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Measuring and assessing forest-based circular bioeconomy to implement the National Sustainable Development Strategy in Italy

Messung und Bewertung der forstbasierten zirkulären Bioökonomie zur Umsetzung der Nationalen Strategie für nachhaltige Entwicklung in Italien

Alessandro Paletto[1*], Claudia Becagli[2], Elisa Bianchetto[2], Sandro Sacchelli[3], Isabella De Meo[2]

Keywords: Sustainable Development Goals (SDGs), circular economy, bioeconomy, sustainability, forest-wood chain

Schlüsselbegriffe: Nachhaltige Entwicklungsziele (SDG), Kreislaufwirtschaft, Bioökonomie, Nachhaltigkeit, Wald-Holz-Kette

Abstract

In the last decades, the circular bioeconomy concept has gained research and political interest, in line with the goals of the 2030 Agenda for Sustainable Development. In this context, the forest-based sector plays a key role ensuring the sustainable and balanced environmental, economic, and social development using bio-based resources. The present study is aimed at implementing the Italian National Sustainable Development Strategy 2017/2030 (NSDS) in the forest-based sector. Specifically, our study aims to define a set of practical, simple, and easy to apply indicators to assess the performance of the forest-wood chain following the principles of circular bioeconomy. Adopting a bottom-up approach the study was structured in three steps: (1) literature review on circular bioeconomy related to forest-based science by applying social network analysis to bibliometric science; (2) identification of a set of indica-

[1] Consiglio per la ricerca in agricoltura e l'analisi dell'economia agraria (CREA), Research Centre for Forestry and Wood, Trento (Italy)
[2] Consiglio per la ricerca in agricoltura e l'analisi dell'economia agraria (CREA), Research Centre for Agriculture and Environment, Firenze (Italy)
[3] Department of Agriculture, Food, Environment and Forestry; Consorzio interuniversitario Istituto Nazionale di Studi su Agribusiness e Sostenibilità, University of Florence
*Corresponding author: Alessandro Paletto, alessandro.paletto@crea.gov.it

tors suitable to assess the forest-based sector; (3) decision makers' involvement at regional level (Tuscany, Central Italy) through a questionnaire survey and evaluation of the indicators' suitability to assess the performance of the forest-wood chain. The results of literature review show some clusters in the circular bioeconomy literature related to key topics such as climate change mitigation, environmental impacts, biotechnology, and sustainability. Through the literature review, a set of 14 indicators was developed and classified considering the three pillars of sustainability (environmental, economic, and social) and the 4R (Reduce, Reuse, Recycle, Recover) of circular economy. 30 decision makers evaluated and prioritized the indicators evidencing the most important to assess circular bioeconomy. Our study of the monitoring of the performance of the forest-based sector provide insights for researchers, managers, and policy makers to network together for advancing the sustainability transition to a circular bioeconomy in accordance with the principles of a low-carbon society.

Zusammenfassung

In den letzten Jahrzehnten hat das Konzept der zirkulären Bioökonomie im Einklang mit den Zielen der Agenda 2030 für nachhaltige Entwicklung in Forschung und Politik an Bedeutung gewonnen. In diesem Zusammenhang spielt der forstbasierte Sektor eine Schlüsselrolle bei der Gewährleistung einer nachhaltigen und ausgewogenen ökologischen, wirtschaftlichen und sozialen Entwicklung unter Verwendung biobasierter Ressourcen. Diese Studie zielt darauf ab, die italienische nationale Strategie für nachhaltige Entwicklung 2017/2030 (NSDS) im forstbasierten Sektor umzusetzen. Insbesondere fokussieren wir uns darauf, eine Reihe praktischer, einfacher und leicht anzuwendender Indikatoren zu definieren, um die Leistung der Wald-Holz-Kette nach den Prinzipien der zirkulären Bioökonomie zu bewerten. Nach einem Bottom-up-Ansatz war die Studie in drei Schritte gegliedert: (1) Literaturrecherche zur zirkulären Bioökonomie in Bezug auf die forstbasierte Wissenschaft durch Anwendung der Analyse sozialer Netzwerke auf die bibliometrische Wissenschaft; (2) Ermittlung einer Reihe von Indikatoren, die zur Bewertung des forstbasierten Sektors geeignet sind; (3) Einbeziehung der Entscheidungsträger auf regionaler Ebene (Toskana, Mittelitalien) durch eine Fragebogenerhebung und Bewertung der Eignung der Indikatoren zur Bewertung der Leistung der Wald-Holz-Kette. Die Ergebnisse der Literaturrecherche zeigen einige Cluster in der zirkulären Bioökonomie-Literatur, die sich auf Schlüsselthemen wie Klimaschutz, Umweltauswirkungen, Biotechnologie und Nachhaltigkeit beziehen. Durch die Literaturrecherche wurde ein Satz von 14 Indikatoren entwickelt und klassifiziert, wobei die drei Säulen der Nachhaltigkeit (Umwelt, Wirtschaft und Soziales) und der 4R (Reduzieren, Wiederverwenden, Recyceln, Wiederherstellen) der Kreislaufwirtschaft berücksichtigt wurden. 30 Entscheidungsträger bewerteten und priorisierten die Indikatoren, die die wichtigsten für die Bewertung der zirkulären Bioökonomie belegen. Unsere Studie zur Überwachung der Leistung des forstbasierten Sektors liefert Forschern, Managern und politischen Entscheidungsträgern Erkenntnisse, wie Vernetzung helfen kann, den Übergang der Nachhaltigkeit zu einer zirkulären Bioökonomie gemäß den Grundsätzen einer kohlenstoffarmen Gesellschaft voranzutreiben.

1. Introduction

On 25th September 2015, the international political community adopted the 2030 Agenda for Sustainable Development, which includes a set of 17 Sustainable Development Goals (SDGs) supported by 169 targets, ranging from 5 to 12 targets per goal (UN, 2015). The SDGs are aimed to end poverty, protect all that makes the planet habitable, and ensure that all persons enjoy peace and prosperity, now and in the future (Morton *et al.*, 2017). Besides, the 17 SDGs are related to five main areas of critical importance (Allen *et al.*, 2018): People with six goals; Planet with three goals; Prosperity with six goals; Peace and Partnerships with two goals. The Goals extend the previous Millennium Development Goals (MDGs) (Sachs, 2012) and updated the concept of sustainable development defined in 1987 by the Report of the World Commission on Environment and Development "Our Common Future" (also known as Brundtland report). In accordance with the Brundtland report, sustainable development can be defined as "… the development that meets the needs of the present without compromising the ability of future generations to meet their own needs". In addition to considering intergenerational equity, the Goals emphasize the integration between the three pillars of sustainability (environmental, economic, social) (Hák *et al.*, 2016) and the harmonious relationship between humanity and nature (Le Blanc, 2015). In early 2016, the implementation of the 2030 Agenda for Sustainable Development (run from 2016 to 2030) at national level has started in many countries following three main approaches related to the involvement of the stakeholders in the decision-making process: top-down, bottom-up or hybrid approach (Allen *et al.*, 2016).

