



# Exploring regional transitions to the bioeconomy using a socio-economic indicator: the case of Italy

Idiano D'Adamo<sup>1,2</sup> · Pasquale Marcello Falcone<sup>1,3</sup> · Enrica Imbert<sup>1</sup> · Piergiuseppe Morone<sup>1</sup>

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## Abstract

In recent years, there has been a growing awareness of the need to analyze and measure the performance of sustainable transitions at a regional level. This work presents the results of an application of the socio-economic indicator for the bioeconomy (SEIB) to evaluate the socio-economic performance of the bioeconomy at a regional level, providing evidence for the Italian case. Two versions of the SEIB were applied: the first included all sectors of the bioeconomy while the second considered only manufacturing and bio-energy sectors, excluding all primary sectors. The indicator was further analyzed from spatial and longitudinal perspectives. The results showed that four regions (i.e. Trentino A.A. and Veneto in the north and Toscana and Umbria in central Italy) emerged among the five highest performing regions based on both versions of the indicator. Overall, the results underlined that the northern regions performed best when overall sectors were considered, while the central regions performed best when only manufacturing and bio-energy sectors were considered. What emerged most clearly, however, is that regions in southern Italy lagged far behind the national average, particularly when primary sectors were excluded from the analysis.

**Keywords** Bioeconomy · Indicators · policy implications · Regional performance · Sustainable transition

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✉ Piergiuseppe Morone  
piergiuseppe.morone@unitelmasapienza.it

Extended author information available on the last page of the article

## 1 Introduction

The bioeconomy represents a new model for industry that aims at solving major economic, societal and ecological challenges, such as resource reduction, food insecurity and climate change (Wydra 2020). It is an important step on the path towards achieving sustainable goals (Morone 2018) and therefore a relevant mission for regional, national and European public policies (Befort 2020). In particular, the bioeconomy may foster competitiveness, sustainable economic growth and job creation in rural and industrial areas (Vivien et al. 2019). It is expected to reduce dependence on traditional fossil-based feedstocks (Hurmekoski et al. 2019) and to promote the utilization of locally sourced wastes and residues (Agovino et al. 2019), in support of the circular economy (Zabaniotou and Kamaterou 2019; Zotti and Bigano 2019).

Although the bioeconomy is generally viewed as a positive “comprehensive societal transition”, potential trade-offs and negative impacts have also been recognized. Specifically, in addition to the rather well-known concerns surrounding the sustainability of the bioeconomy, food security, land grabbing, change in direct and indirect land use and other issues have been raised (see Choi et al. 2019; Falcone and Imbert 2019). Researchers have emphasized that the development of the bioeconomy is likely to place increased pressure on water bodies and natural ecosystems, and that this might limit any reduction in emissions (Pfau et al. 2014). Moreover, when considering sustainable transitions, regional differences must be considered (Ingrao et al. 2018).

The sustainable development of regional bioeconomy systems is becoming increasingly difficult to evaluate (Ronzon and Sanjuán 2020). In particular, as Wohlfahrt et al. (2019) identified, any evaluation must incorporate the circularity of matter and energy, the strategies and concerns of various categories of stakeholders, different spatial and temporal scales involved in the value chain, the effects of exogenous drivers (e.g. policies and regulations) and the interactions between these aspects.

In investigating the urgency of the transition from a fossil- to a bio-based economy, some works have focused on environmental aspects (Brizga et al. 2019), while others have referred to socio-economic dimensions (Jarosch et al. 2020) and still others to environmental-economic perspectives (Jander et al. 2020). Finally, some have included all three pillars of sustainability (Egenolf and Bringezu 2019).

In the present study, we assessed socio-economic dimensions, following a defined line of research underlying that the monitoring systems of the bioeconomy should quantify the socio-economic developments across various sectors (Ronzon et al. 2020). Currently, the literature is lacking multi-dimensional studies of the socio-economic impact of such systems (Sanz-Hernández et al. 2019).

Ronzon and M'Barek (2018) provided a socio-economic assessment of the bioeconomy performance of European countries based on an analysis of the number of workers, turnover and value added in several bioeconomy sectors. Starting with this analysis, a new socio-economic indicator for the bioeconomy (SEIB)

was introduced by D’Adamo et al. (2020a, b). The SEIB was created using multi-criteria decision analysis (MCDA), and two variants were provided to define the impact of innovative sectors. Notably, in conducting a comparison of the bioeconomy performance of several countries, Capasso and Klitkou (2020) focused their attention on specific regions, underlying the need for a new socio-economic indicator to measure the regional performance of bioeconomy sectors. Against this background, the present study aimed at evaluating regional performance related to the bioeconomy. Specifically, we examined the case of Italy—a country with a historically strong economic base in primary production—employing an MCDA technique that, drawing on Istat data and applying the analytic hierarchy process (AHP), enabled the direct comparison of Italian regions. Two versions of the SEIB were applied: the first included all sectors of the bioeconomy while the second considered only manufacturing and bio-energy sectors, excluding all primary sectors.

The remainder of the paper is organized as follows: Sect. 2 provides a review of the literature. Section 3 describes the materials and methods; Sect. 4 presents the results while Sect. 5 discusses the main findings. Finally, Sect. 6 concludes and illustrates some limitations of the work.

## 2 Background

### 2.1 The spatial dimension in transitions towards sustainability

Transitions towards sustainability are given a high priority, worldwide (Matschoss et al. 2020). However, the task of facilitating such transitions is complex, as they typically involve multi-scalar relations of actors operating in different domains of society (Essletzbichler 2012) and at different geographical scales (Bridge et al. 2013). In this perspective, the geography of transitions concerns the understanding of similarities and differences so as to develop insights about institutional frameworks, local values, social networks and resource endowments at the basis of sustainability transitions (Köhler et al. 2019). However, the overall debate over sustainability transitions has often ignored the places where transitions occur, which determine the spatial configurations and dynamics of the relevant networks (Fastenrath and Braun 2018). The spatial view represents a relational perspective, whereby distance or proximity—understood as more than simply area on a map—may be seen to dictate the space within which actors exert influence (Coenen et al. 2012).

As emphasized by Li et al. (2011), relational networks, characterized by the proximity between actors, might assume a key role in the development of new innovative niches, as well as the expansion of industrial clusters. Proximity, itself, describes a multi-dimensional and intersecting form of relationship between actors whose geographical positions, socio-economic and managerial practices and backgrounds might affect the opportunity and timing for a transition to occur (Boschma 2005). In a seminal contribution, Gibson et al. (2000) argued that absolute proximity refers to cities, regions, nations and so on, as containers of spatial and geographical variables explaining transitions. However, transitions not only happen within a bounded

spatiality, but they might also be the result of the multi-scalar relations (i.e. relative proximity) between spatially dispersed actors within multi-level structures (Raven et al. 2012). Scholars in the field of economic geography distinguish between four dimensions of relative proximity: (i) cognitive, referring to the background knowledge shared by actors; (ii) organizational, denoting the organizational characteristics shared by actors; (iii) social, indicating the trust, reciprocity and shared experiences among actors; and (iv) institutional, representing shared cultural backgrounds, norms and values among actors (Boschma 2005; Raven et al. 2012). While relative proximity is certainly relevant for building trust among actors, geographical proximity is important for stimulating learning processes between them (Coenen et al. 2010). As a matter of fact, local actors and institutions may play a key role in translating sustainability perspectives into tangible experiences, and they are thus fundamental for fostering social learning and acceptability within communities in order to catalyze socio-technical change (Truffer and Coenen 2012).

Against this background, the development of the bioeconomy represents a complex sustainability transition with deep geographical implications (Calvert et al. 2017) requiring appropriate strategies and adequate instruments to support it (Angenendt et al. 2018). Recently, transitions towards a more advanced bioeconomy have been studied on a regional scale for the purposes of: (i) providing a representative case study of the impact of transitioning from biowaste to biofuel energy (Kokkinos et al. 2020); (ii) identifying potential opportunities for—and barriers to—solid wood cascading within the forest and bioproduct industry (Husgafvel et al. 2018); (iii) ascertaining the role of regional clusters in realizing the bioeconomy's potential (Kircher et al. 2018); (iv) and assessing regional differentials in the social impact of wood-based production chains (Jarosch et al. 2020).

## 2.2 Development of the bioeconomy

The term “bioeconomy,” also referred to as the “bio-based economy”, has been in circulation since the early 2000s (Scarlat et al. 2015). It describes the substitution of non-renewable resources with bio-based alternatives (D’Amato et al. 2017), highlighting the role of bio-based energy and materials in decreasing negative environmental impacts (Bugge et al. 2016). The application of circular economy principles to the bioeconomy could potentially optimize bioeconomy performance (Corrado and Sala 2018). Indeed, the bioeconomy is part of the circular economy, characterized by a circular and closed flow of materials, whereby waste from one process becomes input for another (van Meijl 2019).

The development of the bioeconomy involves the reduction and re-integration of waste streams so as to generate a multitude of socio-economic opportunities through the science, design and improvement of production and processing facilities in related industries (Wreford et al. 2019). In 2012, the European Commission issued its first Bioeconomy Strategy, marking a milestone in national government commitments and public policies to promote new ways of innovating, producing and creating jobs. A few years later, the European Commission launched an incremental development of the strategy, aimed at advancing

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 (SDGs) (European Commission 2018). Particularly, the updated Bioeconomy Strategy aims at supporting key EU policy priorities, such as the renewed Industrial Policy Strategy, the Circular Economy Action Plan and the Communication on Accelerating Clean Energy Innovation (European Commission 2018). In addition to contributing to socio-economic goals, the bioeconomy is also expected to help meet important environmental goals by merging bio- and circular economy principles, which are considered complementary; in this way, it addresses the abovementioned sustainability issues related to the bioeconomy (European Environment Agency 2018). The priorities and related perspectives of the European Commission include a wide range of sectors, and consider market uptake aspects as well as research and innovation facets to foster environmentally friendly processes. They require policy makers to adapt and continuously develop national agendas and initiatives (Schütte 2018), as well as to ensure efficient financial support for the development of industrial innovative sectors (Shi et al. 2019).

At the country level, seminal bioeconomy initiatives and strategies were first released in northern European countries between 2012 and 2014 [e.g. Ireland (Government of Ireland 2012), Denmark (National Bioeconomy Panel 2014)]; however, in southern European countries (i.e. France, Italy, Spain), strategies were released only recently. In line with the European vision, the new Italian bioeconomy strategy aims at supporting the sustainable production of renewable biological resources by converting these resources and waste streams into value added products, such as food, feed, bio-based products and bio-energy (Italian Government 2019). According to the latest Eurostat data, Italy remains significantly above the European average for dependency on energy import, at a rate of 77% (Eurostat 2019). Therefore, despite the sharp drop in the price of crude oil, increased energy production from alternative sources remains central, given the recent and complex international developments that have affected many of Italy's major energy partners.

