virtuous" (> 5%): Ireland, Denmark, the Netherlands, Austria, Portugal, Romania, Spain and Greece.
- "In-between" (± 5%): France, Germany, Lithuania, Belgium, Italy and Finland.
- "Laggard" (< 5%): Poland, Bulgaria, Hungary, Croatia, United Kingdom, Estonia, Latvia, the Czech Republic, Sweden, Cyprus, Slovenia, Slovakia, Luxembourg and Malta.

Recalling the two dimensions of the SEIB, we present also the composition of the three groups considering the SEIB for manufacturing and bio-energy sectors:

- "Virtuous": Ireland, Portugal, Denmark, Germany, Austria, Belgium, Bulgaria and Croatia.
- "In-between": United Kingdom, Finland, Lithuania and France.
- "Laggard": the Netherlands, Estonia, Poland, Italy, the Czech Republic, Hungary, Spain, Latvia, Greece, Sweden, Romania, Cyprus, Slovenia, Luxembourg, Slovakia and Malta.

Particularly, when moving from SEIB for overall sectors to SEIB for manufacturing and bio-energy sectors the composition of the three groups changes significantly (Fig. 5).

Specifically, Ireland, Portugal, Denmark and Austria confirmed their position within the "virtuous" group, demonstrating strong engagement in developing a bioeconomy beyond the agriculture sector. Germany and Belgium – positioned in the "in-between" group – and Bulgaria and Croatia – positioned in the "laggard" group – see their relative ranking improving when excluding the primary sectors. The opposite is true for the Netherlands, Romania, Spain and Greece, which see their ranking worsening when moving from the "SEIB for overall sectors" to the SEIB for manufacturing and bio-energy sectors".

The present focus on bioeconomy performance highlights that the better performing MSs (i.e. Ireland and Denmark) are among those countries that provided early political support to developing the bioeconomy. Indeed, seminal bioeconomy policies were first released in North European countries between 2012 and 2014 (e.g. Ireland (Government of Ireland, 2012), Denmark (National Bioeconomy Panel, 2014), while in South European MSs (i.e. France, Italy and Spain), strategies were released only recently. To appraise this collective effort, it is necessary to introduce a monitoring system at the EU level to measure progress (European Commission, 2018). Such an initiative would be particularly effective when harmonized among the MSs.

The bioeconomy strategies and related perspectives incorporate a broad spectrum of sectors, contemplating market uptake facets as well as research and innovation aspects to support more efficient and environmentally friendly processes. This requires for policy makers the adaptation and continued development of national agendas and initiatives (Fiorillo and Sapio, 2019) as well as efficient regional public–private partnerships encouraging cross-sectoral alliances in order to enable value creation across various industrial innovative sectors (Schütte, 2018).

By developing the bioeconomy, countries can identify innovative solutions to meet food, product and energy needs without exhausting the planet's limited biological resources (Sadhukhan et al., 2018). Dealing with innovative technologies and applications under resource constraints requires the understanding of complex dynamics, where interaction, participatory activity and common vision creation are necessary (Maes and Van Passel, 2019). Therefore, the development of bioeconomy innovative sectors (i.e. bio-based materials, bio-energy, etc) requires the joint effort of all concerned parties, including citizens, public institutions and industry (Corrado and Sala, 2018). In this perspective, an emerging literature distinguishes between the 'old bioeconomy' and the 'innovative bioeconomy', differentiating between the traditional primary sector production and the more innovative and non-fossil fuel dependant bioeconomy (Wreford et al., 2019). The final aim of SEIB is to aggregate the contribution of all bioeconomy sectors highlighting as there is no a direct competition among them. However, the development of bioeconomy can be boosted by the implementation of innovative practices within manufacturing and bio-energy sectors, therefore two versions of SEIB are proposed to single out the impact of most innovative sectors.

A monitoring system can support policy makers providing detailed information on the opportunities and challenges of several MSs. Following this direction, some actions could be undertaken: i) increasing human capital; ii) fostering technological innovations and iii) promoting R&D activities. Moreover, in order to provide a comprehensive assessment for bioeconomy development, policy makers should facilitate the gathering of harmonized data with respect to, for example, resource efficiency, climate change and eco-innovation. The methodology presented in this work could then be used to aggregate all these parameters in order to provide a country's overall sustainability score for the bioeconomy. Both industrial players and policy makers could exploit these outcomes to make more informed choices.

5. Conclusions

The world is undergoing a great revolution in its effort to produce concrete answers to environmental challenges. Traditional models of production and consumption have significantly damaged ecosystems and only some countries have been able to pursue and secure economic development and social welfare. By increasing food, fiber and other bio-based products, which require less input for production and demonstrate better end of life options, we will be more effective at reducing greenhouse gas emissions.

