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A literature review on forest bioeconomy with a bibliometric network analysis

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Abstract: Over the last couple of decades, many peer-reviewed publications focused on the bioeconomy, which it is frequently argued to be a key part of the solution to global challenges (climate change, ecosystem degradation). This study investigates the scientific literature on forest bioeconomy by applying a social network analysis to the bibliometric science. The bibliometric network analysis was performed over the time-frame of 2003–2020 to provide an overview on the main aspects characterising the forest bioeconomy issue. The results show that 225 documents on forest bioeconomy were published by 567 organisations from 44 countries. Finland and Canada are the two most productive countries with 32.8% and 12.7% of forest bioeconomy documents respectively. The co-occurrence network map of the keywords shows that the forest bioeconomy is related to three main concepts: sustainable development, bioenergy production, climate change mitigation.

Keywords: green economy; circular economy; forestry; bibliometric analysis; sustainability; VOSviewer software

The economy is based on the availability of natural capital stock that can be differentiated in renewable and non-renewable natural capital (Costanza, Daly 1992). In the last decades, starting from the awareness that natural resources are limited, sustainability has been a main concept in global research and political agendas (Garud, Gehman 2012; Markard et al. 2012). In international literature, the concept of sustainability has been interpreted in a "weak" or "strong" way. Weak sustainability presupposes an intergenerational equity – current resources must also be available for future generations – and the substitutability of the natural capital with a manufactured capital or human capital such as skills, education, capacity and attributes of labour (Cabeza-Gutés 1996). Conversely, strong sustainability should be achieved by conserving the stock of human capital, technological capabilities, natural resources, and environmental quality (Brekke 1997; Ayres et al. 2001). Therefore, for strong sustainability, ecological, economic, and social capital should be independently maintained because natural resources are essential inputs in the economic production and cannot be replaced by manufactured capital or human capital (Ang, Van Passel 2012).

In accordance with the principles of sustainability, a "circular economy", "green economy" and "bioeconomy" have been introduced in the global

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political agenda to transform the linear economy paradigm towards a more sustainable one aimed at reducing the use of fossil fuels and the impacts on natural resources (Bruhn et al. 2016). Loiseau et al. (2016) and D'Amato et al. (2017) have identified a circular economy, green economy and bioeconomy as key, hierarchical, and interconnected concepts in sustainability research.

A circular economy can be defined as (Kirchherr et al. 2017): "... an economic system that is based on business models which replace the 'end-of-life' concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes, thus operating at the micro level (products, companies, consumers), meso level (eco-industrial parks) and macro level (city, region, nation and beyond), with the aim to accomplish sustainable development, which implies creating environmental quality, economic prosperity and social equity, to the benefit of current and future generations". In other words, the main objective of a circular economy is to have a minimal input and production of system "waste" by redesigning the life cycle of the "product", so economic actors would exert no net effects on the environment (Loiseau et al. 2016). As emphasised by several authors, a circular economy is based on the 4R framework ("Reduce", "Reuse", "Recycle", "Recover") – to reduce the negative impacts on the environment and to enhance the waste from the production process – and the "cascade" principle that implies the use of raw materials according to a priority based on the added potential value (Van Buren et al. 2016; Proskurina et al. 2016).

A green economy can be defined as "results in improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities. In its simplest expression, a green economy can be thought of as one which is low carbon, resource efficient and socially inclusive" (UNEP 2011). From a theoretical point of view, a green economy is based on three fundamental principles (Ivlev, Ivleva 2018): the mutual dependence of all life on the planet; the refusal of the requirement to meet the ever-growing needs in a limited amount of resources; and the refusal of the endless expansion in a limited space. The objectives of a green economy with special regard to the forest-based sector as mentioned by the "Rovaniemi Action Plan for the Forest Sector in a Green Economy" (ECE/TIM/SP/35) are (Marchetti et al. 2014; Yakovleva, Subhonberdiev 2019): (1) the sustainable production and consumption of forest products; (2) the contribution of the forest-based sector to mitigate the climate change; (3) the contribution of the forest-based sector to achieve the social objectives of a green economy with special emphasis to provide green jobs; (4) the long-term provision of forest ecosystem services; and (5) policy development and monitoring of the forest-based sector in relation to a green economy.

Considering the principles and objectives, the concept of a green economy emphasises the harmonious coexistence of nature and society and the importance of ecosystem services provided by natural capital (Marchetti et al. 2014). Therefore, in a green economy, the core of the concept is protecting the environment and natural resources rather than promoting economic growth and development. To effectively protect the environment, a green economy must distance itself from the old concept of sustainable growth (Barbier 2011).

The theoretical foundations of a bioeconomy were developed by Georgescu-Roegen (1975, 1977), who highlighted the entropic limits of the economic growth process. Georgescu-Roegen (1977) emphasised the necessity of connecting institutional, biological, biophysical and social issues with economic theory. The updated concept of a bioeconomy, developed over the last decade, is rooted in the idea that industrial inputs (e.g., material, chemicals, energy) should be derived from renewable biological resources, with research and innovation enabling the transformational process (Kleinschmit et al. 2014; Pfau et al. 2014; Bugge et al. 2016). In this context, forestry, agriculture, fisheries and aquaculture can play a fundamental role in providing bio-based substitutes for non-renewable sources (Ollikainen 2014; Roos, Stendahl 2015).