In Italy, the National Strategy for Sustainable Development (SNSvS) has been developed in 2017 adopting a bottom-up approach based on the direct involvement of institutional actors (Ministries, public administrations, universities and research institutes) and the consultation of civil society. The SNSvS has defined 52 national strategic objectives divided into 13 strategic choices and in five areas of critical importance for humanity and the planet. In SNSvS context, the forest-based sector plays a key role ensuring the sustainable and balanced environmental, economic, and social development through the use of bio-based resources in a "circular bioeconomy" perspective (Falcone *et al.*, 2020).

At different political levels, the crucial role of circular bioeconomy to achieve the Goals of Agenda 2030 has been recognized (European Commission, 2018; Global Bioeconomy Summit, 2018). However, in the international literature a very limited number of studies have revealed links between SDGs and circular bioeconomy (Calicioglu and Bogdanski, 2021). The circular bioeconomy is a meeting point between bioeconomy and circular economy defined as the sustainable, cascading processing of biological residues into bio-based products, which can be shared/reused/remanufactured and recycled or released safely to the biosphere via organic and nutrient cycles (Carus and Dammer, 2018). Bioeconomy was firstly conceptualized by Georgescu-Roegen (1975) who offered a biophysical perspective to the economy. Recently, bioeconomy has been defined as an economy, which can meet the conditions required for environmental, social and economic sustainability, and where the industrial inputs are derived from renewable biological resources (D'Amato *et al.*, 2017; McCormick and Kautto, 2013).

Circular economy emerged during the 70's and the 80's from a rethinking of the industrial processes and spread during the 90's, in opposition to linear economy. Circular economy contemplates that actors do not exert net effects on the environment and aims at generating minimal input and minimal production of 'waste' through the redesigning of the life cycle of the 'product' (D'Amato *et al.*, 2017; Frosch and Gallopoulos, 1989).

On the one hand, the concept of bioeconomy emphasizes the importance of technological innovations aimed at complementing or substituting non-renewable resources with bio-based alternatives (D'Amato *et al.*, 2019).

On the other hand, the concept of circular economy focuses on the technological innovations aimed at accounting for and reducing resource use and consumption, improve resource use efficiency and recycling, and minimize waste and emissions (D'Amato *et al.*, 2019). The circular bioeconomy can be considered an alternative to the linear economy focused on reducing the use of resources and waste produced during the production cycle (Sariatli, 2017).

The long-term benefits provided by the circular bioeconomy in Europe are: i) to promote the maximum reuse/recycling of materials, goods and components, ii) to decrease waste generation in accordance with the Communication of the European Commission "Towards a circular economy: A zero waste program for Europe" (COM/2014/0398 final), and iii) to shift towards a zero-emission society in accordance with the objectives of the Paris Agreement on Climate Change (2015). In other words, the circular bioeconomy should be characterized by shifting from an economy based on fossil fuels to an economy based on renewable resources, and then improving the efficiency in the use of resources and in the recovery/recycling of waste generated by the production cycle. The key principle of circular bioeconomy is the 4R framework (Reduce, Reuse, Recycle, Recover), in which the hierarchy among the R is a fundamental aspect (Van Buren *et al.*, 2016): the first R (Reduce) is considered to be a priority to the second R (Reuse) and so on. This hierarchical relationship is closely linked to the "cascade" principle that implies the use of raw materials according to a priority based on the added potential value (Ciccarese *et al.*, 2014; Proskurina *et al.*, 2016; Paletto *et al.*, 2019).

In the implementation of the SNSvS, forest-based sector can play a key role in achieving various national strategic objectives regarding the sustainable management of natural resources and the supply of ecosystem goods and services useful for human well-being. Wood is a versatile raw material used to produce high added value products (*e.g.*, furniture, flooring, specialized paneling), but also a renewable resource for bioenergy production (Antikainen *et al.*, 2017). As the forest-based sector is one of the most important sectors for the development of a bioeconomy (Linser and Leier, 2020), also in national bioeconomy strategies, and specifically in the Italian SNSvS, it plays a fundamental role in the pursuit of the following choices and objectives (Biancolillo *et al.*, 2020a):

– Prosperity. Choice III. Ensure sustainable production and consumption patterns:

- Strategic objective III.1 Dematerialize the economy, improving the efficient use of resources and the circular economy;
- Strategic objective III.5 Reduce waste production and promote secondary raw material market;
- Strategic objective III.7 Boost sustainable farming and forestry throughout the production and supply chain.

– Prosperity. Choice IV. Decarbonize the economy:

- Strategic objective IV.1 Increase energy efficiency and renewable energy production, avoiding or reducing impacts on natural and cultural heritage and landscapes;
- Strategic objective IV.3 Reduce greenhouse gas emissions in non- ETS sectors.

Many authors underline the importance of monitoring and assessing the progress of the above-mentioned bioeconomy objectives and strategies through the implementation of different national indicators which can be differently related to the Goal indicators of Agenda 2030 and to other already established national or regional indicators of the forest sector (Linser and Lier, 2020) . Indicators can be used as a basis for monitoring the bioeconomy assessing various features of development, such as productivity, performance, and efficiency. The information produced can be used and aggregated at different levels, with a focus on the global, national, regional, or local level (Diaz-Chavez *et al.*, 2019; Egenolf and Bringezu, 2019). An important prerequisite of bioeconomy indicators is the balanced integration of the environmental, social, and economic dimensions that influence sustainability. Some studies indicate that more attention has been paid to environmental and economic indicators respect to socio-economic ones (Diaz-Chavez, 2014). Ronzon and M'Barek (2018) propose socio-economic indicators for an analysis of the bioeconomy of the EU Member States, while D'Adamo *et al.* (2020a) propose the "socio-economic indicator for the bioeconomy" (SEIB) to measure the socio-economic performance of bioeconomy sectors at regional level. The SEIB was tested and analyzed from spatial and longitudinal perspectives in four Italian regions (D'Adamo *et al.*, 2020b). At the regional and local level, the application of indicators is fundamental to support decision makers in identifying problems related to the transition towards the bioeconomy and to provide solutions for sustainable development (Diaz-Chavez, 2014).

Starting from these considerations, the aim of the present study is to define a set of indicators to monitor and assess the performance of the forest-wood chain following the mission and principles of circular bioeconomy. The transition toward a wood-based bioeconomy encompasses different sectors and could generate potential environmental, economic and social benefits and risks (Gottinger *et al.*, 2020). Particularly, social implications may influence the acceptance of the development of a bioeconomy at local level (Siebert *et al.*, 2018) and to ensure acceptance of solutions a range of stakeholders should be involved in the selection of monitoring indicators (Miola and Schiltz, 2019). This bottom-up approach can be considered a good solution to ensure the development of socially acceptable policy in the forest-based sector (Šimunović *et al.*, 2019).

A bottom-up approach was adopted in this study through the integration of the affected stakeholders to ensure the contribution of heterogeneous views and insights of different actors of the sector. The indicators identified by the researchers have been assessed and evaluated by a sample of Italian decision makers. A set of practical and easy to apply indicators to monitor the performance of the forest-wood chain under the principles of bioeconomy has been finally produced.

The study was conducted within the project "Decision Support System to improve the performance of the forest-wood supply chain in a circular bioeconomy perspective (FOR.CIRCULAR)" funded by the Italian Ministry f of Ecological Transition to support the implementation of the SNSvS. The research and the questionnaire survey was developed involving decision makers operating in the forest-based and bioenergy sector in the pilot region of the project (Tuscany region, Central Italy).