In this context, the Italian bioeconomy, whose overall production value in 2017 was estimated at slightly less than €330 billion, including 2 million jobs (Intesa San Paolo 2019), may play a strategic role in redirecting conventional industry towards sustainability and aligning the country with the new European Bioeconomy Strategy. The Italian bioeconomy strategy provides a shared vision of the economic, social and environmental opportunities and challenges associated with bioeconomy development, based on longer, more sustainable and more local value chains. It also denotes a significant opportunity for Italy to boost its competitiveness and role in fostering sustainable growth in Europe and the Mediterranean region (SVIMEZ 2019). To speed up this process, decision makers must support the development of the bioeconomy. Doing so is likely to have two primary benefits: stimulating sustainable growth processes in the long term and bringing the policy measures in the north and south of Italy into greater equilibrium. This might catalyze Italy's transition towards the bioeconomy and bring significant growth and sustainability (Ladu et al. 2020).

### 2.3 Indicators for monitoring the bioeconomy development

Indicators and monitoring schemes for the development of the bioeconomy have recently been proposed to inform decision makers about socio-economic and environmental performance throughout the transition. Lier et al. (2018) reviewed several economic, social and ecological indicators of the bioeconomy that have been proposed at the sectorial, the national, and the EU level. Some of the reviewed studies focused on national-level indicators (Blumberga et al. 2017; Talavyria et al. 2017), while others provided a systematic approach to understanding and quantifying the socio-economic performance of the EU's bioeconomy (Ronzon and M'Barek 2018), while also highlighting the impact of its most innovative sectors (i.e. manufacturing and bio-energy) (D'Adamo et al. 2020b). Several other contributions examined bio-based sectors, such as the wood (Budzinski et al. 2017), forestry (Karvonen et al. 2017) and bioenergy, biomaterials and biochemicals sectors (van Meijl et al. 2018). Special attention is also paid to the end of life management of bio-based products in order to favour the circularity of resources (D'Adamo et al. 2020a).

Although the literature on this topic is constantly developing, there remains a clear need for new methods of measuring the development of the bioeconomy within the social sciences (Sanz-Hernández et al. 2019). In particular, to ensure the long-term sustainability of the bioeconomy, researchers must gain significantly more insight into its influence on the planet's ecological capacity (Brizga et al. 2019), the current economic and ecological transition (Toppinen et al. 2017), primary sectors (Asada and Stern 2018) and the potential for unexplored resources to be used as biofuels and bioproducts (Guo and Song 2019). None of the previously proposed indicators adequately measures the full scope of the transition from a fossil- to a bio-based economy, although, taken together, they provide useful direction for the development of new indicators (Jander and Grundmann 2019). In this regard, O'Brien et al. (2017) claimed that an overall monitoring framework for the bioeconomy is needed to consider various levels of analysis and include targets for evaluating sustainability. The authors applied the DPSIR<sup>1</sup> framework (EEA 1999) to the bioeconomy in order to link changes in production and consumption to environmental impacts, both domestically and abroad. Later, Egenolf and Bringezu (2019) used the DPSIR to create a new indicator based on a detailed set of variables to measure the economic, social and environmental sustainability of the bioeconomy. Finally, Zeug et al. (2019) identified priority issues for the monitoring of the bio-economy, drawing on sustainability aspects identified during a German stakeholder survey; such issues included the complementary objectives of food security, sustainable final consumption, sustainable production and sustainable infrastructures.

Relying on the extensive and interdisciplinary academic research on bioeconomy monitoring, the present analysis contributes new empirical evidence, from a regional level. Specifically, prior analyses of the bioeconomy have neglected the role of smaller geographical configurations (Falcone et al. 2020), despite the growing role

<sup>1</sup> DPSIR (drivers, pressures, state, impact and response model of intervention) is a causal framework for describing the interactions between society and the environment.

of urban studies in demonstrating the key role of cities and regions in sustainability transitions (Cerciello et al. 2019). At this level, monitoring is particularly relevant for efficient policy making, since it enables proposed schemes and environmental management policies to be tailored to local needs.

### 3 Materials and methods

The MCDA framework supports decision makers in appraising multiple and conflicting items (Leoncini et al. 2019). It defines the best solution among several alternatives, which are evaluated according to two criteria: (i) performance (scoring criteria) and (ii) relevance (weighting criteria). MCDA is popular, thanks to its flexibility. For example, some authors have applied specific indicators as criteria (Kumar et al. 2017); this approach was used by Antanasijević et al. (2017) and Vavrek and Chovancová (2019), considering countries as alternatives. The application of MCDA to define new indicators is well established in the literature: Almeida (2019) proposed this method to compare Brazilian municipalities, Cucchiella et al. (2017) used the approach to compare European countries and Su et al. (2020) applied it in a comparison of Europe and China. All of these studies were applied to investigate sustainability. We followed the approach presented in a previous work (D’Adamo et al. 2020b), which introduced a new indicator (the SEIB) to measure the performance of bioeconomy sectors. We employed both versions of the SEIB to measure the socio-economic performance of Italian bioeconomy sectors at a regional scale. The first version of the SEIB considers all bio-based sectors (“SEIB for all sectors”), while the second excludes all primary sectors (“SEIB for manufacturing and bio-energy sectors”).

The SEIB is a dimensionless indicator that combines 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 on two levels:

1. assessment of each bio-based sector (SEIB<sub>SK-(MS)</sub>)—Eq. (1); and
2. aggregation of SEIB<sub>SK-(R)</sub>, considering all bio-based sectors—Eq. (2).

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

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

in which VP<sub>SK-(R)-PJ</sub>=the value of the parameters calculated for the following combinations: (i) bio-based sector SK with K=1 ... N, in which N=the number of bio-based sectors; (ii) region R, which represents the alternatives to compare, for which the total number is equal to 20 (i.e. the number of Italian regions) and (iii) socio-economic parameter X=1 ... J, in which J=the number of socio-economic



parameters. Additionally,  $WP_{SK-PX}$  is defined according to the following combinations: (i) bio-based sector SK with  $K=1 \dots N$  and (ii) socio-economic parameter  $X=1 \dots J$ . Finally,  $WS_{SK-PX}$  considers the following combinations: (i) bio-based sector SK with  $K=1 \dots N$  and (ii) socio-economic parameter  $X=1 \dots J$ . The value of  $VP_{SK-(R)-PJ}$  is specific for each R, while either  $WP_{SK-PJ}$  or  $WS_{SK-PJ}$  is independent.

Our methodology adhered to the following steps:

1. selection of bioeconomy sectors, according to the NACE classification;
2. choice of parameters for measuring socio-economic performance, according to the literature review (Ronzon and M'Barek 2018);
3. assignment of values to the parameters for each bioeconomy sector, based mainly on Istat data;
4. assignment of weights to the parameters for each bioeconomy sector, based on a pairwise comparison provided by experts; and
5. definition of weights to the bio-based sectors, based mainly on Istat data.

Concerning the first step, ten macro-sectors were selected according to the official statistical classification of economic activities of the European Community (NACE rev. 2) (Ronzon and M'Barek 2018):  $K=1 \rightarrow$  Agriculture (A01);  $K=2 \rightarrow$  Forestry (A02);  $K=3 \rightarrow$  Fishing and aquaculture (A03);  $K=4 \rightarrow$  Manufacture of food, beverages and tobacco (comprising Manufacture of food (C10), Manufacture of beverages (C11) and Manufacture of tobacco (C12));  $K=5 \rightarrow$  Manufacture of bio-based textiles (comprising Manufacture of textiles (C13), Manufacture of wearing apparel (C14) and Manufacture of leather (C15));  $K=6 \rightarrow$  Manufacture of wood products and furniture [comprising Manufacture of wood products (C16) and Manufacture of furniture (C31)];  $K=7 \rightarrow$  Manufacture of paper (C17);  $K=8 \rightarrow$  Manufacture of bio-based chemicals, pharmaceuticals, plastics and rubber (excluding biofuels) (comprising Manufacture of chemicals (excluding biofuels) (C20), Manufacture of pharmaceuticals (C21) and Manufacture of bio-based plastics and rubber (C22));  $K=9 \rightarrow$  Manufacture of liquid biofuels [comprising Manufacture of bioethanol (C2014) and Manufacture of biodiesel (C2059)] and  $K=10 \rightarrow$  Production of bio-electricity (D3511). The NACE classification does not distinguish between bio-based and non-bio-based activities. Nine of the 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, using either biomass or carbon fossil-based feedstock (e.g. C13, C14, C31, C20, C21, C22, C2014, C2059 and D3511). For the latter, it was necessary for us to estimate their bio-based share.

Regarding the second step, the choice of parameters was based on the literature (Ronzon and M'Barek 2018). Precisely, three parameters were considered: (i) turnover; (ii) value added and (iii) workers. No environmental parameter was used, due to an absence of reliable data; however, the choice adopted in this work was justified by the gap in the literature concerning the socio-economic dimensions of the bioeconomy. Specifically, turnover and value added are economic in nature, while workers are a social factor.



Concerning the third step, we drew on Istat statistics for the Italian regions, with the most recent data available referring to 2015 (Istat 2019). In the case of hybrid sectors, a sectoral bio-based share was applied, following the approach used by Ronzon et al. (2017), using values calculated by D'Adamo et al. (2020a, b). We compared Eurostat data and values proposed by Ronzon et al. (2017) to calculate an average value for each country over a 2-year time period. As it was not possible to access region-specific data, we applied national data to each region. This choice was justified by the literature (Capasso and Klitkou 2020). The following sectoral bio-base shares were used: 45% for C13, 39% for C14, 6% for C20, 56% for C21, 4% for C22, 3% for C2014, 8% for C2059, 42% for C31 and 7% for D3511.

In accordance with other works evaluating sustainability (Cucchiella et al. 2017; Szopik-Depczyńska et al. 2018), each value was divided by the relevant population figure, in order to homogenize the data between regions. All input data are reported in Tables A1–A7. Where data was lacking, values were assumed equal to those of the previous year; where this was not possible, the data were adjusted using an iterative approach.

Regarding the fourth step, the AHP methodology developed by Saaty (1980) enabled us to produce a list of priorities through pairwise comparisons based on expert judgments. The questionnaire employed in our analysis was built with the Qualtrics Research Suite survey software and managed with the CAWI (computer-assisted web interview) technique (Falcone et al. 2019). The questionnaire was administered to a final list of 20 experts, including a wide range of academics and researchers (i.e. research fellows, lecturers, associate professors, full professors) with long-standing experience in the bioeconomy. For this phase, we used weights calculated in previous research (D'Adamo et al. 2020b). This choice was justified by the following observations: (i) the consistency of the pairwise comparison matrix was verified for all experts; (ii) the panel of experts did not refer to the Italian national context, but the wider European context; and (iii) the time period between the data collection of the present study and that of D'Adamo et al. (2020a, b) was short. However, the subjectivity of the some weighting procedure is acknowledged as a limitation of the present work. A different panel of experts, representing other categories of stakeholders (i.e. policy makers, managers), may have proposed different value choices.