The bioeconomy covers different science fields – e.g., life sciences, agronomy, ecology, engineering and management sciences – following a multidisciplinary approach (Golembiewski et al. 2015). According to the Organization for Economic Co-operation and Development (OECD), a bioeconomy is an innovative approach of transforming knowledge into new sustainable and eco-efficient product that is also competitive (OECD 2009).

The drivers of bioeconomy knowledge are not only science, but also innovative companies with extensive knowledge on bio-based products and services on offer (Woźniak, Twardowski 2018).

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A bioeconomy is interconnected with different primary resources (forestry, agriculture, fisheries and aquaculture) and sectors (food, chemical, energy, industrial materials, tourism-recreation and well-being). A bioeconomy implies the sustainable exploitation of biological resources to produce new bio-based products (Lainez et al. 2018), providing conditions for an increased standard of living (Aguilar et al. 2013).

In the last years, the term bioeconomy has been progressively used in political documents stressing the importance of this concept for policy makers. In 2009, the OECD published "The Bioeconomy to 2030: Designing a Policy Agenda" that has an evidence-based technology approach, focusing on biotechnology applications and the future developments of the bioeconomy in primary production, health, and industry. The idea of the "The Bioeconomy to 2030: Designing a Policy Agenda" is to analyse the bioeconomy through an interdisciplinary approach. Implementation pathways determine the technology-based approach and socioecological approach, where the latter includes an inter- and transdisciplinary approach in research (Priefer et al. 2017).

In 2012, the European Commission has published the European Union (EU) Bioeconomy Strategy entitled "Innovating for Sustainable Growth. A Bioeconomy for Europe" (European Commission 2012). Particularly, the EU Bioeconomy Strategy has identified five main societal challenges thus summarised (Wolfslehner et al. 2016): ensuring food security; managing natural resources sustainably; reducing dependence on non-renewable resources; mitigating and adapting to climate change; and creating jobs and increasing European competitiveness.

In the recent Updated EU Bioeconomy Strategy, the European Commission (2018) emphasised that the bioeconomy is a central element to the functioning and success of the EU economy and is a key element to build a carbon neutral future in line with the Climate objectives of the Paris Agreement (2015). To increase the competitiveness of the EU companies, the modernisation and strengthening of the EU industrial base through the creation of new value chains and greener ones is a mandatory aspect. The idea of the Updated EU Bioeconomy Strategy is that EU bio-based companies diversify their business models and product portfolios by developing new high added value products and services.

With regard to the forest-based sector, the "new EU Forest Strategy: for forests and the forest-based sector" (2013) by the European Commission highlighted that advanced wood-based materials and chemicals, together with non-wood forest products, are expected to play a major role in the EU bioeconomy to satisfy the growing consumers' demand. In the future, the forest-based sector would play an increasing key role for smart and green growth according to the potential development of new bioeconomy products such as advanced biofuels, intelligent packaging, bio-textiles, and biochemicals (Hetemäki 2014; Hetemäki et al. 2020).

Starting from these considerations, the main aim of the present study is to explore the international scientific literature on the "forest bioeconomy" issue tracking its evolution by applying a bibliometric network analysis. The bibliometric network analysis provides maps and statistics based on network data displaying the relationships among organisations, countries and keywords involved in the forest bioeconomy scientific production.

MATERIAL AND METHODS

The literature review was made with the aim of analysing peer-reviewed publications (books, chapters, articles, and papers published in conference proceedings) concerning the forest bioeconomy issue.

The peer-reviewed publications were retrieved from the Scopus database (https://www.scopus.com) on March 4th 2020 using "forest bioeconomy" as the keyword search. The definition provided by Karvonen et al. (2017) was used in this literature review: a forest bioeconomy is an activity utilising wood and other non-wood products obtained from forests or side streams of the forest biomass from other industrial activities including forestry related operations such as harvesting, transporting and refining of the forest biomass. The above-mentioned keyword was searched in the title, abstracts and keywords of the individual peer-reviewed publications. The time-frame was set from 2003 to 2020.

All the data were exported as "comma-separated values" (csv) files and processed through a bibliometric network analysis using the VOSviewer software (1.6.11, Leiden University, Netherlands).

The VOSviewer software was developed by Van Eck and Waltman (2014; 2020) for the creation, visualisation, and exploration of maps based on the bib-

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liometric network data. From the theoretical point of view, the bibliometric network analysis is based on the combination of a bibliometric approach and a Social Network Analysis (SNA) approach.

The bibliometric approach is used to analyse and measure the scientific productivity on a specific 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 the publications, authors and areas of research).

The SNA approach is aimed at understanding the relationships among all the components (e.g., actors, organisations, countries, concepts, words) of a system to identify and analyse the key role of some components in the system (Wasserman, Faust 1994). From a practical point of view, the output results are displayed in clusters to visualise the existing connections among the bibliometric data. Table 1 summarises the main technical terms used by the VOSviewer software.