The paper is structured as follows: Section 2 shows an overview of existing studies on circular bioeconomy applied to the forest-based sector and defines a set of indicators suitable for the evaluation of the sector. This section also details the methodology used to assess the indicators through a bottom-up approach. The resulting findings are presented in Section 3, and insights from these are discussed in Section 4. Based on these, we conclude in this section that indicators to assess the performance of forest-based sector are crucial for building and monitoring bioeconomy strategies and to consider effects they can bring to move towards a low-carbon society.

2. Materials and methods

A questionnaire survey was conducted to identify suitable indicators to assess the performance of the forest-wood chain with an application at local level in a case study in Tuscany region. After an overview of the literature on circular bioeconomy, a set of indicators was identified. Following a bottom-up approach the indicators were assessed by a sample of decision-makers identified through a snowball sampling.

This study consists of three methodological stages (Figure 1): (1) literature review on circular bioeconomy related to forest-based sector by applying social network analysis to bibliometric science (bibliometric network analysis); (2) identification of the set of indicators suitable to monitor the performance of the forest-based sector based on the results of the literature review; (3) decision makers' involvement through a questionnaire survey and evaluation of the circular bioeconomy indicators.

In the present study, a bibliometric network analysis was chosen to identify the hot topics and trends in the circular bioeconomy research field and the relationships between key concepts. Alternatively, a systematic literature review could have been implemented to collect multiple research studies (policy documents, journal articles, book chapters, blogs and publications) and systematically summarizes them to answer the research questions (van Dinter *et al.*, 2021).

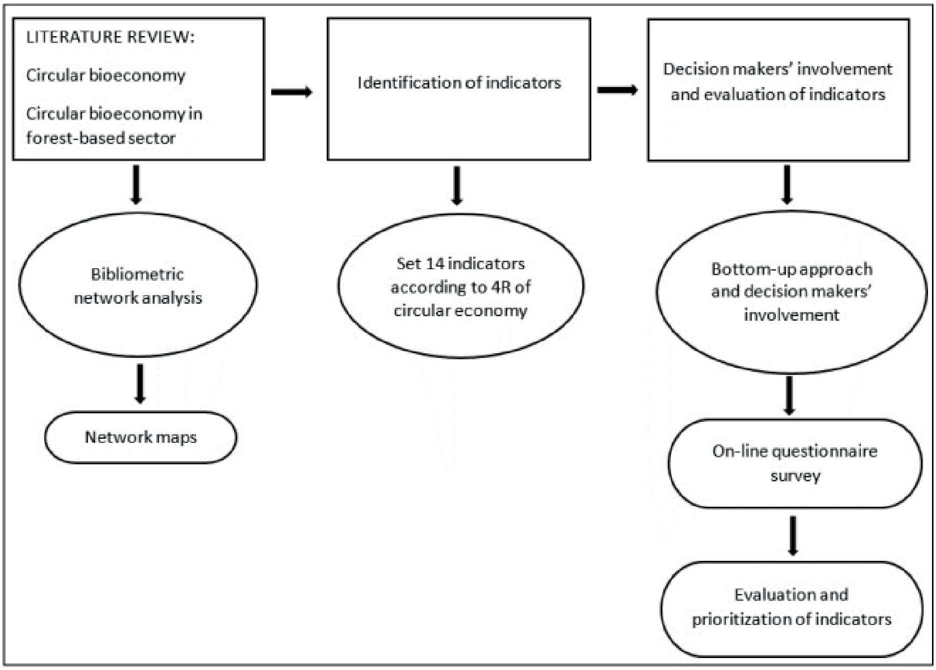

Figure 1: Methodological framework used to identify the indicators to assess the performance of forest-wood chain.

Abbildung 1: Methodischer Rahmen zur Ermittlung der Indikatoren zur Bewertung der Leistung der Wald-Holz-Kette.

2.1 Literature review

During the literature review, the peer-reviewed publications concerning circular bioeconomy in general and circular bioeconomy applied to the forest-based sector were collected and analyzed. The peer-reviewed publications were retrieved from Scopus database (https://www.scopus.com) on 20th September 2020 using as keywords "bioeconomy", "circular economy", "circular bioeconomy" and "forest". The above-mentioned keywords were searched in the title, abstracts and keywords of the individual peer-reviewed publications. The timeframe was set from 2003 to 2020. All data were exported as "comma-separated values" (.csv) files and processed through a bibliometric network analysis using the VOSviewer software (version 1.6.11).

The VOSviewer software was developed by Van Eck and Waltman (2014) of the Leiden University (the Netherlands) for the creation, visualization, and exploration of maps based on the bibliometric network data. The bibliometric network analysis is based on the combination of bibliometric approach and Social Network Analysis (SNA) approach with the aim to provide network maps and statistics based on the relationships among countries, journals, organizations, authors, and keywords (Skaf *et al.*, 2020).

The bibliometric approach aims to analyze the scientific productivity on a topic adopting three types of bibliometric indicators: quantity indicators (which measure the productivity of a researcher); quality indicators (which measure the performance of a researcher's output); and structural indicators (which measure connections between publications, authors and areas of research).

SNA approach aims to understand the relationships among all components (*e.g.*, actors, organizations, countries, concepts, words) of a system to identify and analyze the key role of some components in the system (Wasserman and Faust, 1994). The output of the SNA is displayed in clusters to visualize the existing connections among the bibliometric data.

The bibliometric network analysis is a useful tool to quantitatively assess trends and patterns of scientific literature as highlighted by many authors (Otte and Rousseau, 2002; Pauna *et al.*, 2018). Some authors focused on issues related to the forest-based sector such as on natural capital, climate change, ecosystem services, and sustainable tourism (Pauna *et al.*, 2019; Biancolillo *et al.*, 2020b; Demiroglu and Hall, 2020).

In the present study, the co-occurrence of different terms connected to the global research on circular bioeconomy was analyzed with the aim of identifying thematic clusters of scientific production. The co-occurrences of two keywords is the number of publications in which both keywords occur together in the title, abstract or keyword list (Van Eck and Waltman, 2014, 2020). The co-occurrence analyses were conducted to create network maps about keywords used in the circular bioeconomy literature.

Each network map that resulted from the analyses contains nodes with size determined by number of documents, and lines connecting the nodes with thickness based on "link strength". The link strength is an attribute of each link, expressed by a positive numerical value (in the co-occurrence links, the higher is the value, the higher the number of publications the two keywords are together).

2.2 Identification of indicators

At the end of the literature review, some thematic clusters have been identified based on co-occurrence analysis within each network (bioeconomy, circular bioeconomy, forest circular bioeconomy networks). Afterwards, the clusters related to the assessment and evaluation of different sectors were analyzed in detail to identify the publications on performance indicators. Overall, 112 peer-reviewed publications were identified in the clusters, but only 18 focused on indicators useful to monitor the performance of the circular bioeconomy and only one of them was focused on the forest-based sector. In addition, all the national bioeconomy strategies published by the European countries were analyzed, highlighting 53 indicators suitable to monitor the forest-based sector at the regional level, but many without any relationship with the circular economy. Subsequently, the project and strategic documents of the European Union (EU), the Food and Agricultural Organization (FAO), and the European Forest Institute (EFI) were analyzed identifying 80 new potential monitoring indicators. All potential indicators identified were assessed considering the relationship with the circular bioeconomy and applicability to the forest-based sector.