Finally, the fifth step concerned the distribution of weights among several bio-based sectors, which were calculated using statistical data with reference to the Italian average in 2015.

The construction of this indicator was motivated by a need to measure the performance of the bioeconomy. Accordingly, it initially calculated performance as the product of the values and weights assigned to each socio-economic parameter. However, as the bioeconomy involves several bio-based sectors, a third component was added to the measure: sector size. Sector size was obtained from the specific weights assigned to the bio-based sectors as a function of the socio-economic parameters. The assignment of weights to the bio-based sectors was not subjective, because the weights were defined as the ratio between the specific and overall values.

A further limitation of the present study is the compensatory nature of the additive aggregation method. For instance, an increase in any of the dimensions considered by the indicator could be offset by progress in any of the remaining aspects (i.e.

a decline in employment could be fully compensated by an increase in turnover or value added). This issue was limited by the presence of weights within the indicator. In fact, variation in the performance of the socio-economic parameters was multiplied for both the parameter weights and the dimension of the bio-based sector. We believe that this issue can be checked via two actions: (i) monitoring single components of the indicator during the relevant time period and (ii) drawing comparisons with other indicators (e.g. the ratio between turnover and workers, the ratio between value added and workers).

The SEIB was developed using multi-criteria analysis; however, the literature also proposes alternative methods (Nardo et al. 2008). In fact, a typical approach is to use different MCDA methods, aggregating single indicators into composite ones (El Gibari et al. 2019). This technique enables comparisons to be drawn between countries and full rankings (Castillo-Giménez et al. 2019).

## 4 Results

### 4.1 Assessment of socio-economic parameters

The first output of our indicator, which aimed at measuring regional performance, calculated the performance of socio-economic parameters ( $VP_{SK-(R)-PX}$  in Eq. (1)). Each input figure was subdivided by the relevant population figure in order to homogenize the data and facilitate comparisons between regions of differing size. Subsequently, data was normalized using the min/max method. For example, the highest number of workers in sector A01 was registered in Puglia (146,929 units), followed by Sicilia (106,056 units) (see Tables A1–A2). The ratio of these values with the relative regional population (see Table A7) determined the figures of 0.036 and 0.021 workers per capita in Puglia and Sicilia, respectively (see Table 1). When comparing all 18 per capita values, Basilicata presented the highest number, with 0.040 workers per capita. Applying a normalization approach, the maximum value of 1 was associated with Basilicata, while the minimum value of 0 was attributed to the lowest value (registered by Lazio). For example, an intermediate value of 0.877 was calculated for Puglia. The same logic was used to calculate the values of turnover and value added. Regarding turnover, Veneto registered the first position, with 6,511,000 thousand €, followed by Lombardia, with 6,018,000 thousand € (see Tables A3–A4). Following the normalization procedure, Trentino emerged as the first region, with 1.65 thousand € per capita, while Veneto occupied the second position, with 1.32 thousand € per capita (see Table 2). Concerning value added, Lombardia and Puglia demonstrated the best performance, with 3,337,000 and 3,100,000 thousand €, respectively (see Tables A5–A6). Also in this case, the normalization changed the ranking, with the first two positions occupied by Trentino, with 1.18 thousand € per capita, and Calabria, with 0.79 thousand € per capita (see Table 3). The same approach was applied to the other nine bio-based macro-sectors (see Sect. 3).

The normalization approach was obtained as a function of the population, according to the sustainability literature (Barbier and Burgess 2019; Cucchiella

**Table 1** Normalized value of workers in 2015

| Region         | K=1   | K=2   | K=3   | K=4   | K=5   | K=6   | K=7   | K=8   | K=9   | K=10  |
|----------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Piemonte       | 0.268 | 0.022 | 0.000 | 0.301 | 0.289 | 0.129 | 0.472 | 0.493 | 0.491 | 0.176 |
| Valle d'Aosta  | 0.562 | 0.037 | 0.000 | 0.343 | 0.014 | 0.257 | 0.000 | 0.014 | 0.000 | 1.000 |
| Liguria        | 0.141 | 0.008 | 0.275 | 0.111 | 0.015 | 0.018 | 0.103 | 0.159 | 0.203 | 0.201 |
| Lombardia      | 0.018 | 0.081 | 0.000 | 0.194 | 0.428 | 0.250 | 0.682 | 0.946 | 1.000 | 0.188 |
| Trentino A.A   | 0.845 | 1.000 | 0.000 | 0.558 | 0.088 | 0.633 | 0.666 | 0.294 | 0.368 | 0.603 |
| Veneto         | 0.311 | 0.017 | 0.276 | 0.480 | 0.491 | 0.528 | 0.961 | 0.500 | 0.439 | 0.081 |
| Friuli V.G     | 0.119 | 0.002 | 0.293 | 0.167 | 0.060 | 0.822 | 0.714 | 0.261 | 0.204 | 0.034 |
| Emilia Romagna | 0.215 | 0.038 | 0.195 | 0.415 | 0.300 | 0.192 | 0.526 | 0.524 | 0.642 | 0.252 |
| Toscana        | 0.149 | 0.113 | 0.217 | 0.401 | 0.894 | 0.227 | 1.000 | 0.465 | 0.340 | 0.124 |
| Umbria         | 0.159 | 0.157 | 0.000 | 0.623 | 0.429 | 0.270 | 0.690 | 0.169 | 0.226 | 0.178 |
| Marche         | 0.280 | 0.045 | 1.000 | 0.200 | 0.690 | 0.620 | 0.871 | 0.582 | 0.258 | 0.064 |
| Lazio          | 0.000 | 0.038 | 0.148 | 0.073 | 0.038 | 0.015 | 0.196 | 0.374 | 0.143 | 0.263 |
| Abruzzo        | 0.301 | 0.125 | 0.540 | 0.316 | 0.300 | 0.133 | 0.752 | 0.375 | 0.234 | 0.075 |
| Molise         | 0.847 | 0.144 | 0.724 | 0.206 | 0.119 | 0.062 | 0.084 | 0.263 | 0.351 | 0.136 |
| Campania       | 0.138 | 0.020 | 0.190 | 0.185 | 0.152 | 0.027 | 0.279 | 0.117 | 0.093 | 0.000 |
| Puglia         | 0.877 | 0.020 | 0.638 | 0.160 | 0.183 | 0.106 | 0.153 | 0.078 | 0.083 | 0.048 |
| Basilicata     | 1.000 | 0.068 | 0.000 | 0.226 | 0.046 | 0.118 | 0.101 | 0.071 | 0.014 | 0.130 |
| Calabria       | 0.551 | 0.000 | 0.316 | 0.059 | 0.007 | 0.032 | 0.032 | 0.012 | 0.035 | 0.043 |
| Sicilia        | 0.455 | 0.005 | 0.895 | 0.108 | 0.008 | 0.004 | 0.071 | 0.063 | 0.101 | 0.032 |
| Sardegna       | 0.461 | 0.075 | 0.591 | 0.162 | 0.007 | 0.084 | 0.051 | 0.064 | 0.176 | 0.152 |
| Italy          | 0.265 | 0.061 | 0.281 | 0.240 | 0.275 | 0.189 | 0.468 | 0.401 | 0.379 | 0.140 |

et al. 2017; Szopik-Depczyńska et al. 2018). However, alternative approaches may be based on other variables, such as land area and gross domestic product (Martinico-Perez et al. 2018).

An analysis of Tables 1, 2 and 3 reveals that not all macro-sectors registered the maximum value of 1, due to the presence of two or more micro-sectors in five macro-sectors (K=4, K=5, K=6, K=8 and K=9). In fact, a max/min normalization approach was applied to all bio-based micro-sectors and, in the absence of synchronism, the maximum value was not reached (e.g. sector K=8, composed of C20, C21 and C22, showed the value of 1 only for turnover and value added, but not for workers). While the normalization approach had the great advantage of making all data comparable, it had the limitation of rendering the performance of individual regions relative to that of the leading region. Figure 1 shows the list of regions occupying the first position for each macro-sector and socio-economic parameter. The prevalence of northern and central regions can be easily identified, showing that these regions were typically macro-sector leaders, regardless of the indicator considered.

**Table 2** Normalized value of turnover in 2015

| Region         | K=1   | K=2   | K=3   | K=4   | K=5   | K=6   | K=7   | K=8   | K=9   | K=10  |
|----------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Piemonte       | 0.363 | 0.022 | 0.000 | 0.310 | 0.296 | 0.111 | 0.277 | 0.457 | 0.492 | 0.054 |
| Valle d'Aosta  | 0.349 | 0.037 | 0.000 | 0.170 | 0.009 | 0.107 | 0.000 | 0.010 | 0.000 | 0.717 |
| Liguria        | 0.062 | 0.008 | 0.275 | 0.027 | 0.011 | 0.010 | 0.060 | 0.208 | 0.393 | 0.542 |
| Lombardia      | 0.223 | 0.081 | 0.000 | 0.259 | 0.446 | 0.268 | 0.424 | 1.000 | 1.000 | 0.494 |
| Trentino A.A   | 1.000 | 1.000 | 0.000 | 0.490 | 0.172 | 0.583 | 0.686 | 0.253 | 0.353 | 0.285 |
| Veneto         | 0.756 | 0.017 | 0.276 | 0.536 | 0.662 | 0.449 | 1.000 | 0.404 | 0.357 | 0.052 |
| Friuli V.G     | 0.237 | 0.002 | 0.293 | 0.147 | 0.046 | 0.904 | 0.409 | 0.252 | 0.170 | 0.136 |
| Emilia Romagna | 0.328 | 0.038 | 0.195 | 0.429 | 0.352 | 0.197 | 0.373 | 0.491 | 0.619 | 0.084 |
| Toscana        | 0.221 | 0.113 | 0.217 | 0.340 | 0.933 | 0.160 | 0.864 | 0.363 | 0.318 | 0.047 |
| Umbria         | 0.222 | 0.157 | 0.000 | 0.511 | 0.303 | 0.169 | 0.395 | 0.152 | 0.150 | 0.030 |
| Marche         | 0.133 | 0.045 | 1.000 | 0.080 | 0.542 | 0.551 | 0.394 | 0.498 | 0.182 | 0.020 |
| Lazio          | 0.000 | 0.038 | 0.148 | 0.099 | 0.044 | 0.016 | 0.103 | 0.332 | 0.101 | 1.000 |
| Abruzzo        | 0.339 | 0.125 | 0.540 | 0.158 | 0.171 | 0.110 | 0.854 | 0.208 | 0.158 | 0.024 |
| Molise         | 0.491 | 0.144 | 0.724 | 0.081 | 0.041 | 0.034 | 0.029 | 0.081 | 0.133 | 0.045 |
| Campania       | 0.139 | 0.020 | 0.190 | 0.152 | 0.102 | 0.035 | 0.161 | 0.097 | 0.038 | 0.000 |
| Puglia         | 0.715 | 0.020 | 0.638 | 0.107 | 0.097 | 0.077 | 0.059 | 0.072 | 0.131 | 0.025 |
| Basilicata     | 0.667 | 0.068 | 0.000 | 0.095 | 0.059 | 0.069 | 0.063 | 0.033 | 0.005 | 0.007 |
| Calabria       | 0.698 | 0.000 | 0.316 | 0.008 | 0.002 | 0.016 | 0.009 | 0.009 | 0.026 | 0.012 |
| Sicilia        | 0.309 | 0.005 | 0.895 | 0.054 | 0.004 | 0.003 | 0.029 | 0.084 | 0.159 | 0.000 |
| Sardegna       | 0.414 | 0.075 | 0.591 | 0.102 | 0.003 | 0.037 | 0.027 | 0.066 | 0.171 | 0.024 |
| Italy          | 0.331 | 0.061 | 0.281 | 0.227 | 0.280 | 0.173 | 0.342 | 0.379 | 0.366 | 0.223 |