The bibliometric network analysis is a useful tool to quantitatively assess trends and patterns of scientific literature (Otte, Rousseau 2002). Recent environmental science studies used a bibliometric network analysis to investigate the scientific literature on natural capital, ecosystem services, food security, sustainable tourism, and a circular economy (Buonocore et al. 2018; Pauna et al. 2018, 2019; Türkeli et al. 2018; Skaft et al. 2020; Demiroglu, Hall 2020).

In the present study, two analyses were carried out: the co-authorship and the co-occurrence. The co-authorship analyses were conducted to create network maps showing the organisations, countries and the link among each other, based on the number of publications they have authored jointly.

The number of co-occurrences of two keywords is the number of publications in which both keywords occur together in the title, abstract or keyword list. The co-occurrence analyses were conducted to create network maps about keywords used in the forest bioeconomy literature.

Each network map that resulted from the analyses contains nodes with the size determined by the number of documents, and lines connecting the nodes with thickness based on the "link strength" (Table 1). The number of clusters visualised in the network maps is determined by the resolution parameter. The higher its value is, the higher the level of details. This value can be set to visualise an appropriate number of clusters in the maps (Van Eck, Waltman 2020). In this study, the resolution was set to 1.

In addition, the ratio between the citations and documents (R) was calculated for each organisation, author, and country involved in the scientific production on the forest bioeconomy. The ratio R provides synthetic information about the impact of the publications on the scientific community (Equation 1):

$$R = \frac{\Sigma_{(i=1)}^{n} C_i \ / \ D_i}{n} \qquad (1)$$

Where:

n – total number of documents on the forest bioeconomy issue published in the time-frame 2003 to 2020;

D_i – document i;

C_i – total number of citations received by document i.

Table 1. The main technical terms used in the VOSviewer software (Van Eck, Waltman 2020)

Term	Description
Items	objects of interest (e.g., publications, researchers, keywords, authors)
Link	connection or relation between two items (e.g., co-authorship)
Link Strength	attribute of each link expressed by a positive numerical value; in the case of co-authorship links, the higher the value is, the higher the number of publications the two researchers have co-authored
Network	set of items connected by their links
Cluster	sets of items included in a map; one item can only belong to one cluster
Weight attribute:	
Number of Links	the number of links of an item with other items
Total Link Strength	the cumulative strength of the links of an item with other items

https://doi.org/10.17221/75/2020-JFS

RESULTS

Publication trend analysis

The Scopus database search resulted in 225 forest bioeconomy publications in the period between January 2003 and March 4th, 2020. On average 12.5 peer-reviewed publications on forest bioeconomy (SD = 16.9; median = 2) have been published every year.

The number of documents on the forest bioeconomy show an increasing trend in the investigated time-frame (Figure 1). However, this growth trend is characterised by some differences: in the first period (2003-2012) on average 1.7 documents on the forest bioeconomy (SD = 2.7; median = 1) were published every year, while in the second period (2013–2020) the average number of publications on the forest bioeconomy was 26.0 (SD = 17.6; median = 26).

In 2003, the first article on a forest bioeconomy was published on the Forestry Chronicle journal with the title "The bioeconomy and the forestry sector: Changing markets and new opportunities" (Duchesne, Wetzel 2003). Those authors emphasised the potential economic impact of the bioeconomy on the following Canadian economic sectors: energy and transportation, food and agro-food, pharmaceuticals, nutraceuticals, forestry, materials and manufacturing, waste management and a large variety of consumer goods. Three years later, the same authors estimated the value of many forest-derived bio-products and gave concrete indications of their potential contribution to a sustainable Canadian economy (Wetzel et al. 2006). The first publications focused on a forest bioeconomy in Europe were published in 2011. Those publications emphasised the results of the seventh Forest-Based Sector Technology Platform (FTP) conference entitled "Pacing Innovation for the Bioeconomy" (Fojutowski, Strykowski 2011), and the potential role of forestry and agroforestry for the European bioeconomy (Kikuchi 2011). Also, the trend of the scientific publications on the forest bioeconomy was influenced by the EU Bioeconomy Strategy (2012) with an increase in published documents since 2013. As highlighted by Lovrić et al. (2020), research activities in the field of a forest bioeconomy grew in the period 2008–2018 thanks to the EU Seventh Framework Programme (FP7), H2020, and the Work Programme on European Research Area (ERA-NETs).

Organisation network analysis

There are 567organisations (universities and research institutes) that have published documents on a forest bioeconomy in the period 2003–2020. Particularly, 4 organisations have published 3 or more documents (0.71% of the total organisations), 16 organisations have published 2 documents (2.82%), and the remaining 547 have only published one document (96.47%).