At the end of the screening, a final set of 14 indicators suitable to monitor the performance of the forest-based sector in accordance with the principles of circular bioeconomy was obtained (Table 1). The indicators have been divided into four groups corresponding to the 4R of circular bioeconomy. The first group (Reduce) is composed of three indicators concerning the reduction of the use of raw materials and of the emissions during the production process, and the shortening of the supply chain. The five indicators of the second group (Reuse) focus on the reuse of wood products. The wood reuse is investigated in terms of quantity, time, and number of cycles but also as potential reuse of wood products. The third group (Recycle) is composed by two indicators considering the valorization of high-quality wood materials and the recycle of waste products. The four indicators of the last group (Recover) focus on emissions saved from energy recovery and on energy recover from waste, deadwood, and discarded wood products.

Table 1: Indicators based on the 4R framework of the circular bioeconomy.

Tabelle 1: Indikatoren basierend auf dem 4R-Rahmen der zirkulären Bioökonomie.

4R	Indicator	Definition	Source
Reduce	I_1 - Ratio (on annual basis) between annual value in euro and annual mean volume of harvested mass [€ m^{-3} yr^{-1}]	Improving of the process efficiency reducing the utilization of natural resources	Pieratti et al. (2019)
	I_2 - CO_2 emissions per unit of wood product [tCO_2/m^3]		Cosola et al. (2016), Bracco et al. (2019)
	I_3 - Short supply chain: distance between sawmills and forests; distance between first and second wood processing companies (carpentry and joinery) [Km]	Development of short supply chains: reduction of polluting emissions	Malak-Rawlikowska et al. (2019)
Reuse	I_4 - The linear flow [%]	Percentage of material that has a linear trend in the process (incoming virgin material, outgoing non-recycled waste). Ratio between wood waste left in the forest and total wood waste produced by harvesting.	Korhonen et al. (2018)
	I_5 - The time of use of products [years]	Wood products life span of product	Pieratti et al. (2019)
	I_6 - The potential reuse [%]	Percentage of wood product / material that can be reused (e.g., corks)	Shaurette (2006), Diyamandoglu and Fortuna (2015)
	I_7 - Numbers of cycles [years]	Number of cycles of wood product reuse	Go et al. (2015)
	I_8 - The potential enhancement of disposal wood products index [%]	Percentage of roundwood reutilization for new wood infrastructures and objects (e.g., old beams recovered and reused)	Shaurette (2006)
Recycle	I_9 - Ratio between the potential economic value of the wood assortment and the real value earned [€/€].	Valorisation of the valuable wood high quality assortments	Pieratti et al. (2019)
	I_{10} - Percentage of wood waste used in high value supply chains [%]	Recovery of biochemical substances from waste products (cellulose, hemicellulose, lignin) for the production of bio-fabrics and bio-plastics.	Terzopoulou and Kamperidou (2019)
Recover	I_{11} - Percentage of wood waste for bioenergy production [%]	Energy recovery from waste wood products	Wolfslehner et al. (2016), Paletto et al. (2019), Bracco et al. (2019)
	I_{12} - Amount of roundwood recovered from infrastructures and products converted into bioenergy [m^3]	Energy recovery from discarded wood products	Ince (1996),
	I_{13} - Amount of CO_2 emissions saved per unit of energy produced by wood wastes [gCO_2 kW/h]	Emissions saved from energy recovery from waste wood products	Pan et al. (2015), Paletto et al. (2019)
	I_{14} - Ratio between deadwood used for energy purpose and total deadwood in forest [m^3/ m^3]	Energy recovery from forest deadwood	Pieratti et al. (2019)

2.3 Decision makers' involvement and evaluation of indicators

The last step of the present study was the production of a set of practical indicators to monitor the performance of the forest-wood chain under the principles of bioeconomy. This result was obtained through a bottom-up approach finalized at involving stakeholders in the selection and prioritization of monitoring indicators to contribute to the social acceptance of the development of the bioeconomy at the local level.

To identify a sample of potential stakeholders, in October and November 2020 a snowball sampling has been conducted and a sample of 56 decision makers operating in the forest-based and bioenergy sectors in the pilot region of the project (Tuscany region) has been identified. Snowball sampling is typically used in research situations in which is difficult to identify in advance the target population, meaning all those who might fall into the category of interest for survey (Hall and Hall, 1996). In this situation the research group identify one or a few qualified respondents from the category of interest, and then solicit the respondent's support in identifying other people (Hair *et al.*, 2000). One of the problems with using snowball sampling is the fact that it is unlikely to obtain a representative sample, because there is no real control of the snowball effect. In the present study, following this method, a preliminary list with 12 names of decision makers drawn up by the researchers involved in the project was integrated and 56 decision makers were identified at the end of snowball sampling. The final list was made up as follows: 28 representatives of public administrations, 16 private companies and 12 freelancers operating in the forest-based sector.

Successively, the decision makers were asked to fill in an online semi-structured questionnaire finalized at evaluating the suitability of the indicators to assess the performance of the forest-wood chain. Respondents were invited by email or by phone to participate the survey and a brief explanation of the project and of the questionnaire was given. After a couple of days an email was sent to each potential respondent with a link to the online questionnaire. Reminder emails were sent after a week and a period of around 14 days was allowed to complete the questionnaire.

The performance of the forest-wood chain was assessed at the light of some criteria selected starting from the outputs provided by Gallego Carrera and Mack (2010), and Dale *et al.* (2013) and adapted to the context of the forest-based circular bioeconomy. The criteria used to assess the indicators can be thus synthesized:

- efficiency in achieving the goals of the SNSvS and those of Bioeconomy Strategy with special regard to improve the efficient use of resources and the circular economy (dematerialize the economy) and to increase energy efficiency and renewable energy production, avoiding or reducing impacts on natural and cultural heritage and landscapes;

- applicability to the forest-wood supply chain at local level (data availability/ease of data collection);
- replicability in other forest contexts both at local level and regional level.

The semi-structured online questionnaire was created by the researchers involved in the FOR.CIRCULAR project using Google spreadsheet tool to guarantee speed and timely processing of data gathering. The questionnaire was pre-tested with six decision makers, identified among academics, freelancers, and representatives of public administrations operating in Tuscany region and near to the researchers involved in the present research. These decision makers have not been involved in the final survey. The pre-test stage is aimed at verifying the understandability of all items, at highlighting complex and misguided questions and at estimating the compilation time.

The final version of the questionnaire – modified in accordance with the observations provided by the respondents involved in the pre-test – is formed by 20 open-ended and closed-ended questions divided in two thematic sections. Brief instructions and presentation of the project were inserted at the beginning of the questionnaire to aid the respondents. The first section is composed by 5 questions and focuses on the personal information of respondents: the age of the respondent (<30, 31-40, 41-50, 51-60, >60 years old), the employment (public sector, private sector, freelancer); the name of organization/institution in which he/she works; the role in the organization/institution; and the years of expertise in the forest-based sector (<1 year; 1-5 years; 6-10 years; 11-15 years; >15 years). The second section is composed by 15 questions, corresponding to the 14 indicators and to a final question. In each question, the respondents are asked to assess one indicator considering the three criteria (efficiency, applicability, replicability) and using a 5-point Likert scale format (from 1=very low importance to 5=very high importance). At the end of the questionnaire, an open question investigates possible proposals for other indicators to assess the performance of the forest-wood chain.