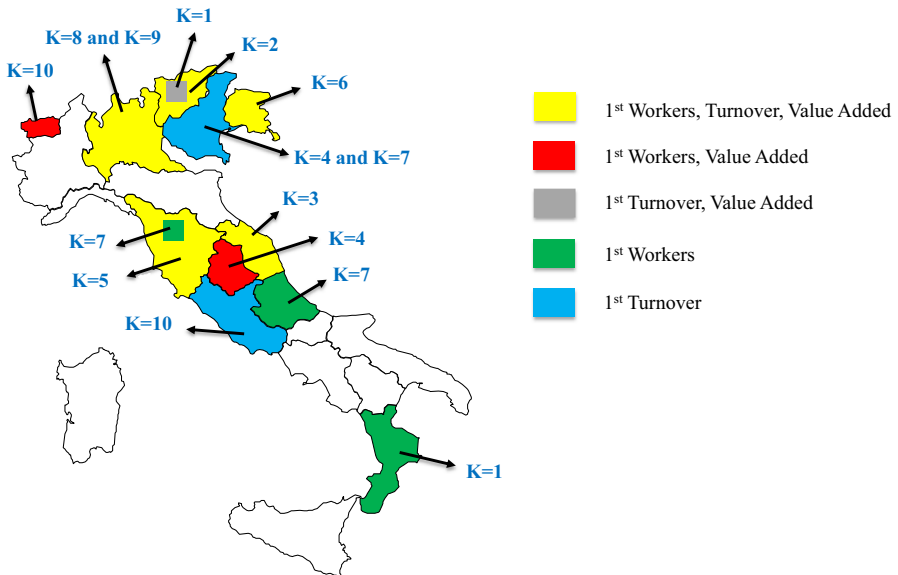
## 4.2 Assessment of socio-economic parameters

The second SEIB component ( $WP_{SK-PX}$  in Eq. (1)) was not calculated in the present study; rather, we used the results of previous research (D'Adamo et al. 2020b). These results were obtained through an AHP methodology comparing three socio-economic parameters for each macro bio-based sector. Consequently, the weighting was based on the judgment of experts. Also in this phase, all judgements were normalized using the procedure identified by Belton and Gear (1983), which permitted normalized values in which the sum of three weights referring to socio-economic parameters was equal to 1 (see Table 4).

The SEIB differs from other indicators in its ratio between turnover and workers, and between value added and workers, because an increase in workers basically determines an overall improvement in the SEIB value. However, the impact of workers is lower than that of turnover and value added. In fact, the results reported in Table 5 show that workers registered a lower weight in all sectors other than  $K=5$  (in which workers had a greater weight than value added). Amongst all sectors, the weight of workers ranged from 0.289 to 0.332. Turnover represented the most significant parameter, with values ranging from 0.337 to 0.368. Thus, the minimum value assigned to turnover (in  $K=5$ ) exceeded the maximum value associated with workers (also in  $K=5$ ). Finally, value added was considered important, with weights

**Table 3** Normalized value of value added in 2015

| Region         | K=1   | K=2   | K=3   | K=4   | K=5   | K=6   | K=7   | K=8   | K=9   | K=10  |
|----------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Piemonte       | 0.278 | 0.022 | 0.000 | 0.365 | 0.348 | 0.108 | 0.364 | 0.519 | 0.483 | 0.134 |
| Valle d’Aosta  | 0.379 | 0.037 | 0.000 | 0.444 | 0.009 | 0.151 | 0.000 | 0.010 | 0.010 | 1.000 |
| Liguria        | 0.134 | 0.008 | 0.275 | 0.068 | 0.012 | 0.020 | 0.091 | 0.358 | 0.816 | 0.274 |
| Lombardia      | 0.191 | 0.081 | 0.000 | 0.290 | 0.504 | 0.285 | 0.454 | 1.000 | 1.000 | 0.198 |
| Trentino A.A   | 1.000 | 1.000 | 0.000 | 0.530 | 0.139 | 0.629 | 0.766 | 0.263 | 0.298 | 0.847 |
| Veneto         | 0.423 | 0.017 | 0.276 | 0.540 | 0.590 | 0.472 | 0.746 | 0.459 | 0.370 | 0.058 |
| Friuli V.G     | 0.221 | 0.002 | 0.293 | 0.160 | 0.047 | 0.830 | 0.490 | 0.253 | 0.201 | 0.023 |
| Emilia Romagna | 0.289 | 0.038 | 0.195 | 0.400 | 0.330 | 0.173 | 0.397 | 0.557 | 0.689 | 0.157 |
| Toscana        | 0.187 | 0.113 | 0.217 | 0.393 | 0.945 | 0.173 | 0.794 | 0.402 | 0.316 | 0.109 |
| Umbria         | 0.203 | 0.157 | 0.000 | 0.635 | 0.535 | 0.216 | 0.410 | 0.167 | 0.202 | 0.120 |
| Marche         | 0.137 | 0.045 | 1.000 | 0.143 | 0.657 | 0.533 | 0.597 | 0.518 | 0.192 | 0.036 |
| Lazio          | 0.000 | 0.038 | 0.148 | 0.094 | 0.055 | 0.020 | 0.132 | 0.311 | 0.082 | 0.315 |
| Abruzzo        | 0.313 | 0.125 | 0.540 | 0.204 | 0.245 | 0.105 | 1.000 | 0.367 | 0.146 | 0.046 |
| Molise         | 0.385 | 0.144 | 0.724 | 0.083 | 0.011 | 0.042 | 0.033 | 0.267 | 0.328 | 0.086 |
| Campania       | 0.151 | 0.020 | 0.190 | 0.149 | 0.102 | 0.034 | 0.168 | 0.086 | 0.053 | 0.000 |
| Puglia         | 0.598 | 0.020 | 0.638 | 0.088 | 0.117 | 0.065 | 0.073 | 0.061 | 0.057 | 0.068 |
| Basilicata     | 0.562 | 0.068 | 0.000 | 0.157 | 0.060 | 0.085 | 0.058 | 0.043 | 0.000 | 0.070 |
| Calabria       | 0.631 | 0.000 | 0.316 | 0.015 | 0.003 | 0.015 | 0.008 | 0.008 | 0.022 | 0.067 |
| Sicilia        | 0.326 | 0.005 | 0.895 | 0.047 | 0.006 | 0.006 | 0.029 | 0.040 | 0.052 | 0.037 |
| Sardegna       | 0.387 | 0.075 | 0.591 | 0.099 | 0.004 | 0.052 | 0.027 | 0.032 | 0.084 | 0.098 |
| Italy          | 0.279 | 0.061 | 0.281 | 0.243 | 0.297 | 0.177 | 0.347 | 0.397 | 0.367 | 0.137 |



**Fig. 1** Top-ranking Italian regions in 2015

**Table 4** Normalized weights of the socio-economic parameters (D'Adamo et al. 2020b)

| Bio-based sector   | 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 bio-electricity (K=10)   | 0.319   | 0.353    | 0.328       |

ranging from 0.327 to 0.343; however, its weight never exceeded that of turnover. Specifically, we registered a difference of 7.9% between the weights of turnover and workers in sector  $K=1$ ; in the same macro-sector, the difference between turnover and value added was only 2.5%. Lower differences were registered in another key macro-sector ( $K=4$ ): 2.9% between turnover and workers and 1.2% between turnover and value added.

### 4.3 Assessment of bio-based sectors

The final component of the SEIB measures the weight of several bio-based sectors ( $WS_{SK-PX}$  in Eq. (1)). The value of this weight is calculated as the ratio between the specific value of the bio-based sector analyzed and the total value. Consequently, normalization is not necessary. In the present research, weights were calculated using historical data. Table 5 shows the overall value of the three socio-economic parameters.

The results demonstrate the key role played by two macro bio-based sectors:

- Agriculture ( $K=1$ ) registered the highest values for workers (44.8%) and value added (31.0%) and the third highest value for turnover (15.5%); and
- Manufacture of food, beverages and tobacco ( $K=4$ ) occupied the first position in terms of turnover (44.7%) and the second position in terms of both value added (30.6%) and workers (22.5%).

With respect to turnover, the second highest position was registered in the Manufacture of bio-based textiles ( $K=5$ ), with 16.6%; this sector also showed the third highest value for both workers (14.3%) and value added (14.9%). All weights are reported in Table 6.

