The Scientific Research on Environmental Accounting: A Bibliometric Network Analysis

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Abstract. Environmental accounting refers to methodologies aimed at assessing natural resources and the impacts human activities generate on them. Over the past few years, there has been an increasing interest in environmental accounting both in scientific and policy contexts, which recognize its important role in assessing the environmental costs and impacts generated by humans on natural ecosystems. In this study, we explored the global scientific literature on environmental accounting over the last fifty years. Based on scientific publications data, the VOSviewer software was used to generate network maps on environmental accounting displaying the relationships among scientific journals, keywords, researchers, and countries. In total, environmental accounting resulted to be the subject of 1,603 publications. The main keywords related to environmental accounting were "sustainable development", "environmental economics", and "sustainability", highlighting the important role played by environmental accounting tools for assessing environmental sustainability. In addition, United Kingdom, United States, and Italy, resulted the top countries in the research field of environmental accounting. In conclusion, the application of systems thinking in bibliometric science allowed a broad investigation of the research on environmental accounting, resulting a valuable approach for identifying trends and gaps in this research area.

Keywords: Environmental accounting, ecosystem accounting, natural resources, bibliometric network analysis, VOSviewer.

1. Introduction

Environmental accounting is a research field aimed at identifying resource use, measuring and communicating the costs and the impacts on the environment generated by human activities (Deegan, 2013). It is a useful tool to assess multiple aspects dealing with the stocks of natural capital and their exploitation, among which sustained environmental costs, received benefits, and generated impacts (Häyhä and Franzese, 2014). Environmental accounting systems play an important role in

implementing management schemes and policies oriented to the sustainable use of natural resources by exploring the connections between natural ecosystems and human activities and providing useful information to stakeholders (Buonocore et al., 2018).

In the late 19th, a growing concern on natural resources, on which human economy depends, paved the way for reconsideration of traditional growth models (Galos et al., 2015; Hecht, 2007b).

As early as 1970s, a few European countries were experimenting ways to include environmental data into their national accounts (Hecht, 2007a). Influenced by a growing environmental movement and the publication of the book Limits to Growth (Meadows et al., 1972), Norway was one of the first countries to develop accounts for tracking the use of their forests, fisheries, energy, and land. The Netherlands was also a leader country in the development and adoption of environmental accounting systems. The third earliest adopter of environmental accounting was France, which developed an approach termed "*comptes du patrimoine*". Parts of this system were constructed, but its complexity made it difficult its full implementation (Hecht, 2000).

In addition to the efforts of leading countries, some studies tried to stimulate the interest in the field of environmental accounting. Two influential studies were on Indonesia. The first study was undertaken by the World Resources Institute (Repetto et al., 1989) and the authors estimated what GDP (Gross Domestic Product) might have been if natural resources were depreciated in the same way as manufactured ones. The second is an empirical study (Magrath and Arens, 1989) that estimated the cost to the economy of soil erosion. Another early accounting project of the Chesapeake Bay region of the eastern United States, undertaken by the US Environmental Protection Agency (EPA) and led by the economist Henry Peskin, incorporated the full value of non-marketed goods and services in the economic accounts, and all changes in value of capital were deducted from gross indicators to calculate net ones.

In the 1980s, organized international efforts to share the knowledge on environmental accounting and develop rules matching the system of national accounts (SNA) began. The World Bank and the United Nations Environmental Program (UNEP) held a series of workshops that led to the publication of two papers that became reference works in the field (Ahmad et al., 1989; Lutz, 1993).

In 1992, the Agenda 21, adopted at the United Nations Conference on Environment and Development, gave a boost to work in the field. The Agenda 21 called for "Establishing systems for integrated environmental and economic accounting" (UN, 1992). In response to policy demands, the 1993 SNA devoted a separate section to integrated system of environmental-economic accounts (SEEA) (Stahmer, 1997).