The Institute of Energy Systems and Environment of Riga Technical University (Latvia) is the most productive organisation with 3.18% of the to-

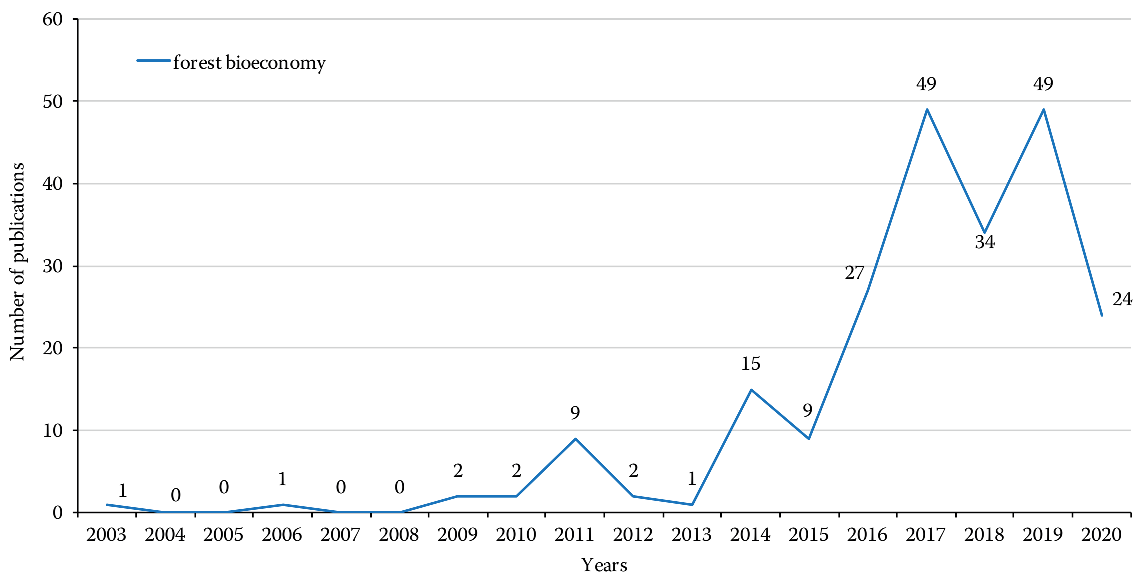

Figure 1. Trend of publications on the forest bioeconomy on an international level (period 2003–2020)

https://doi.org/10.17221/75/2020-JFS

Table 2. The top ten organisations that have published on the forest bioeconomy (period: 2003–2020), ranked by the total number of documents

Organizations	Documents	Total link strength	Links	Frequency (%)	*R*
Institute of Energy Systems and Environment, Riga Technical University (Latvia)	7	1	1	3.18	6.29
European Forest Institute (Finland)	6	15	15	2.73	7.17
Department of Forest Sciences, University of Helsinki (Finland)	3	5	5	1.36	27.33
School of Forest Sciences, University of Eastern Finland (Finland)	3	3	3	1.36	12.00
Department of Mathematics and Statistics, Auburn University (United States)	2	7	7	0.91	9.00
Natural Resources Institute Finland (Finland)	2	7	7	0.91	1.00
Natural Resources Canada, Canadian Forest Service (Canada)	2	5	5	0.91	15.50
Forest Health Dynamics Laboratory, School of Forestry and Wildlife Sciences, Auburn University (United States)	2	5	3	0.91	17.00
Forest Products Development Center, School of Forestry and Wildlife Sciences, Auburn University (United States)	2	5	3	0.91	17.00

tal documents (Table 2), followed by three organisations located in Finland: the EFI (with 2.73% of total documents); the Department of forest Sciences of University of Helsinki (1.36%), and the University of Eastern Finland with the School of Forest Sciences (1.36%).

Observing the data by the author, the results show that three of the five most productive authors belongs to organisations located in Finland: Toppinen A. (Department of Forest Sciences, University of Helsinki) with 12 documents; Blumberga D. with 8 documents and Muizniece I. with 7 documents (Institute of Energy Systems and Environment of Riga Technical University); D'Amato D. (Department of forest Sciences, University of Helsinki) and Hetemäki L. (EFI) with 5 documents.

Observing the data by the ratio between the citations and documents (*R*), the results show that the Department of Forest Sciences of the University of Helsinki (Finland) has the highest scientific impact (R = 27.33), followed by three departments of Auburn University (USA) with the same ratio (R = 17.00): the Center for Bioenergy and Bioproducts; the Forest Health Dynamics Laboratory; and the Forest Products Development Center.

A co-authorship network map of organisations was produced considering the number of publications. The top 150 organisations for the total link strength and that published at least one document on a forest bioeconomy were selected.

The network maps show clusters in different colours grouping the items characterised by a higher level of collaboration. The size of the circles represents the weight of items based on the number of documents.

Observing the network map (Figure 2), most of the organisations have the same importance in the diffusion of scientific knowledge, only the European Forest Institute (EFI) emerges above the others. The key role of the EFI is due to the participation in two clusters (the yellow and fuchsia clusters) and the publication of many monographs on a forest bioeconomy such as: "Future of the European Forest-Based Sector: Structural changes towards bioeconomy" (Hetemäki 2014), "Leading the way to a European circular bioeconomy strategy" (Hetemäki et al. 2017), "Towards a sustainable European forest-based bioeconomy (Winkel 2017), and "Forest bioeconomy – a new scope for sustainability indicators" (Wolfslehner et al. 2016).