In analyzing Table 6, it is necessary to underline that the relevant factors include not only sector position, but also the great differences across sectors, in terms of value. Specifically: (i) the weight of workers in  $K=1$  was double that of  $K=4$ ; (ii)

**Table 5** Socio-economic parameters in Italy in the year 2015 (Istat 2019). Workers expressed as number of persons employed; turnover and value added measured in million €

| Bio-based sector   | Workers   | Turnover | Value added |
|--|-----------|----------|-------------|
| Agriculture (K = 1)  | 853,685   | 45,440   | 25,842      |
| Forestry (K = 2)   | 51,011    | 2489     | 1229        |
| Fishing and aquaculture (K = 3)  | 19,600    | 904      | 1032        |
| Manufacture of food, beverages and tobacco (K = 4)                               | 427,808   | 131,318  | 25,459      |
| Manufacture of bio-based textiles (K = 5)  | 272,586   | 48,805   | 12,444      |
| Manufacture of wood products and furniture (K = 6)                               | 162,641   | 21,680   | 5925        |
| Manufacture of paper (K = 7)   | 70,337    | 22,341   | 4952        |
| Manufacture of bio-based chemicals, pharmaceuticals, plastics and rubber (K = 8) | 43,858    | 18,033   | 5587        |
| Manufacture of liquid biofuels (K = 9)   | 1601      | 899      | 193         |
| Production of bio-electricity (K = 10)   | 2087      | 1972     | 661         |
| Bioeconomy   | 1,905,215 | 293,880  | 83,324      |

**Table 6** Bio-based sector weights in the year 2015

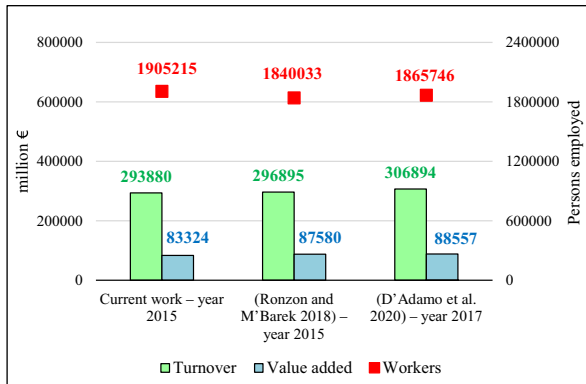
| Bio-based sector   | Workers | Turnover | Value added |
|--|---------|----------|-------------|
| Agriculture (K = 1)  | 0.448   | 0.155    | 0.310       |
| Forestry (K = 2)   | 0.027   | 0.008    | 0.015       |
| Fishing and aquaculture (K = 3)  | 0.010   | 0.003    | 0.012       |
| Manufacture of food, beverages and tobacco (K = 4)                               | 0.225   | 0.447    | 0.306       |
| Manufacture of bio-based textiles (K = 5)  | 0.143   | 0.166    | 0.149       |
| Manufacture of wood products and furniture (K = 6)                               | 0.085   | 0.074    | 0.071       |
| Manufacture of paper (K = 7)   | 0.037   | 0.076    | 0.059       |
| Manufacture of bio-based chemicals, pharmaceuticals, plastics and rubber (K = 8) | 0.023   | 0.061    | 0.067       |
| Manufacture of liquid biofuels (K = 9)   | 0.001   | 0.003    | 0.002       |
| Production of bio-electricity (K = 10)   | 0.001   | 0.007    | 0.008       |

the weight of turnover in K=4 was more than double that of K=5; and (iii) the weight of value added in both K = 1 and K = 4 was double that of K = 5.

By aggregating the values of several bio-based sectors, it was possible to monitor the performance of the bioeconomy, year on year. To this end, Fig. 2 presents a comparison of some of the values registered for the Italian territory. It should be noted that it was not possible to propose values for 2017 because, as explained in Sect. 3, there were no data available. To fill this gap, we used national data from Eurostat (D'Adamo et al. 2020b). These data had already been used by other authors, albeit in reference to another period (Ronzon and M'Barek 2018).

Figure 2 explains the crucial role of input data. The same approach was used to estimate values prior to 2015 regarding the bio-base share of the hybrid sector, but the overall value was different. In particular, the difference concerned the





**Fig. 2** Comparison of values referring to the Italian bioeconomy. Workers expressed as number of persons employed; turnover and value added measured in million €

Agriculture sector. The present research drew on Istat data for each region, with the overall value represented as the sum of each regional contribution. While both turnover and value added demonstrated growth from 2015 to 2017, workers showed the opposite trend.

#### 4.4 SEIB calculation for overall sectors in Italian regions

Assessment of the SEIB comprised two main steps. First, the SEIB was calculated for each socio-economic parameter as the product of three components. Second, the contributions of the three parameters were added to obtain the value of the SEIB for each bio-based sector (see Eq. (1)). The overall value of the SEIB was calculated as the sum of all SEIBs related to each bio-based sector (see Eq. (2)). The indicator was further analyzed from spatial and longitudinal perspectives to measure regional performance and identify policy recommendations.

Starting with these equations and considering the values previously calculated (see Tables 1, 2, 3, 4 and 6), the SEIB for all Italian regions was calculated (Table 7) and the regions were subdivided into two groups (Fig. 3), using the overall Italian value as a benchmark.

For example, we considered Italy as an alternative and Agriculture as a bio-based sector ( $K=1$ ). Furthermore, we identified workers ( $X=1$ ), turnover ( $X=2$ ) and value added ( $X=3$ ). Consequently, Eq. (3) shows the values referred to in Eq. (1), in which we identified the following input data: 0.265 [ $VP_{S1-Italy-P1}$  (Table 1)], 0.331 [ $VP_{S1-Italy-P2}$  (Table 2)], 0.279 [ $VP_{S1-Italy-P3}$  (Table 3)], 0.289 [ $WP_{S1-P1}$  (Table 4)], 0.368 [ $WP_{S1-P2}$  (Table 4)], 0.343 [ $WP_{S1-P3}$  (Table 4)], 0.448 [ $WS_{S1-P1}$  (Table 6)], 0.155 [ $WS_{S1-P2}$  (Table 6)] and 0.310 [ $WS_{S1-P3}$  (Table 6)]. In this way, we obtained a  $SEIB_{S1-Italy}$  equal to 0.083; Eq. (4) shows the values referred to in Eq. (2), in which the overall SEIB was obtained as the sum of the SEIBs for each bio-based sector.

$$\begin{aligned} \text{SEIB}_{S1-(Italy)} &= 0.265 * 0.289 * 0.448 + 0.331 * 0.368 * 0.155 \\ &+ 0.279 * 0.343 * 0.310 = 0.034 + 0.019 + 0.030 = 0.083 \end{aligned} \quad (3)$$

$$\begin{aligned} \text{SEIB}_{(Italy)} &= 0.083 + 0.001 + 0.002 + 0.077 + 0.043 + 0.014 \\ &+ 0.022 + 0.020 + 0.001 + 0.001 = 0.264 \end{aligned} \quad (4)$$

The definition of a benchmark was useful because it enabled us to subdivide Italy's regions into two distinct groups: (i) those with a SEIB higher than the Italian value (11 regions) and (ii) those with a SEIB lower than the Italian value (9 regions). The SEIB of reference (Italian value) was 0.264. Figure 4 shows a decomposition analysis of this indicator, subdividing the weight of the three socio-economic parameters for each region. The results underline that all sectors contributed to Italy's final value and were useful for the development of the bioeconomy; however, two bio-based sectors played a key role: Agriculture ( $K=1$ ) and the Manufacture of food, beverages and tobacco ( $K=4$ ). The maximum value of the SEIB was 0.273 (Trentino A. A.) for sector  $K=1$  and 0.189 (Umbria 0.189) for sector  $K=4$ . Other maximum values were attributed to Toscana (0.141) in sector  $K=5$  and Friuli V.G. (0.065) in sector  $K=6$ .

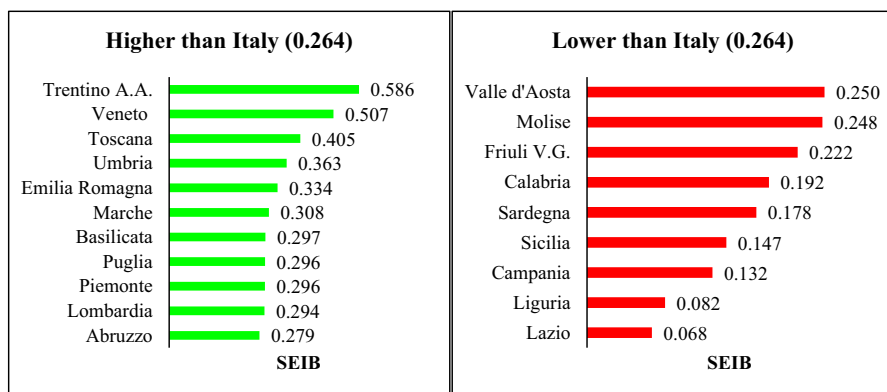
The first five regions in the ranking were among the first six positions of sector  $K=4$  with respect to all three socio-economic parameters; however, only Trentino A.A. and Veneto also achieved high rankings in sector  $K=1$ . In particular, the results underline the presence of Puglia and Basilicata in the top five regions across all three socio-economic parameters for this sector. This determined the final result of only three southern regions in the "higher" side of the ranking: Puglia, Basilicata and Abruzzo. Regarding the central regions, three out of four had a SEIB greater than 0.264: Toscana, Umbria and Marche. The exception was represented by Lazio, which occupied the last position of the ranking. Finally, Piemonte and Lombardia achieved values higher than the benchmark, as did Trentino A.A., Veneto and Emilia Romagna in the northern regions.

Another point of reflection pertains to the relevance of the parameter values. For example, in sector  $K=1$ , the weight of workers was greater than that of turnover and value added, with Basilicata generating a value of 1 and Trentino A.A., in fourth position, presenting a figure of 0.845. This difference was not significant. However, the same was not true when turnover and value added were considered: Trentino A.A. had the highest value (1) in both, while Basilicata presented values of 0.667 (turnover) and 0.561 (value added). This resulted in the final performance of Trentino A.A. surpassing that of Basilicata (0.273 vs. 0.227). The same was verified in sector  $K=4$ , where turnover had a greater weight than workers and value added. Here, Veneto had the best performance in turnover, followed by Umbria (0.536 vs. 0.511); however, the difference was not significant. Instead, there was a significant difference in the other two parameters: Umbria occupied the first position in terms of value added (0.635 vs. 0.540 for Veneto in the second position) and workers (0.622 vs. 0.480 for Veneto in the third position). The final performance of Umbria was better than that of Veneto (0.189 vs. 0.173).