3. Results

3.1 Literature review

The results of the literature review show overall 1,756 peer-reviewed publications on bioeconomy (with an average of 97.5 publications per year), 293 publications on circular bioeconomy (16.3 publications per year), and 31 publications on circular bioeconomy applied to forest-based sector (1.7 publications per year) in the timeframe 2003-2020.

The publications on bioeconomy are characterized by an increasing trend divided in two main periods: a first period (2003-2012) with an average of 20.4 documents on bioeconomy per year, while a second period (2013-2020) with an average of 194.0 documents per year (Figure 2). With regard to the circular bioeconomy, all publications are concentrated in the period from 2015 to 2020 following the first publications that associated the concept of bioeconomy with that of circular economy (Kircher, 2015; Mohan et al., 2016; Viaggi, 2016). The term "sustainable and circular bioeconomy" has begun to be used in the political agenda to emphasize the minimization of waste and the re-use throughout the bio-based production cycle (Viaggi, 2016). Therefore, the concept of circular bioeconomy can be considered an integration between bioeconomy – aimed at complementing or substituting non-renewable resources with bio-based alternatives – and circular economy aimed at accounting for and reducing resource use and consumption, improve resource use efficiency and recycling, and minimize waste and emissions (D'Amato *et al.*, 2017, 2019).

The publications focused on circular bioeconomy in forest-based sector are 10.6% of total publications on circular bioeconomy. On average, 48.8 peer-reviewed publications on circular bioeconomy per year and 5.2 publications on circular bioeconomy in forest-based sector per year were published in the timeframe 2015-2020.

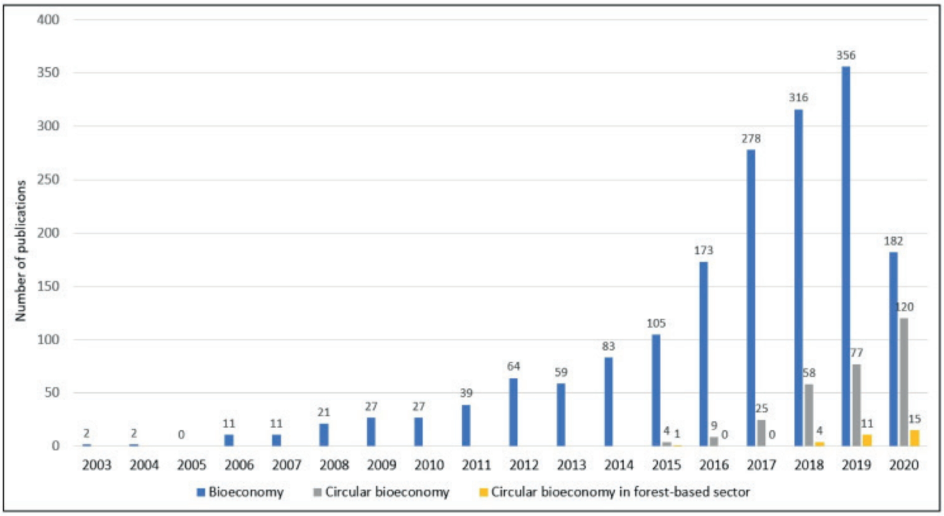

Figure 2: Trends of publications on bioeconomy, circular bioeconomy and circular bioeconomy applied to forest-based sector (timeframe 2003-2020).

Abbildung 2: Trends in Publikationen zu Bioökonomie, zirkulärer Bioökonomie und zirkulärer Bioökonomie im forstbasierten Sektor (Zeitrahmen 2003–2020).

The analysis of the keywords generated 9,854 results for bioeconomy, but only 886 keywords have at least five co-occurrences. The most important keywords used in the peer-reviewed publications are (Table 2): "bioeconomy" (7.03% of frequency), followed by "biomass" (3.39%), "sustainable development" (2.46%), and "biotechnology" (2.32%).

The bioeconomy network map (50 most used keywords) is characterized by three clusters highly interconnected (Figure 3). The red cluster focuses on the role of bioeconomy in mitigating climate change and reducing dependence on fossil fuels. In this cluster, the importance of the wood resource (keywords: "wood" and "biomass") is empathized a tool for a zero-emission society. The core of the blue cluster are biorefineries which can be considered multi-product factories capable of integrating biomass conversion processes and equipment to produce bio-products (*e.g.*, bio-plastics) and bioenergy (*e.g.*, biodiesel, green electricity, heat and pellets). The red and blue clusters are linked by the keyword "biomass" emphasizing the importance of raw materials (wood biomass) to produce both low-value and high-value products. The green cluster focuses on biotechnology by taking into consideration both technical and economic aspects.

Table 2: Top ten keywords related to bioeconomy, circular bioeconomy, and circular bioeconomy in forest-based sector ranked by co-occurrence.

Tabelle 2: Die zehn wichtigsten Stichwörter in Bezug auf Bioökonomie, zirkuläre Bioökonomie und zirkuläre Bioökonomie I Waldbasierter Sektor, sortiert nach Koexistenz.

Keyword	Co-occurence	Frequency (%)	Total link strength	Links
Bioeconomy				
Bioeconomy	693	7.03%	10587	4906
Biomass	334	3.39%	8065	3718
Sustainable development	242	2.46%	5171	2466
Biotechnology	229	2.32%	5232	2422
Sustainability	177	1.80%	3253	1758
Economics	162	1.64%	3784	1903
Priority journal	154	1.56%	5329	2543
Biofuels	138	1.40%	3441	1851
Forestry	137	1.39%	2775	1604
Bioenergy	136	1.38%	3223	1691
Circular bioeconomy				
Bioeconomy	116	4.18%	505	47
Circular economy	99	3.56%	531	48
Sustainable development	74	2.66%	527	49
Biomass	70	2.52%	481	49
Sustainability	57	2.05%	374	49
Circular bioeconomy	53	1.91%	311	48
Refining	48	1.73%	447	49
Priority journal	44	1.58%	488	49
Biorefineries	41	1.48%	358	49
Biofuels	39	1.40%	376	48
Circular bioeconomy in forest-based sector				
Forestry	17	4.59%	111	40
Sustainable development	12	3.24%	106	45
Circular economy	12	3.24%	86	41
Bioeconomy	12	3.24%	72	36
Biomass	8	2.16%	70	42
Sustainability	8	2.16%	66	34
Timber	5	1.35%	30	20
Circular bioeconomy	5	1.35%	26	19
Industrial economics	5	1.35%	22	13
Forest	4	1.08%	44	29