Country network analysis

The co-authorship analysis of countries provided 44 results for a forest bioeconomy. Finland is the most productive country with 72 publications (32.75% of the total documents), more than dou-

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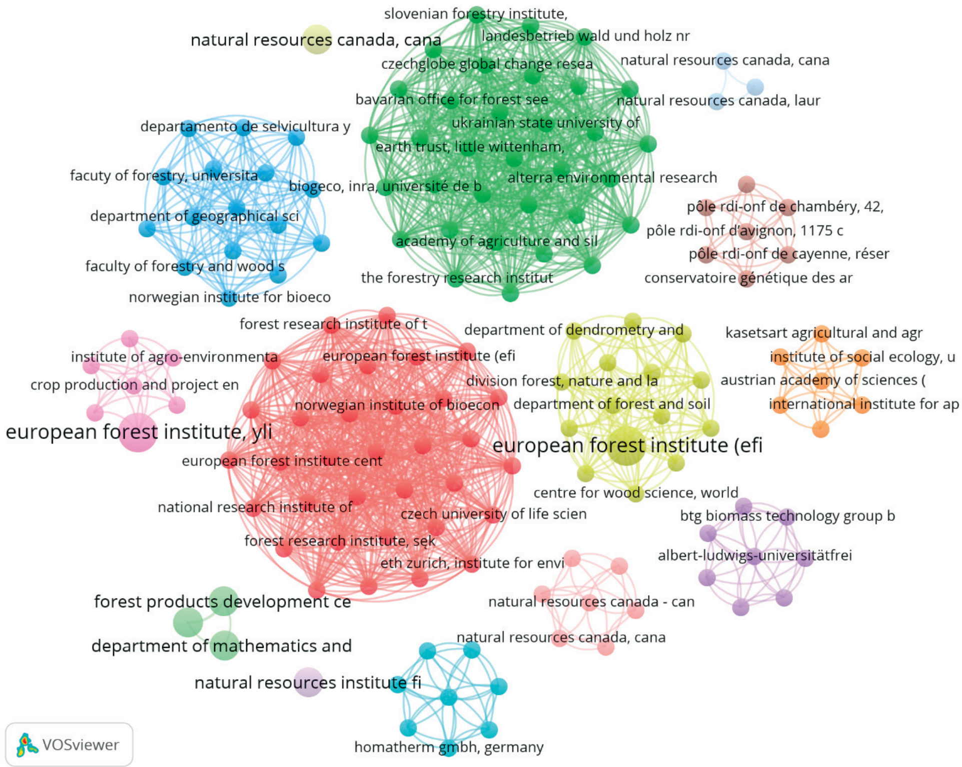

Figure 2. Co-authorship network map of top 150 organisations for the total link strength that have published at least one document on a forest bioeconomy

ble compared to Canada which is the second most productive country with 28 documents (12.73% of total documents) (Table 3).

Observing the data by the ratio between the citations and documents (R), the results show that the highest ratio is for the paper published by Italian authors (R = 20.24), followed by Norwegian authors (R = 11.57) and Swedish authors (R = 11.41).

The co-authorship network map shows that there is a high level of collaboration among countries that have published on a forest bioeconomy (Figure 3). The forest bioeconomy network map shows that European countries play a key role in the network with special regard to six countries: Finland, Germany, Sweden, Austria, Italy, and Norway. In addition, the results show that there are some dense clusters such as: one cluster (the green cluster) among Eastern European countries (Bosnia and Herzegovina, Bulgaria, Estonia, Lithuania North Macedonia, Serbia), and one cluster among the Mediterranean countries (Portugal, Greece, Italy, Spain).

The results of the present study confirm those provided by Lovrić et al. (2020) about the research

Table 3. The top ten countries publishing on the forest bioeconomy, ranked by the total number of documents

Nations	Documents	Total link strength	Links	Frequency (%)	R
Finland	72	117	33	32.73	8.35
Canada	28	7	6	12.73	8.39
Sweden	27	68	32	12.27	11.41
Germany	26	88	31	11.82	10.35
Italy	25	88	31	11.36	20.24
Austria	23	95	33	10.45	9.70
United States	21	25	20	9.55	6.90
Norway	14	61	29	6.36	11.57
France	13	76	31	5.91	6.62
Latvia	10	29	28	4.55	6.80