**Table 7** SEIB for bio-based sectors in 2015

|                | K=1   | K=2   | K=3   | K=4   | K=5   | K=6   | K=7   | K=8   | K=9   | K=10  |
|----------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Piemonte       | 0.085 | 0.000 | 0.000 | 0.107 | 0.047 | 0.009 | 0.020 | 0.025 | 0.001 | 0.001 |
| Valle d'Aosta  | 0.133 | 0.001 | 0.000 | 0.096 | 0.002 | 0.013 | 0.000 | 0.001 | 0.000 | 0.005 |
| Liguria        | 0.036 | 0.000 | 0.002 | 0.019 | 0.002 | 0.001 | 0.005 | 0.014 | 0.001 | 0.002 |
| Lombardia      | 0.035 | 0.001 | 0.000 | 0.084 | 0.070 | 0.020 | 0.028 | 0.051 | 0.002 | 0.002 |
| Trentino A.A   | 0.273 | 0.016 | 0.000 | 0.170 | 0.021 | 0.047 | 0.042 | 0.014 | 0.001 | 0.003 |
| Veneto         | 0.128 | 0.000 | 0.002 | 0.173 | 0.090 | 0.037 | 0.053 | 0.023 | 0.001 | 0.000 |
| Friuli V.G     | 0.052 | 0.000 | 0.002 | 0.051 | 0.008 | 0.065 | 0.029 | 0.013 | 0.000 | 0.000 |
| Emilia Romagna | 0.077 | 0.001 | 0.002 | 0.137 | 0.050 | 0.014 | 0.024 | 0.027 | 0.001 | 0.001 |
| Toscana        | 0.052 | 0.002 | 0.002 | 0.122 | 0.141 | 0.014 | 0.051 | 0.020 | 0.001 | 0.000 |
| Umbria         | 0.055 | 0.003 | 0.000 | 0.189 | 0.064 | 0.017 | 0.027 | 0.008 | 0.000 | 0.000 |
| Marche         | 0.058 | 0.001 | 0.008 | 0.041 | 0.096 | 0.044 | 0.032 | 0.027 | 0.000 | 0.000 |
| Lazio          | 0.000 | 0.001 | 0.001 | 0.030 | 0.007 | 0.001 | 0.008 | 0.017 | 0.000 | 0.003 |
| Abruzzo        | 0.091 | 0.002 | 0.005 | 0.068 | 0.036 | 0.009 | 0.052 | 0.015 | 0.000 | 0.000 |
| Molise         | 0.179 | 0.002 | 0.006 | 0.036 | 0.008 | 0.004 | 0.002 | 0.010 | 0.000 | 0.000 |
| Campania       | 0.042 | 0.000 | 0.002 | 0.052 | 0.018 | 0.002 | 0.011 | 0.005 | 0.000 | 0.000 |
| Puglia         | 0.218 | 0.000 | 0.005 | 0.037 | 0.020 | 0.006 | 0.005 | 0.004 | 0.000 | 0.000 |
| Basilicata     | 0.227 | 0.001 | 0.000 | 0.047 | 0.008 | 0.007 | 0.004 | 0.002 | 0.000 | 0.000 |
| Calabria       | 0.178 | 0.000 | 0.003 | 0.007 | 0.001 | 0.002 | 0.001 | 0.000 | 0.000 | 0.000 |
| Sicilia        | 0.111 | 0.000 | 0.008 | 0.021 | 0.001 | 0.000 | 0.002 | 0.003 | 0.000 | 0.000 |
| Sardegna       | 0.124 | 0.001 | 0.005 | 0.037 | 0.001 | 0.004 | 0.002 | 0.003 | 0.000 | 0.000 |
| Italy          | 0.083 | 0.001 | 0.002 | 0.077 | 0.043 | 0.014 | 0.022 | 0.020 | 0.001 | 0.001 |

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 bio-electricity (K=10).

**Fig. 3** Higher and lower SEIB value for overall sectors in Italian regions, relative to Italy in 2015

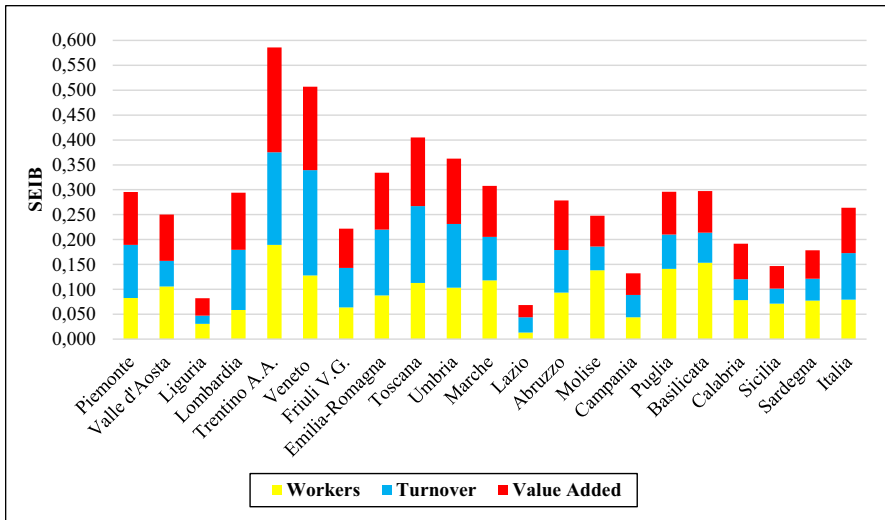


Fig. 4 A decomposition analysis of regional SEIBs, relative to Italy’s SEIB, in 2015

### 4.5 Comparison of the three indicators

The present work proposed a new indicator (the SEIB) to provide a unique value associated with three socio-economic parameters; this represents a main advantage over two other indicators: the ratio between turnover and workers and the ratio between value added and workers (D’Adamo et al. 2020a, b; Ronzon and M’Barek 2018; Ronzon et al. 2017). While the SEIB incorporates all of the parameters of the other measures, it enables workers to act as a positive driver, thereby increasing the final value. In contrast, an increase in one of the three parameters does not necessarily determine a consequent increase in the SEIB. Furthermore, the performance of a single region must always be compared to the leading region, due to the requirement for normalization. Finally, the SEIB does not provide a sustainable dimension, because the environmental side is not evaluated. Table 8 presents a comparison of the three indicators examined in this sub-section.

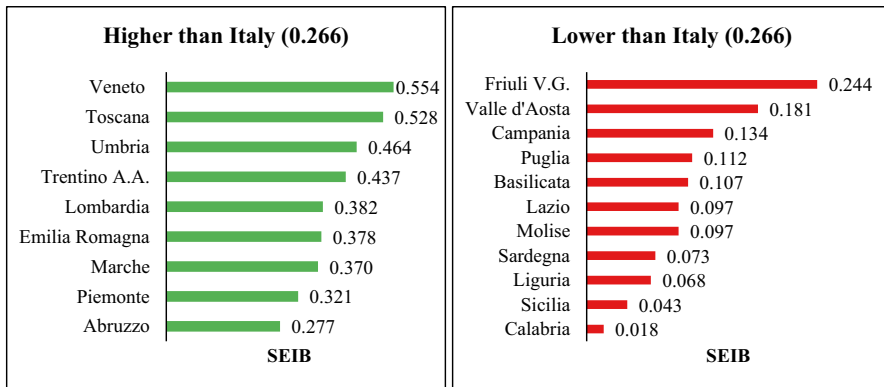
Relative to the SEIB, both the turnover/workers and the value added/workers indicators produced different results. The reason for this is mathematic. When analyzing parameter weights in a single region relative to a national value, one might assert that if the percentage weight of workers is lower than that of turnover (or value added), the relative indicator should have a greater value than the national value. For example, Umbria had 1.5% of all Italian bioeconomy sector workers, while its percentage weight in terms of turnover and value added was 1.2% and 1.6%, respectively. Thus, the ratio between turnover and workers was 148 thousand € per worker (lower than 185 thousand € per worker), while the ratio between value added and workers was 54 thousand € per worker (greater than 52 thousand € per worker). Liguria showed a similar situation, with a weight of 1.4% in terms of workers; this exceeded the weight of 1.3% for turnover and

**Table 8** Three indicators of the bioeconomy in 2015

| SEIB (dimensionless) |       | Turnover/workers (thousand € per worker) |     | Value added/workers (thousand € per worker) |    |
|----------------------|-------|--|-----|---|----|
| Trentino A.A         | 0.586 | Lazio                                    | 302 | Lombardia                                   | 77 |
| Veneto               | 0.507 | Lombardia                                | 294 | Liguria                                     | 69 |
| Toscana              | 0.405 | Emilia Romagna                           | 243 | Lazio                                       | 68 |
| Umbria               | 0.363 | Veneto                                   | 220 | Emilia Romagna                              | 62 |
| Emilia Romagna       | 0.334 | Piemonte                                 | 199 | Piemonte                                    | 59 |
| Marche               | 0.308 | Friuli V.G                               | 194 | Umbria                                      | 54 |
| Basilicata           | 0.297 | Italy                                    | 185 | Veneto                                      | 54 |
| Puglia               | 0.296 | Toscana                                  | 184 | Friuli V.G                                  | 53 |
| Piemonte             | 0.296 | Liguria                                  | 177 | Italy                                       | 52 |
| Lombardia            | 0.294 | Umbria                                   | 148 | Toscana                                     | 51 |
| Abruzzo              | 0.279 | Marche                                   | 137 | Trentino A.A                                | 50 |
| Italy                | 0.264 | Trentino A.A                             | 136 | Valle d'Aosta                               | 49 |
| Valle d'Aosta        | 0.250 | Campania                                 | 135 | Abruzzo                                     | 46 |
| Molise               | 0.248 | Abruzzo                                  | 132 | Marche                                      | 42 |
| Friuli V.G           | 0.222 | Valle d'Aosta                            | 94  | Campania                                    | 39 |
| Calabria             | 0.192 | Sardegna                                 | 87  | Calabria                                    | 35 |
| Sardegna             | 0.178 | Puglia                                   | 78  | Sardegna                                    | 33 |
| Sicilia              | 0.147 | Sicilia                                  | 75  | Sicilia                                     | 30 |
| Campania             | 0.132 | Molise                                   | 66  | Molise                                      | 28 |
| Liguria              | 0.082 | Calabria                                 | 66  | Puglia                                      | 27 |
| Lazio                | 0.068 | Basilicata                               | 59  | Basilicata                                  | 26 |

was lower than the weight of 1.8% for value added. All other Italian regions presented the same issue. On the one hand, Lombardia, Veneto, Emilia Romagna, Piemonte, Lazio and Friuli V.G. had greater values for both turnover/workers and value added/workers than the national figures. The first four regions confirmed the performance defined by the SEIB, while Lazio and Friuli V.G did not. In particular, Lazio occupied the first region for turnover, with 302 thousand € per worker. Its weight of 3.7% for workers was lower than its weights of 6.1% and 4.9% for turnover and value added, respectively. The first position for value added was assumed by Lombardia, with 77 thousand € per worker. Lombardia had a weight of 17% for workers, lower than its weights of 27% and 25% for turnover and value added, respectively. On the other hand, among the 12 regions with a lower value for both turnover/workers and value added/workers relative to the national figures, there was a great prevalence of southern regions. This was determined by the high numbers of workers, compared to the values for turnover and value added.

Table 8 identifies two different pictures of the Italian bioeconomy as a function of the selected indicator. Thus, the distribution of regions compared to the Italian average changed as a function of the role of workers. A significant limitation of



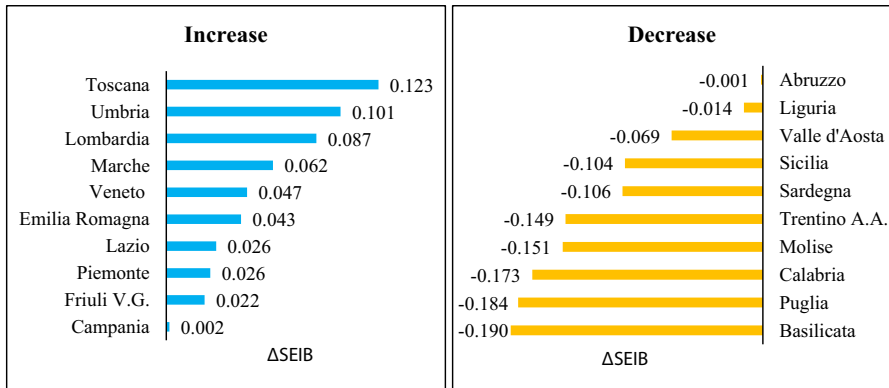
**Fig. 5** Higher and lower SEIB values for Italian manufacturing and bio-energy sectors, by region, relative to the overall SEIB for Italy in 2015

using either turnover/workers or value added/workers in this measurement is that an increase in workers will determine a reduction in the above-cited ratios. Conversely, an increase in the number of workers should determine a greater SEIB value, but since this indicator was the output of multi-criteria analysis (and thereby an aggregation of several specific components), in the present analysis, this did not always occur. Notwithstanding this limitation, the SEIB assigns a more positive role to workers relative to other socio-economic indicators.