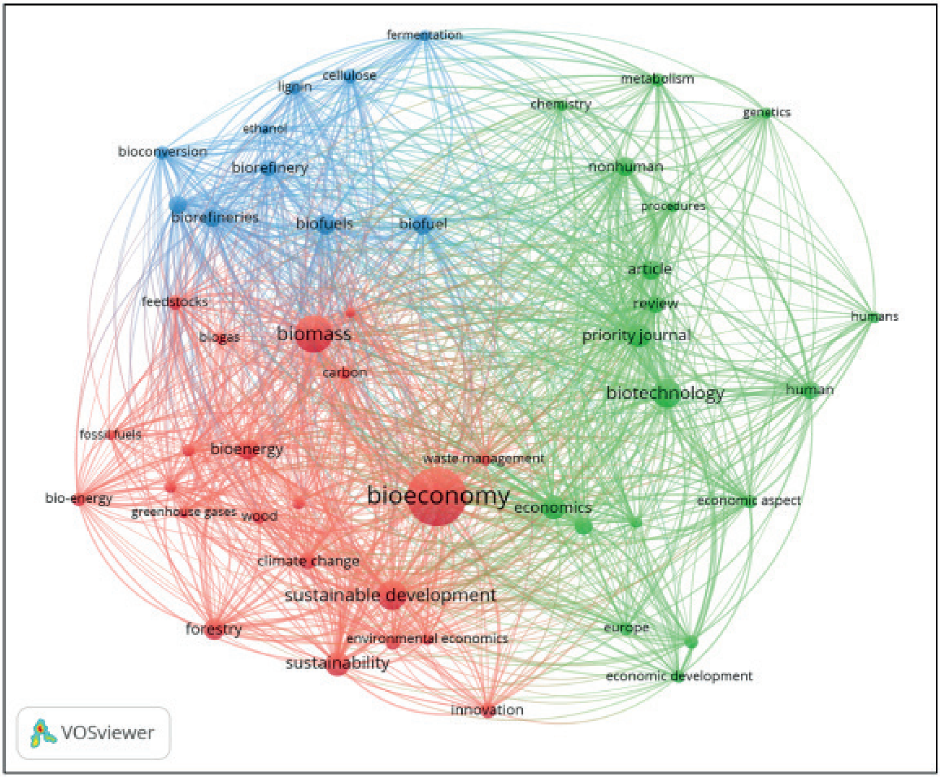

Figure 3: Co-occurrence network map of 50 most used keywords related to bioeconomy.

Abbildung 3: Koexistenz-Netzwerkkarte der 50 am häufigsten verwendeten Stichwörter im Zusammenhang mit der Bioökonomie.

The circular bioeconomy map shows three closely interconnected clusters (Figure 4). The blue cluster connects the bioeconomy and the circular economy to the climate change mitigation, sustainability, and environmental protection. Most of the publications concerning the role of the agro-forestry sector in the circular bioeconomy are included in this cluster. The green cluster focuses on waste management, greenhouse gas (GHG) emissions and environmental impacts quantified through the Life Cycle Assessment (LCA). The green cluster is also the one that most emphasizes the environmental impacts related to the circular bioeconomy. The red cluster focuses on biorefineries and on aspects related to the production of biofuels (biogas and biodiesel) through bio-processes such as anaerobic digestion and fermentation, using food and industrial waste as well as micro-algae. The keyword "bioenergy" is strictly connected to this cluster, as energy production is one of the outputs of the biorefineries, but at the same time it is a "bridge" between the red cluster with the blue one, highlighting the relationship between the biorefineries and the positive impacts in terms of climate change mitigation and sustainability.

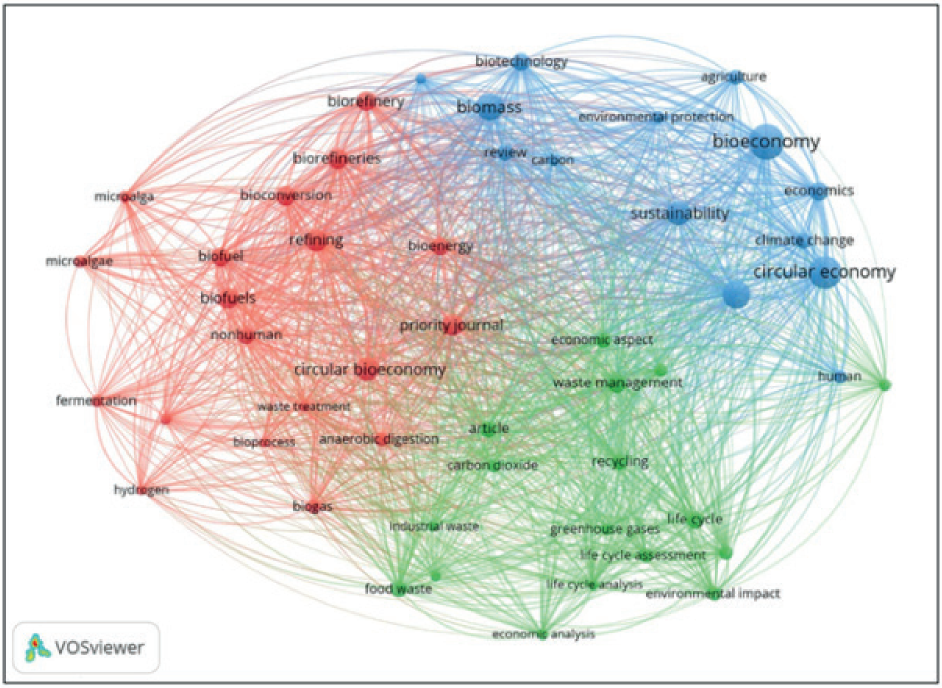

Figure 4: Co-occurrence network map of 50 most used keywords related to circular bioeconomy.

Abbildung 4: Koexistenz-Netzwerkkarte mit 50 am häufigsten verwendeten Stichwörter im Zusammenhang mit der zirkulären Bioökonomie.

The forest circular bioeconomy map shows four clusters characterized by few ties (Figure 5). The green cluster focuses on the environmental and climate change impacts generated by the forest circular bioeconomy. This cluster is linked to the yellow cluster and to the red cluster to the keyword "life cycle". In the yellow cluster, there are many studies on the circular bioeconomy in the forest-wood supply chain with an emphasis on impacts on sustainability and biodiversity. Conversely, the red cluster is more focused on the economic aspects of the forest-wood supply chain such as economic sustainability, industrial economics, and economic development. Finally, the blue cluster considers the technological aspects related to the use of woody biomass to produce both high added value products and bioenergy.

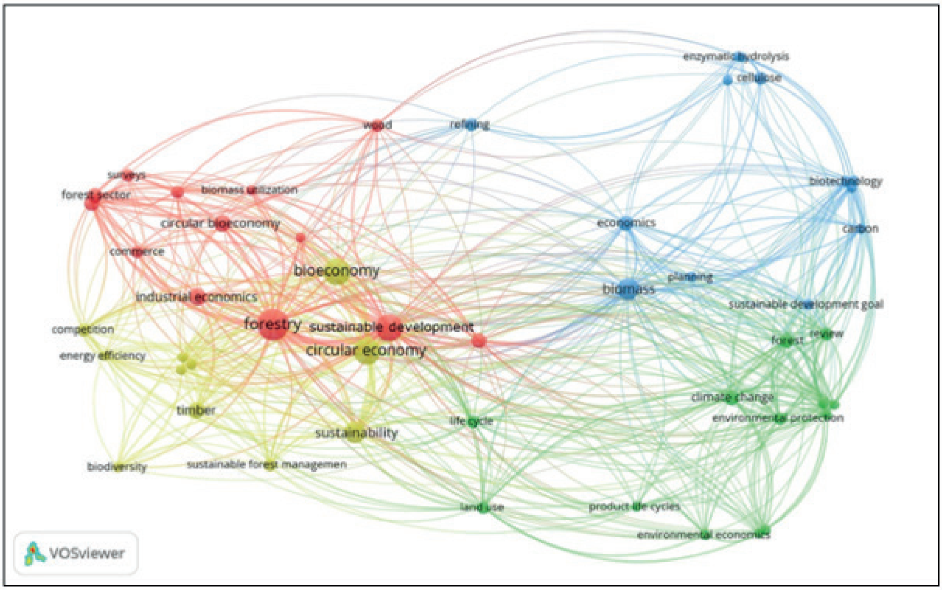

Figure 5: Co-occurrence network map of 50 most used keywords related to circular bioeconomy in forest-based sector.