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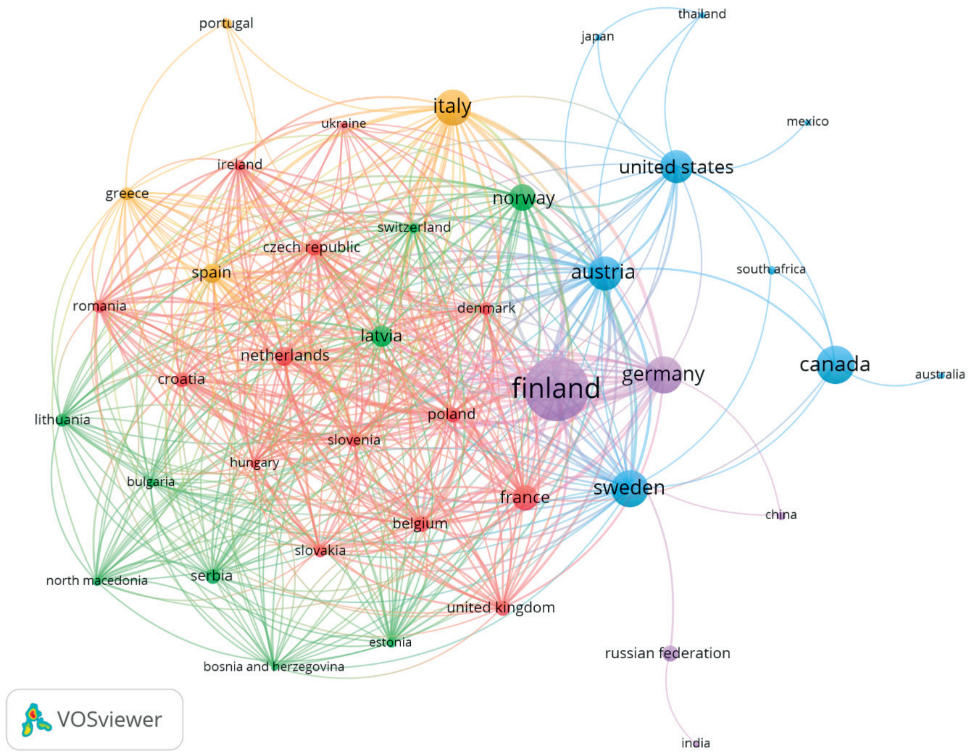

Figure 3. Co-authorship network map of the countries that have published on a forest bioeconomy, based on the number of documents

projects developed in the forest bioeconomy field. Those authors show the high centralisation of the research to a few countries from North-Western Europe (i.e., Germany, Finland, France, Sweden), while Eastern Europe is not adequately integrated into the European research network.

Keyword network analysis

The analysis of the keywords generated 1 897 results for a forest bioeconomy. However, only 93 keywords have at least five co-occurrences. The most important keyword is "forestry" (a frequency of 5.69%), followed by "bioeconomy" (4.96%), "biomass" (3.00%), "sustainable development" (2.16%), and "sustainability" (1.85%) (Table 4).

The co-occurrence network map of keywords related to a forest bioeconomy (Figure 4) shows the 50 most used keywords. The size of the circle is proportional to the co-occurrence of that item, the shorter the distance is among the items, the stronger their relation is.

In the forest bioeconomy network map, there are four clusters highly interconnected. The red cluster mainly considers the forest-related circular bioeconomy as an engine for sustainable development (sustainability). The yellow cluster considers the relationship between the bioenergy production and climate change mitigation. The green cluster mainly focuses on biotechnologies for biofuels production, while the blue cluster focuses on the forest-wood chain related to the wood biomass extraction and the potential negative impacts on the biodiversity conservation.

DISCUSSION

The scientific community and policy makers agree that a forest bioeconomy is the potential engine of the future economic growth able to satisfy the needs of the current generation without compromising the natural resources stock. However, many authors have emphasised the positive socio-economic impacts of a bioeconomy (Schmid et al. 2012), while other authors have highlighted the role of a bioeconomy to reduce the negative effects of economic growth on the environment and the consumption of natural resources (Liobikiene et al. 2019).

In other words, according to Pülzl et al. (2017), the scholarly literature on a forest bioeconomy follows one of the three main visions:

(1) a "bio-technology" vision that emphasises the importance of bio-technology research;

(2) a "bio-resource" vision that focuses on the processing and upgrading biological raw materials; and

https://doi.org/10.17221/75/2020-JFS

Table 4. The top ten keywords related to the forest bioeconomy, ranked by the co-occurrence

Keyword	Co-occurrence	Frequency (%)	Total link strength	Links
Forestry	108	5.69	2042	1202
Bioeconomy	94	4.96	1419	922
Biomass	57	3.00	1210	797
Sustainable development	41	2.16	832	558
Sustainability	35	1.85	714	492
Timber	28	1.48	533	392
Bioenergy	26	1.37	537	382
Climate change	26	1.37	558	384
Wood	26	1.37	547	402
Economics	21	1.11	421	337

(3) a "bio-ecology" vision that focuses on sustainability and ecological processes.

In this context, the forest-based sector must play a key role by supporting the bioeconomy not only through the provision of wood- and non-wood forest products, but also producing other forest-related ecosystem services in a sustainable way (Purwestri et al. 2020).

Firstly, the use of the forest biomass for bioenergy production can reduce the dependence on non-renewable resources (fossil-based raw materials). The growth in the use of the forest biomass for energy is related to the high potential exploitation of wood residues (e.g., tops, branches, twigs, needles) in mountain and rural areas (Mantau et al. 2010, Nikodinoska et al. 2018). Nevertheless, this is an important issue related to the full exploitation of the bioeconomy concept, because of the easily predictable competition in using the lignocellulose biomass for alternative purposes (Paletto et al. 2019; Pieratti et al. 2020), namely bio-textiles and bio-chemicals.