The literature does not present detailed indicators on the bioeconomy; accordingly, the present work has attempted to fill this gap. A new indicator, SEIB, was defined, based on both historical data and scientific methods. A five-step methodology was proposed to calculate SEIB: i) selecting bio-based sectors, ii) choosing socio-economic parameters, iii) assigning values to these parameters, iv) assigning weights

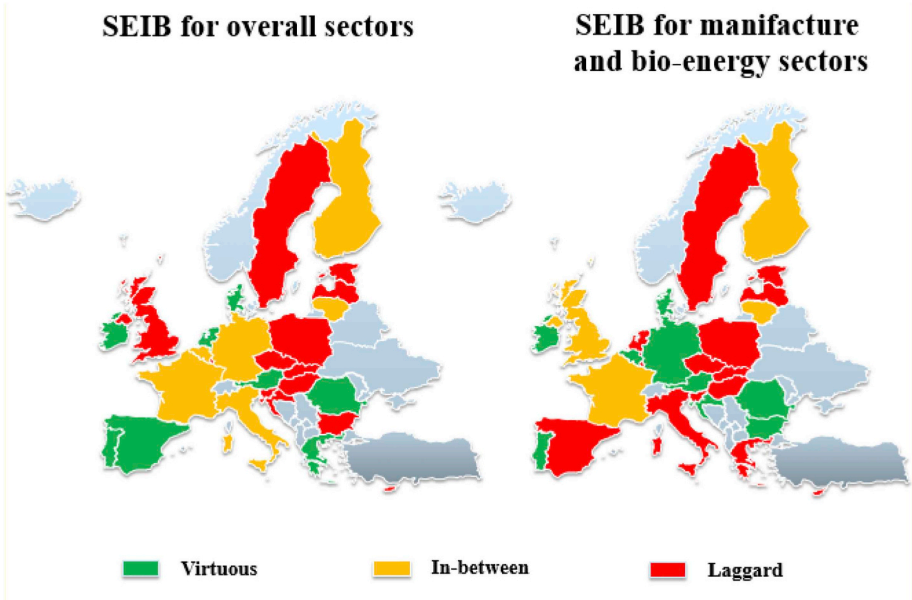

Fig. 5. The breakdown of European countries into three groups.

to the parameters and v) assigning weights to the bio-based sectors. Findings showed that: i) turnover is the socio-economic parameter with the greatest weight, followed by value added; ii) the weights of both agriculture and the manufacture of food, beverages and tobacco were the most significant among the bio-based sector and iii) as absolute values mainly concentrated on the most populated countries, normalisation was required.

The results enabled the European countries to be helpfully divided into different groups. Twelve MSs had a SEIB for overall sectors value greater than the European average and, for the top three countries (Ireland with 0.456, Denmark with 0.400 and the Netherlands with 0.331), the SEIB value exceeded the reference value (EU 28 equal to 0.252) by more than 30%. It was shown that the SEIB incorporates information than both turnover/workers and value added/workers, measuring not only absolute performance but aggregating weights and values of the socio-economic parameters. Finally, a different dimension of the SEIB is presented in order to capture the impact of innovation excluding the primary sector, called SEIB for manufacturing and bio-energy sectors. Both dimensions of SEIB can be monitored annually to rank MSs. When focusing on the second dimension of SEIB, results showed that Ireland (0.400) and Denmark (0.356) keep ranking among the top three best performing countries (with now the inclusion of Portugal). Moreover, findings of this study allowed identifying three groups of MSs (virtuous, in-between and laggard) with reference to the European average. There are only four countries that are qualified as virtuous in both dimensions: Ireland, Denmark, Portugal and Austria.

The proposed SEIB does not consider environmental aspects and this admittedly represents a limit, but currently, there are no specific data on this aspect. Another limit is represented by the use of the European average as a reference value, as opposed to a value more reflective of a sustainable goal (relating to, e.g., share of renewables or reduction in emissions). Another perspective could be to measure the impact of policy strategies on the specific performances evaluating the contribution of single bio-based sectors (distinguishing primary sectors from manufacturing and bio-energy sectors). The monitoring and assessment of indicators with management practices is not only required for European countries, but it must also be developed on a global scale.

Acknowledgments

The authors are very grateful to the STAR-ProBio project (Sustainability Transition Assessment and Research of Bio-based Products) for financial support. The project was funded by the European Union's Horizon 2020 Research and Innovation Programme under Grant Agreement No. 727740, Work Programme BB-01-2016: Sustainability schemes for the bio-based economy.

Some of the findings reported in this article were originally presented at the SFER 2019 Symposium – "The bioeconomy: Organisation, innovation, sustainability and territory," held at the Neoma Business School, Reims, France, on 4–5 June 2019.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ecolecon.2020.106724.

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