Abbildung 5: Koexistenz-Netzwerkkarte mit 50 am häufigsten verwendeten Stichwörter im Zusammenhang mit der zirkulären Bioökonomie im forstbasierten Sektor.

3.2 Decision makers' involvement and evaluation of indicators

At the end of the step of decision makers' involvement through the questionnaire survey, 30 decision makers filled out the questionnaire (response rate of 53.6%) thus distributed by group: 11 representatives of public administrations (response rate of 39.3%), 8 freelancers (50.0%), and 11 representatives of private companies (91.7%).

Concerning the age of respondents, 6.7% is less than 30 years old, 10.0% between 30-40 years old, 66.6% between 41-50 years old, 10.0% between 51-60 years old, and the remaining 6.7% is more than 60 years old. About the years of expertise, most respondents involved in the survey have a high level of expertise: 50% has more than 15 years of expertise, 13.3% 11-15 years, 20.0% 6-10 years and 16,7% 1- 5 years of expertise.

In Table 3 is shown the distribution of the sample of respondents by age and years of expertise, considering the three groups involved in the survey. The results show that representatives of public administrations are – on average – older (100% is more than 40 years old) compared to representatives of private companies (72.7% is more than 40 years old) and freelances (75% is more than 40 years old). In addition, it is interesting to highlight that freelancers have more years of experience in forest-based sector (75.0% has more than 10 years of expertise) compared to the other two groups (63.7% of public administrations and 54.6% of private companies has more than 10 years of expertise).

Table 3: Characteristics of the sample of decision makers involved in the survey with regards to age and expertise.

Tabelle 3: Zusammenfassung der an der Umfrage beteiligten Entscheidungsträger hinsichtlich Alter und Erfahrung.

Characteristics/Group	**Public administrations** (*n*=11)	**Private companies** (*n*=11)	**Freelancers** (*n*=8)
Age			
Less than 30 years old	-	9.1%	12.5%
30-40 years old	-	18.2%	12.5%
41-50 years old	72.7%	63.6%	62.5%
51-60 years old	9.1%	9.1%	12.5%
More than 60 years old	18.2%	-	-
Years of expertise			
1-5 years	27.3%	9.1%	12.5%
6-10 years	9.1%	36.4%	12.5%
11-15 years	18.2%	9.1%	12.5%
More than 15 years	45.5%	45.5%	62.5%

The results of the evaluation of the indicators show that for the decision makers involved in the survey the most important indicator in the “Reduce” group is I_1 (ratio between annual value and annual mean volume harvested) with an average value of the three criteria of 3.46 (Table 4), followed by I_3 (short supply chain) with an average value of 3.37. For the “Reuse” group, in accordance with the decision makers’ opinions, the most important indicator is I_5 (time of use of products) with an average value of 3.22, while the other four indicators have an average value of less than 3.00. For the “Recycle” group, the indicator I_9 (ratio between the potential economic value of the wood assortment and the real value earned) is considered the most important with an average value of 3.14, while for the group “Recover” two indicators are considered as most important: I_{11} (percentage of wood waste for bioenergy production) with an average value of 3.78, and I_{13} (amount of carbon dioxide emissions saved per unit of energy produced by wood wastes) with an average value of 3.61. According to the analysis the best-performing indicator is I_{11}, while the one with the lowest score is I_{14}.

Observing the data by group, the results show that for the "Reduce" group the representatives of public administrations assigned a higher value to indicator I_1 (mean value of 3.70) and I_3 (mean value of 3.82) compared to the other two groups. Conversely, the representatives of private companies assigned a higher value to I_2 (mean value of 3.06) and freelances to I_4 (mean value of 3.08) compared to the public administrations. For the "Reuse" group, the results evidence that representative of public administrations assigned a higher value to I_5 (mean value of 3.48) compared to the other two groups, while freelancers emphasized the importance of I_4 (3.08) and representatives of private companies of I_6 (3.06). For the "Recycle" group, the representatives of public administrations and private companies assigned a higher importance to I_9 (mean value of 3.36 for private companies and 3.39 for pubic administrations), while freelancers assigned equal importance to I_9 and I_{10} (mean value of 2.50). The representatives of private companies considered the indicators of the "Recover" group, the most important among all 4R groups proposed indicators. In particular, I_{11} (mean value of 4.06) and I_{13} (4.00) received the higher scores from private companies' representatives. Instead, I_{14} is considered important only by representatives of public administrations (mean value of 2.52), while freelancers assigned a low importance (1.79). However, the Kruskal-Wallis non-parametric test (α=0.01) show no statistically significant differences among the three groups of decision makers (public administrations, private companies, freelances) for all 14 indicators.

Table 4: Importance of indicators to assess forest-based circular bioeconomy based on decision makers' opinions (mean and standard deviation).

Tabelle 4: Bedeutung von Indikatoren zur Bewertung der forstbasierten zirkulären Bioökonomie auf Basis der Meinungen der Entscheidungsträger (Mittelwert und Standardabweichung).

R	**Indicator**	**Efficiency** (*n*=30)	**Applicability** (*n*=30)	**Replicability** (*n*=30)	**Mean value**
Reduce	I1	3.87 (*1.17*)	3.27 (*1.26*)	3.23 (*1.28*)	3.46
	I2	3.27 (*1.34*)	2.50 (*1.07*)	2.60 (*1.13*)	2.79
	I3	3.80 (*1.24*)	3.13 (*1.33*)	3.17 (*1.32*)	3.37
Reuse	I4	3.00 (*1.34*)	2.70 (*1.26*)	2.57 (*1.30*)	2.76
	I5	3.60 (*1.33*)	3.07 (*1.28*)	3.00 (*1.26*)	3.22
	I6	3.23 (*1.41*)	2.50 (*1.22*)	2.70 (*1.37*)	2.81
	I7	3.07 (*1.44*)	2.43 (*1.30*)	2.50 (*1.41*)	2.67
	I8	2.80 (*1.24*)	2.33 (*1.21*)	2.20 (*1.32*)	2.44
Recycle	I9	3.37 (*1.56*)	3.10 (*1.27*)	2.97 (*1.33*)	3.14
	I10	3.00 (*1.51*)	2.40 (*1.22*)	2.23 (*1.28*)	2.54
Recover	I11	3.87 (*1.31*)	3.67 (*1.30*)	3.80 (*1.27*)	3.78
	I12	2.83 (*1.26*)	2.30 (*1.21*)	2.33 (*1.37*)	2.49
	I13	3.73 (*1.53*)	3.63 (*1.47*)	3.47 (*1.43*)	3.61
	I14	2.43 (*1.22*)	2.13 (*1.11*)	2.23 (*1.19*)	2.27

In the last part of the questionnaire, the respondents were asked to indicate potential additional indicators to the proposed list. The results of this last question show that the following four additional indicators were evidenced as potential forest-based circular bioeconomy indicators: (1) workforce in the forest-based bioeconomy sector (number of employees); (2) ratio between forest area managed according to a forest plan and total forest area; (3) ratio between forest area harvested and forest area damaged by fire; and (4) training courses on bio-based circular bioeconomy for the workforce (number of training courses and percentage of workforce involved in the training courses).