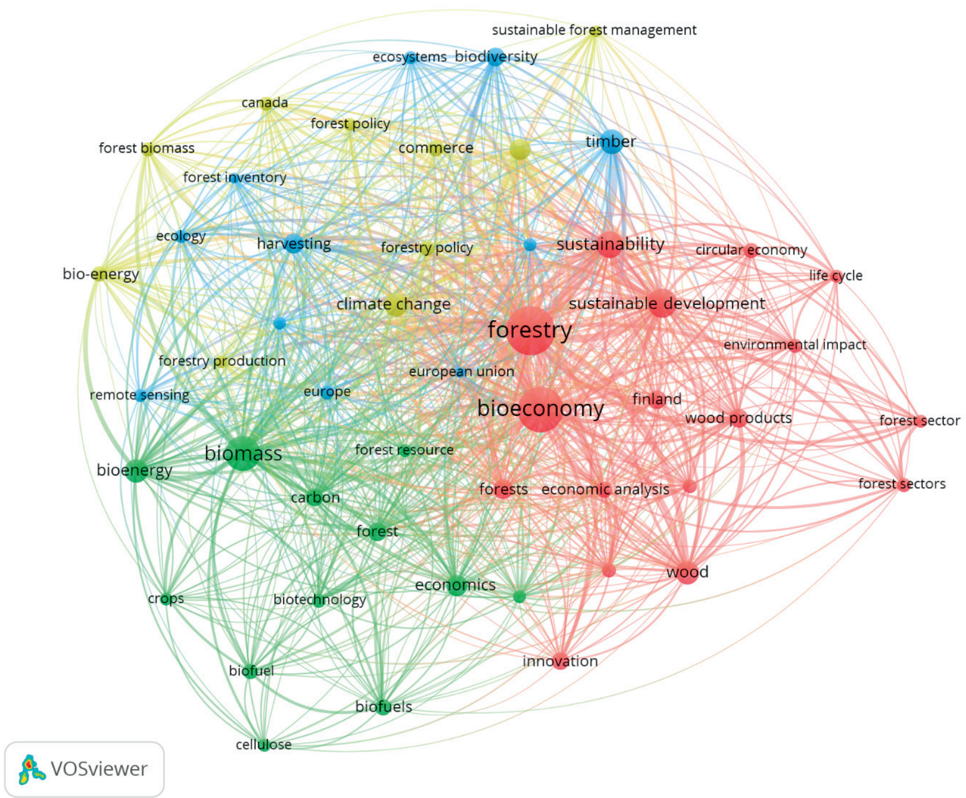

Figure 4. Co-occurrence network map of the 50 most used keywords related to a forest bioeconomy

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In agreement with environmental sustainability, the production of the forest biomass should be encouraged through the valorisation of wood residues from forest operations and wood processing not looking to the realisation of short rotation forestry (SRF) plantations as a unique feasible resource. Secondly, the forest-based sector can contribute to a low-carbon society through a carbon sink into the above- and below-ground biomass and soil, the increasing storage of carbon in wood products, and the use of the wood biomass as a substitute for fossil fuels (Lundmark et al. 2014; Pülzl et al. 2014). Thirdly, the forest-based sector can promote novel and innovative wood bio-materials such as construction materials, chemicals, bio-plastics, packaging materials, and bio-textiles (Ragauskas et al. 2006; Paletto et al. 2019).

The results of this study show that, in the international literature, several definitions of a bioeconomy have been provided demonstrating that this concept is constantly evolving (Table 5). Analysing the main definitions on the bioeconomy, the common key points that emerge in all the definitions are: (1) the concept of sustainability as the theoretical foundation of the bioeconomy; and (2) the innovation and knowledge processes as the engine of the bioeconomy. These common key points are also taken up by some national bioeconomy strategies.

From 2012 to today, many EU member countries have developed a national bioeconomy strategy in accordance with the principles and objectives of the EU Bioeconomy Strategy (Table 6).

The general background to all national bioeconomy strategies is the replacement of fossil resources by biogenic materials to mitigate climate change, so the sustainability has a key role in protecting the environment and conserving natural resources. An effective implementation of bioeconomy strategies is based on a deep change in the economic structure to increase competitiveness (Bmel 2014, Ministry of Employment and the Economy 2014), to create new jobs, to create high added value products and services (Ministry of Employment and the Economy 2014, Ministère de l'Agriculture et de l'Alimentation 2016, Ministry of Trade, Industry and Fisheries 2016, Ministry of Agriculture 2017, Ministry of Economic Affairs and Climate Policy 2018, Department for Business, Energy & Industrial Strategy 2018, Italian Presidency of Council of Ministers 2019), and to improve environment quality. To achieve these objectives, the bioeconomy must use new scientific knowledge and emerging tech-

Table 5. Definitions of a bioeconomy

Definition	Source
The **knowledge-based production** and utilisation of biological resources, **innovative biological processes and principles** to sustainably provide goods and services across all economic sectors	Bioeconomy summit (2005)
The **sustainable**, eco-efficient transformation of renewable biological resources into food, energy and other industrial products	Directorate-General for Research and Innovation (DG RTD 2005)
Set of economic activities in which **biotechnology** contributes centrally to the primary production and industry	Organization for Economic Co-operation and Development (OECD 2009)
Sustainable production and conversion of biomass into a range of food, health, fibre and industrial products and energy. Renewable biomass encompasses any biological material as a product in itself or to be used as raw material	European Plant Science Organisation (EPSO 2011)
The production of **renewable biological resources** and the conversion of these **resources and waste streams** into value added products, such as food, feed, bio-based products and bioenergy. Its sectors and industries have strong innovation potential due to their use of a wide range of sciences, enabling industrial technologies, along with local and tacit knowledge	European Commission (EC 2012)
The **production, utilisation and conservation** of biological resources, including related knowledge, science, technology, and innovation, to provide information, products, processes and services across all economic sectors aiming toward a **sustainable economy**	Global Bioeconomy Summit (2018)