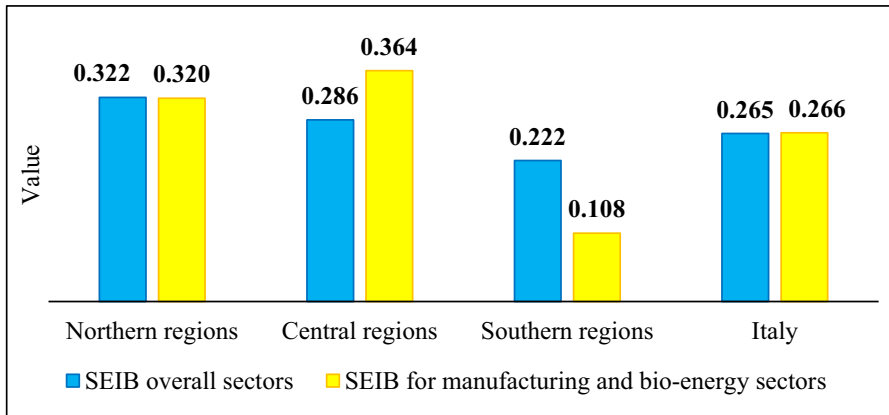
#### 4.6 SEIB for manufacturing and bio-energy sectors

The bioeconomy includes a wide range of sectors. To measure each sector, two versions of the SEIB were applied. Section 4.4 analyzed the SEIB for overall sectors, while this subsection concerns the SEIB for manufacturing and bio-energy sectors, excluding primary sectors (i.e. agriculture, forestry, fisheries and aquaculture). In applying this more restrictive SEIB, we set the weights and values of three sectors ( $K = 1$ ,  $K = 2$  and  $K = 3$ ) equal to 0. This determined a change in weight of the bio-based sectors (see Table 6). For example, the workers, turnover and value added weights of sector  $K = 4$  were initially 0.436, 0.536 and 0.480, respectively. The SEIB values for the second model are proposed in Figs. 5, 6 and 7.

The results confirmed that the Agriculture sector played a key role in the bioeconomy, particularly in southern regions. Considering all eight southern regions, the decrease in SEIB was extremely significant when moving from overall sectors (0.222) to manufacturing and bio-energy sectors, only (0.108). Specifically, only two regions (Puglia and Basilicata) generated higher scores in the SEIB for manufacturing and bio-energy than the SEIB for overall sectors. Furthermore, in the second SEIB, only Abruzzo registered a value greater than the average (0.266). Puglia and Basilicata showed the highest decrease in SEIB from the first to the second model, to the value of 0.190 and 0.184, respectively. With the exception



**Fig. 6** Delta variation between the SEIB for overall sectors and the SEIB for manufacturing and bio-energy sectors



**Fig. 7** Comparison of SEIBs across geographical areas

of Campania, all southern regions showed a decrease from the SEIB for overall sectors to the SEIB for manufacturing and bio-energy.

An opposite trend was verified for all central regions, which showed improved performance on the second model. Total SEIB increased 0.286, generating a final value of 0.364. In particular, Toscana presented the highest increase (of 0.123), followed by Umbria (0.101). However, Lazio’s value did not reach the national average (0.097 vs. 0.266).

The northern regions demonstrated a small decrease in SEIB between the first and second models (from 0.322 to 0.320), with Veneto occupying the first position in terms of the SEIB for manufacturing and bio-energy sectors, with a value of 0.554. Nine regions generated a value greater than the Italian average in both SEIBs:



Veneto, Toscana, Umbria, Trentino A.A., Lombardia, Emilia Romagna, Marche, Piemonte and Abruzzo.

The SEIB of overall sectors depended mainly on two sectors ( $K=1$  and  $K=4$ ), while the SEIB for manufacturing and bio-energy sectors depended on only one sector ( $K=4$ ). Consequently, the performance of regions in the latter SEIB model pertained only to the Manufacture of food, beverages and tobacco. The 0.273 decrease in the SEIB for Trentino A.A. was caused by the exclusion of the Agriculture sector, which was not compensated for by the region's increase in other sectors (e.g.  $K=4$ , which rose from 0.170 to 0.254). The same was verified in Puglia, in which the 0.019 increase in SEIB in sector  $K=4$  was not able to compensate for the 0.218 decrease in sector  $K=1$ . An opposite situation was verified in Lombardia, where the increase in SEIB for sector  $K=4$  (0.122 vs. 0.084) was greater than the decrease associated with that for sector  $K=1$  (0.035). While this was not verified in Veneto (where the SEIB increased from 0.173 to 0.253 in sector  $K=4$  and decreased 0.128 in sector  $K=1$ ), the contribution of other manufacturing and bio-energy sectors determined an increase in the final SEIB value.

#### 4.7 Regional subdivision: virtuous, in-between, laggard

This sub-section does not aim at intervening in the final value of the SEIB models proposed in this work; rather, it aims at proposing a new regional subdivision in terms of performance. In fact, within the two groupings proposed in Figs. 3 and 5, the SEIB assessment of many regions showed great variation. For example, the SEIB for overall sectors in Trentino A.A. was 0.322 greater than the Italian figure, while Abruzzo's was greater by only 0.015. Likewise, Valle d'Aosta presented a SEIB of only 0.014 lower than the Italian figure, while Lazio's was lower by 0.196. To group Italian regions more usefully and provide greater consistency to the analysis, we defined a reference interval. A hypothetical range surrounding the Italian figure ( $-10\%$  to  $+10\%$ ) was assumed and used to classify three groups: virtuous, in-between and laggard. While a previous study considered a variation of  $\pm 5\%$  for this purpose (D'Adamo et al. 2020b), in the present work, this percentage range was not able to determine a significant impact. Regarding the SEIB for overall sectors, in-between values ranged from 0.239 to 0.292; for the SEIB for manufacturing and bio-energy sectors, values ranged from 0.239 to 0.293. Figure 8 shows the new subdivision of all regions for both versions of the SEIB.

Moving from the SEIB for overall sectors to the SEIB for manufacturing and bio-energy sectors, the composition of the three groups did not seem to change significantly. In fact, the results underlined the following breakdown:

- a virtuous ( $>10\%$ ) group, composed of eight regions in both versions of the SEIB: Trentino A.A., Veneto, Toscana, Umbria, Emilia Romagna, Marche, Piemonte and Lombardia;
- an in-between ( $\pm 10\%$ ) group, in which there was only one region in both versions of the SEIB (Abruzzo); and

### SEIB for overall sectors

### SEIB for manufacturing and bio-energy sectors

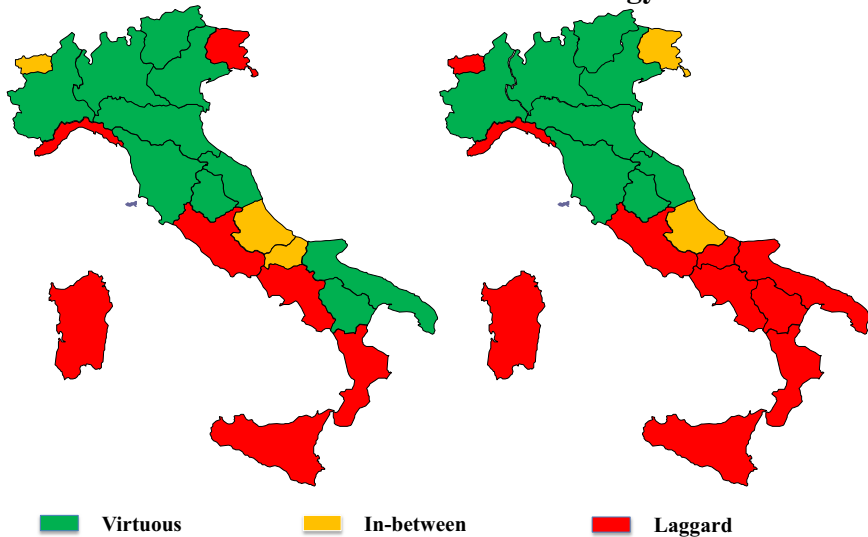


Fig. 8 Subdivision of Italian regions into three groups

- a laggard (< 10%) group, composed of six regions in both versions of the SEIB: Calabria, Sardegna, Sicilia, Campania, Liguria and Lazio.

Five regions showed a shift in group from the SEIB for overall sectors to the SEIB for manufacturing and bio-energy. Puglia and Basilicata moved from virtuous to laggard; Valle d'Aosta and Molise moved from in-between to laggard; and Friuli V.G. moved from laggard to in-between.

#### 4.8 Comparison of socio-economic parameters by geographical area

Generally, Italy presented better performance than the European average in terms of both turnover (5.1 vs. 4.6 thousand € per capita) and value added (1.5 vs. 1.3 thousand € per capita), but a lower than average value for workers per capita (0.031 vs. 0.034) (D'Adamo et al. 2020b). Referring to this finding, some observations may be proposed, considering the absolute values of the main geographical areas of Italy (Fig. 9):

- in the south of Italy, primary sectors had a dominant role, determining 48% of the entire value added and 62% of the total number of workers (but only 27% of the total turnover);
- an opposite situation was verified for central Italy, in which manufacturing and bio-energy sectors played a key role, determining 93% of the total turnover, 86% of the entire value added and 76% of the total number of workers; and

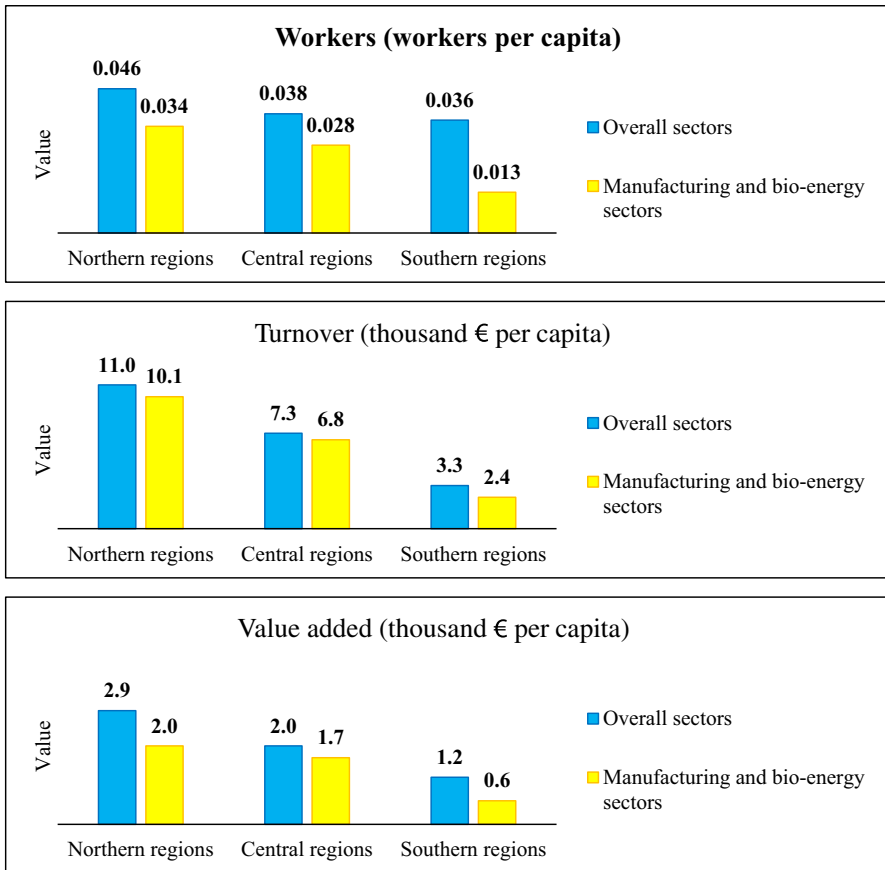


Fig. 9 Geographical comparison of workers, turnover and value added

- the role of manufacturing and bio-energy sectors was also determined in the north of Italy, but with a more significant weight relative to the central region; these sectors determined 92% of the total turnover, 73% of the total number of workers and 68% of the entire value added.