4. Discussion and Conclusions

A continuous monitoring of the progress of the bioeconomy strategies and objectives is possible assessing various features of development, such as productivity, performance, and efficiency. In particular, assessing the performance of the forest-based sector is a key aspect to increase the amount of recovered and recycled wood materials in accordance with the principles of a low-carbon society. For this reason, a standardized monitoring system based on simple and easily applicable indicators can be useful to support decision makers in providing sustainable solutions for the transition towards the bioeconomy. Starting from a literature review on circular bioeconomy, the present study tried to identify a preliminary list of indicators suitable for the forest-based sector.

In the last few years, many studies have pointed to the growth of scientific production on three concepts related to the 2030 Agenda for Sustainable Development, with the common objective of developing a sustainable economy (Pülzl *et al.*, 2014; D'Adamo *et al.*, 2020b; D'Amato *et al.*, 2017, 2019): bioeconomy, circular economy, and green economy. Green economy has been defined by the United Nations Environment Program (UNEP, 2011) as an economy finalized at improving social equity and human well-being reducing ecological lacks and environmental risks. At the end of 2013, Pülzl *et al.* (2014) identified 7510 hits for "bioeconomy" and about 33 hits for "forest bioeconomy" in Google Scholar, and 216 hits, 12 articles for "bioeconomy" and 3 for "forest bioeconomy" in Scopus database. In 2017, D'Amato *et al.* (2017) identified 864 publications on circular economy, 615 on green economy, and 464 on bioeconomy through a bibliometric analysis conducted using the search engine Web of Sciences (WoS) (timeframe: 1990-2017). Those authors have highlighted a substantial number of publications on the circular economy in China and on the green economy and bioeconomy in the United States. Conversely, the European countries focused on all three concepts, in accordance with recent policy documents such as the EU Bioeconomy Strategy published in 2012 and updated in 2018, and the Communication of European Commission "Towards a circular economy: A zero waste programme for Europe" (2014). For the European context, Lovrić *et al.* (2020) identified 444 projects related to the forest-based bioeconomy for a total amount of 1,589 M euro founded by FP7 (period: 2008-2014) and Horizon2020 programme (period: 2015-2018). Recently, Biancolillo *et al.* (2020b) showed a further growth of publications on "forest bioeconomy" in Scopus database thus summarized: 1,756 peer-reviewed publications focusing on bioeconomy (with an average of 97.6 publications per year) and 225 focusing on forest bioeconomy (12.5 publications per year) respectively in the period between January 2003 and March 2020. The results of this study confirm the growth trend of scientific production concerning the interest of the scientific community for circular economy and bioeconomy in several production sectors.

The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2007) highlighted the importance of a sustainable forest management strategy for mitigating CO_2 emissions and the IPCC strategy aims at maintaining forest carbon stocks while producing an annual sustained yield of fiber for energy and materials. The large-scale production of innovative bio-based products derived from forest biomass in addition to traditional wood-based products represents an important challenge to be addressed (Clark *et al.*, 2012). In this framework, the circular bioeconomy can provide an important guiding approach to develop an effective policy framework to support innovation and investment in new technologies reconciling the role of forests as carbon sink (Ladu *et al.*, 2020).

To assess the performance of forest-based sector in accordance with the principles of circular bioeconomy it is necessary to develop standardized and easy to apply indicators. The present study attempted to provide a preliminary list of 14 indicators for this objective. The results show that for all groups of decision makers (freelancers, private companies, public administrations) the most important indicators for each R group of the 4R framework are: ratio between annual value and annual mean volume harvested (Reduce); time of use of products (Reuse); ratio between the potential economic value of the wood assortment and the real value earned (Recycle); and percentage of wood waste for bioenergy production (Recover). In addition, many decision makers emphasized the importance of CO_2 emissions saved per unit of energy produced by wood wastes as-well-as the reduction of CO_2 emissions during all phases of forest-wood chain in accordance with objectives of the Paris Agreement on Climate Change (2015) and the strategic choices of the SNSvS (Choice IV – Decarbonize the economy).

When defining our set of indicators, we focus on the forest-based sector and, therefore, gave preference to indicators for which a plausible link with bio-based production could be assumed. In particular, additional opinions of decision makers show that they put attention on the emission reductions capacity of forestry (Pieratti *et al.*, 2019). We aimed at addressing all three dimensions of sustainability, although our focus was on the economic and environmental dimension of sustainability. In fact, as evidenced by Bracco *et al.* (2019) the economic sustainability of the bioeconomy at the product level is often neglected.

The present study is in line with the one of Linser and Lier (2020), finalized at proposing the most suitable indicators for the sector, in the present case the forest based one, but also at encouraging actors to contribute to develop bioeconomy monitoring systems, using synergies from the already existing sustainable goals and indicators and forest monitoring processes. From the methodological point of view, the main strengths of the proposed method are the identification of simple and easy-to-apply indicators. The identified indicators require a reduced number of primary data and information. Conversely, the main weakness is the adaptation of indicators typical of other bio-based sectors to forest-based sectors. In some cases, the indicators have been adapted and lowered into the forest-based context taking into account the characteristics and peculiarities of this sector.

The results of the present study, evidencing different kind of useful indicators to be adapted to the different situation, can be read in synergy with the results of the Italian study of Falcone *et al.* (2020) aimed at understanding the conditions influencing the forest sector's transition towards a circular bioeconomy. The research is based on a single case study method, drawing on an in-depth literature review, a SWOT analysis, and a questionnaire survey. The results of Falcone *et al.* (2020) show a variety of different strategies for the transition towards a circular bioeconomy and confirm the complexity of the forest sector system and the necessity for decision makers to go beyond a simple best option approach.

Our findings also converge with the several bioeconomy monitoring-related initiatives (SAT-BBE, 2018) that propose a set of indicators and with the activity of organizations like EUROSTAT or Forest Europe that are already collecting data for their indicators.

Future steps of the studies aimed at developing indicators to assess the performance of forest-based sector in accordance with the principles of circular bioeconomy could try to consider effects they can bring to the society social factors. Typically, the implications of bio-based companies and industries are considered using economic, environmental and technical indicators while social factors are frequently neglected, mainly due to the fact they are difficult to be quantitatively analyzed, measured and monitored.

The future actions of the FOR.CIRCULAR project will be to test the set of indicators in different case studies both at local and regional level. In addition, the list of indicators will be integrated with the additional indicators suggested by the decision makers during the survey. The indicators with the respective weights assigned by the decision makers will be used for the development of a Decision Support System (DSS) aimed to improve the performance of the forest-based sector in a circular bioeconomy perspective. The open-source and free DSS will be made available to operators of the forest-based sector.

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