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Table 6. Bioeconomy strategy documents in European countries

Country	Definition	Year
Sweden	"Swedish Research and Innovation – Strategy for a Bio-Based Economy"	2012
Germany	"National Policy Strategy on Bioeconomy"	2014
Finland	"Sustainable Growth from Bioeconomy – The Finnish Bioeconomy Strategy"	2014
France	"A Bioeconomy Strategy for France"	2016
Norway	"The Government's Bioeconomy Strategy – Familiar resources – undreamt of possibilities"	2016
Spain	"Spanish Strategy on Bioeconomy Horizon 2030"	2016
Latvia	"Latvian Bioeconomy Strategy 2030"	2017
Ireland	"National Policy Statement on the Bioeconomy"	2018
The Netherlands	"The position of the bioeconomy in the Netherlands"	2018
The United Kingdom	"Growing the bioeconomy: a national bioeconomy strategy to 2030"	2018
Austria	"Bioeconomy - A Strategy for Austria"	2019
Italy	"BIT II – Bioeconomy in Italy"	2019

nologies in the bio-based production and transfer the natural resources into sustainable products and services in the processing and service industries by applying the principles of cascading, as indicated in the Netherlands bioeconomy strategy (Ministry of Economic Affairs and Climate Policy 2018). Other themes addressed by the strategies are food security (Bmel 2014; Ministère de l'Agriculture et de l'Alimentation 2016) and the development of rural and coastal areas (Spanish Ministry of Economy, Industry and Competitiveness 2016). Some strategies also include cross-sectoral area of action, such as a coherent policy framework for a sustainable bioeconomy, information and dialogue within society (Formas 2012; Bmel 2014; Spanish Ministry of Economy, Industry and Competitiveness 2016). The Irish Bioeconomy Strategy (Department of the Taoiseach 2018) underlines the importance of the cooperation between the public service, industry and the research institutes, while in the German bioeconomy strategy (Bmel 2014), biotechnology has a central role. The UK strategy (Department for Business, Energy & Industrial Strategy 2018) is set to boost the national productivity.

Looking more in depth to the "Scopus" references on the main themes related to a forest bioeconomy, which can be assessed as "bioeconomy concept", which, in turn, must be considered the output of the concrete punctual research on bioenergy, bio-materials and biorefinery. In this sense, representative examples are studies focused on bioenergy production related to a short supply chain and based on bioeconomy principles (Zambon et al. 2016; Delfanti et al. 2014). Nevertheless, in those studies, the term "forest bioeconomy" is not explicitly mentioned. From this point of view, the concept of a short supply chain in forestry is also a fully integrated part of forest bioeconomy (Romagnoli et al. 2019) as-well-as the maximum exploitation of low-quality materials (Romagnoli et al. 2015).

Just to make a comparison, it considers many small rivers of "grey literature" on the bioeconomy, converging to a larger well-structured one, which has kept the national basic assumption on geographical and cultural diversity in mind. In the last years, it has increased the awareness of the bioeconomy concept and, in technical articles, it is now becoming explicit (Zikeli et al. 2020; Marini et al. 2020), which could help in better monitoring the progress and feasibility of the bioeconomy process.

CONCLUSION

In the last years, publications on a forest bioeconomy have rapidly increased confirming that international policies and academic research have recognised a bioeconomy as one of the solutions for sustainable economic growth and green job opportunities. However, the results of this study show that a bioeconomy is an evolving concept. In the international literature, some authors stated that the transition from a linear economy to a bioeconomic one is often argued as playing a key role in targeting challenges such as climate change mitigation, food security, health, industrial restructuring, and energy security.

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From a methodological point of view, a bibliometric network analysis provides an overview on the main aspects characterising the forest bioeconomy issue investigating the relationships occurring among the organisations, countries and keywords. The main advantage of the proposed method is that the integration of a social network analysis and bibliometric science is a useful approach capable of capturing the multidimensional nature of the bioeconomy by analysing a large literature database. The main disadvantage of the proposed method is to consider only peer-reviewed documents (Scopus database) without being able to include grey literature (e.g., technical and project reports, working papers, Bachelor's and Master's thesis). Furthermore, many publications fully integrated in the concept of bioeconomy are missing in our study because they do not explicitly use the term "forest bioeconomy" in the title, abstract or keywords.

The future step of the study will be to analyse the implications of an increasingly diversified forest-based bioeconomy through the individuation of suitable indicators on a local and national scale. In a situation of uncertainty, appropriate indicators can help one avoid unwanted impacts, and support the bioeconomy development.

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