## 5 Discussion

Taken together, the results of the present study adhered to European trends (Ronzon and M’Barek 2018), showing that Agriculture and the Manufacture of food, beverages and tobacco were the driving sectors of the Italian bioeconomy. Interestingly, Manufacture of bio-based textiles (K=5) ranked second in Italy for turnover, whereas in Europe, this sector ranks lower and is surpassed by Agriculture, Manufacture of paper, Manufacture of bio-based chemicals, pharmaceuticals, plastics and rubber and Manufacture of wood products and furniture. Moreover, it emerged that the

Manufacture of bio-based textiles ranked third in Italy in terms of workers and value added. These results were also confirmed by D'Adamo et al. (2020a, b), who found that, within the EU, Italy contributes to this sector 14% in terms of workers, 22% in terms of value added and 23% in terms of turnover. This shows that the Manufacture of bio-based textiles has a solid position in Italy, representing a crucial source of economic strength for the Italian bioeconomy. This represents an important achievement, given that the textile and clothing industries are among the most polluting industries in the world (Boström and Micheletti 2016) and that—prior to the COVID19 crisis—the market for more sustainable textiles was expected to grow, especially for some consumer segments (Gwozdz et al. 2017; Kleinhüchelkotten and Neitzke 2018).

Moving from a country to a regional level, our results clearly show that most high socio-economic performances were concentrated in the northern and central regions. In particular, the results concerning the central regions are worthy of note, since three out of the four regions generated values above the Italian figure in the SEIB for overall sectors. Furthermore, when considering the SEIB for manufacturing and bio-energy sectors, the central regions showed considerable improvement; this was even true of Lazio, which improved its position despite remaining below the Italian figure.

What emerged more clearly was that the southern regions lagged far behind the Italian figure. This result was even more striking considering the generally higher labor intensity of southern regions (due to sectorial specialization) and the positive impact of employment on the SEIB indicator. Abruzzo was the only southern region presenting values above the Italian figure in both SEIB versions, albeit in the last position. Additionally, with the exception of Campania, all southern regions generated lower values in the second version of the SEIB, showing that the gap with the rest of the country was even wider within less traditional sectors. Notwithstanding the limited uptake of less traditional sectors in southern Italy, it should be noted that a large number of innovative initiatives—mostly associated with the green chemistry sector (one of the most innovative and promising sectors of the bioeconomy; Chen et al. 2020)—have recently been developed in the south. Within Campania, for instance, examples of such initiatives include: the GFBiochemicals plant (producing levulinic acid from biomass), the Novamont Research Center (specialized in the development of industrial biotechnologies) and “Rete 100% Campania” (consisting of a cluster of companies covering the entire paper supply chain, aimed at designing and producing sustainable packaging from local pulp waste). In other southern regions, noteworthy initiatives include: the Versalis–Novamont biorefinery (producing a wide range of high value added bio-based products) in Sardegna, university spin-offs and start-ups in Puglia, the Gela Biorefinery in Sicilia, the bioeconomy cluster and the ENEA green chemistry research center in Basilicata (Imbert et al. 2017; Intesa San Paolo 2019). However, these remain fragmented initiatives and the implementation of a more comprehensive and coherent investment policy, as recently highlighted by the Italian Minister for the South, could make a difference.<sup>2</sup>

<sup>2</sup> Minister for the South and Territorial Cohesion (2020), South Plan 2030 Development and cohesion for Italy. Available at: <http://www.ministropersud.gov.it/it/>

Interestingly, the observed north–south regional divide, which grew in the shift from the overall SEIB to the SEIB for manufacturing and bioenergy sectors, resembles the national trend detected in D’Adamo et al. (2020a, b). The authors showed how, when all sectors were considered, the Italian bioeconomy performed in line with the European average, though when the spectrum was restricted to only manufacturing and bioenergy sectors, Italy became a laggard country. This encourages reflection about some potential trade-offs, such as those between bioeconomy sectors (i.e. traditional vs. industrial) and policy priorities. Policy interventions, however, may support synergies between different components of the bioeconomy, mitigating some of the trade-offs and spillover effects (Hetemäki et al. 2017). Indeed, one of the most pressing challenges for sustainable transitions and the circular bioeconomy is to find the right balance between traditional and innovative sectors. In this regard, local/regional policies can be further interconnected to take full advantage of geographical proximity to sustain regional specific assets, of which some clearly emerged in our analysis. For example, the geographical proximity between regions specialized in biomass production (including biowaste and residues) and territories characterized by the significant presence of related processing industries, could be more efficiently exploited through the creation of specialized hubs. In this way, the sustainable combination of traditional and innovative sectors would shorten the value chain, creating growth and increased local employment, while reducing environmental pressure throughout the life cycle (Lokesh et al. 2018). Moreover, regional synergies could reduce trade-offs between the use of biomass, meeting the growing demand for food and non-food goods (Gomez San Juan et al. 2019). Specifically, since the bioeconomy has important repercussions for the agricultural commodity market (and agricultural activities, in general), with an important impact on food security (Heimann 2019), it may be especially important for southern regions specialized in Agriculture and the Manufacture of food, beverages and tobacco. In these regions, a more socially and environmentally responsible approach in these sectors may increase the production of quality food (Agovino et al. 2017), ensuring at the same time the efficient use of biomass, including the valorization of wastes/residues (Falcone and Imbert 2019). This would create additional opportunities for rural areas and attract more public and private investment (European Network for Rural Development 2018). Indeed, this is an important point, since the promotion of rural development is an explicit goal of the Italian bioeconomy strategy (2017), which strongly recommends “interconnecting effectively the main bioeconomy sectors, across sustainable value chains (...) by leveraging traditional sectors deeply rooted in the territory, as well as the public and private stakeholders in local communities” (p. 48).

The sectorial specialization of several regions that emerged in our analysis may provide policy makers with some insights that, although limited to certain socio-economic parameters, may be useful in moving them in this direction. Trentino, for instance, plays a key role in Agriculture and Forestry and Friuli is very strong in the Manufacture of wood products and furniture while Veneto plays a major role in the Manufacture of food, beverages and tobacco. Lombardia is a leader in the Manufacture of bio-based chemicals, pharmaceuticals, plastics and rubber and the Manufacture of liquid biofuels, while Tuscany plays a pivotal role in the Manufacture of bio-based textiles.

## 6 Conclusions

The definition of new indicators for the bioeconomy with applicability to real contexts has become a pressing challenge. In this respect, the literature outlines the need to embrace a regional perspective, in order to monitor the sustainability transitions of many different local realities, identifying their relative strengths and weaknesses. The present research employed the SEIB indicator at the regional level to evaluate the socio-economic performance of bioeconomy sectors, considering three specific parameters (workers, turnover and value added). It drew on literature and statistical data, and provided exploratory results of the socio-economic performance of bioeconomy transitions in Italian regions. It is calculated in two versions, one includes primary activities (agriculture and forestry) while the other one focuses on industrial activities.

The findings show clearly the presence of a gap between Italy's north/central and southern regions—a gap that grows when the SEIB for overall sectors is shifted to the SEIB for manufacturing and bioenergy sectors. The central regions have a significant increase considering SEIB for manufacturing and bioenergy sectors with a leading position (from 0.286 to 0.364). Moreover, the northern regions present the lowest shift between SEIB scores when moving from overall sectors to manufacturing and bioenergy sectors (from 0.322 to 0.320). Finally, the southern regions demonstrate a decrease in this shift (from 0.222 to 0.108), demonstrating their weak performance in manufacturing and bioenergy sectors.

The different competitive advantages and weaknesses that emerged from the regional analysis may provide useful information for policy makers seeking to encourage sustainability transformations at a regional level (e.g. through smart specialization policies). However, it is worth noting that the SEIB indicator lacks an environmental dimension and suffers from other methodological limitations, including the weighting of components and compensability issues. Thus, the SEIB is not appropriate for comprehensive policy guidance, but, as mentioned, as a complementary tool to obtain insights on the socio-economic parameters that it covers.

Further analysis may address some of the major limitations of the SEIB. For example, environmental criteria could be included in the SEIB to determine the potential for bio-based products to reduce greenhouse gas emissions and optimize the use of resources compared to their fossil-based counterparts. Additionally, more parameters such as resource efficiency, resource productivity and circular economy criteria could be considered and the panel of experts could be broadened. Finally, the measure of the bio-based share of several sectors could be improved. In this regard, a recommendation emerging from the present analysis is that the improvement of fine-grained data at a regional level could support the development of more refined versions of SEIB-like indicators.

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## Affiliations

Idiano D'Adamo<sup>1,2</sup> · Pasquale Marcello Falcone<sup>1,3</sup> · Enrica Imbert<sup>1</sup> · Piergiuseppe Morone<sup>1</sup>

Idiano D'Adamo  
idiano.dadamo@uniroma1.it

Pasquale Marcello Falcone  
pasquale.falcone@uniparthenope.it

Enrica Imbert  
enrica.imbert@unitelmasapienza.it

<sup>1</sup> Department of Law and Economics, Unitelma Sapienza-University of Rome, Viale Regina Elena 295, 00161 Rome, Italy

<sup>2</sup> Department of Computer, Control and Management Engineering, Sapienza University of Rome, Via Ariosto 25, 00185 Rome, Italy

<sup>3</sup> Department of Business and Economics, University of Naples Parthenope, Via Generale Parisi, 13, 80132 Naples, Italy