The SEEA, released in 1993, was the first effort to create a synthesis of different concepts and methodologies in the fields of natural resources and environmental accounting. It was revised in 2003,

and in 2012 the SEEA Central Framework was adopted by the United Nations Statistical Commission (UNSC) as an international statistical standard (www.seea.un.org). This framework has been applied in different studies. Among them, the Australian Bureau of Statistics estimated the value of land, mineral resources, energy resources, and timber resources (Obst and Vardon, 2014). Another study examined solid waste production in Australia (Fry et al., 2016). Botswana and Namibia, resource-rich countries in southern Africa, constructed their total wealth accounts (Lange, 2004). Gundimeda et al. (2007) demonstrated how forest resources in India can be integrated into national accounts using the SEEA framework.

Further development of the statistical framework and the continued comprehension and inclusion process of detailed testing, consultation and revision led to the adoption by the UNSC of the SEEA Ecosystem Accounting in March 2021 (Edens et al., 2022). A number of countries have applied this framework, but across these countries differences exist in the coverage and scope of the accounts (Hein et al., 2020). Some countries, such as the Netherlands (Hein et al., 2020) and the UK (ONS, 2019), compiled a complete ecosystem account covering extent, condition, services, and ecosystem assets, including a time series at national level. On the other hand, some countries have compiled only a single account or accounts for a few selected ecosystem services (Bagstad et al., 2020; Bruzón et al., 2022; Heris et al., 2021; Padhan and Das, 2022).

Alongside the SEEA framework, relevant literature on environmental accounting continued to be developed, mainly on methodologies and concepts, including footprint (Chen and Chen 2007; Grande et al., 2023), ecosystem services (Bartelmus, 2015; Boyd and Banzhaf, 2007; Buonocore et al., 2021; Edens and Hein, 2013), and valuation (Obst et al., 2016). These works were more often focused on methodological aspects or on the accounts rather than on potential policy applications.

Although the interest on environmental accounting has increased in the last decades both in scientific and policy context, there is a gap of review studies providing an overview on the topic.

In the last years, the use of bibliometric network analysis has proved to be a powerful tool to quantitatively analyze trends and patterns in the scientific literature considering large amounts of data (Otte and Rousseau, 2002). This approach is an effective tool combining bibliometrics and social network analysis. Bibliometrics uses different statistical techniques to assess research quality and trace the development of fields of science (Reuters, 2008; Temple, 2002; Zou et al., 2018). Applied to scientific literature, bibliometric network analysis allows the investigation of network structures quantitively based on the relationships among countries, organizations, researchers, and keywords dealing with the investigated topic (Buonocore et al., 2018; Galychyn et al., 2020; Pauna et al., 2019; Pauna et al., 2018; Skaf et al., 2020).

In this study, bibliometric network analysis was used to investigate the global scientific literature on "environmental accounting".

2. Methodology

2.1.Bibliometric network analysis

In this study, the VOSviewer software (version 1.6.20) was used to perform bibliometric network analysis. VOSviewer is a software tool based on social network analysis. It allows the creation, visualization, and exploration of maps based on bibliometric network data, and displays clusters that support the classification of output results. The main technical terms used by the software are summarized in Table 1.

In this study, the co-authorship, co-occurrence, and citation analyses were performed to create maps showing the network of: (1) co-authorship among researchers and countries, (2) co-occurrence of keywords, and (3) cited scientific journals (Table 2). In these maps, the size of items is determined by different weight attributes, namely "total link strength", number of citations, and number of documents. The thickness of each connection is based on "link strength". In addition to the maps, the most cited articles on the topic were also investigated.

Table 1. Terminology used by VOSviewer (Van Eck and Waltman, 2018).

Term	Description
Items	Objects of interest (e.g., publications, researchers, keywords, authors).
Link	Connection or relation between two items (e.g., co-occurrence of keywords).
Link strength	Attribute of each link, expressed by a positive numerical value. In the case of co-authorship links, the higher the value, 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 belong only to one cluster.
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.

Table 2. Different VOSviewer types of analyses used in this study (Van Eck and Waltman, 2018).

Types of analyses	Description
Co-authorship	In co-authorship networks, researchers or countries are linked to each other based on the number of publications they have authored jointly.
Co-occurrence	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.
Citation	In citation networks, two items are linked if at least one cites the other.

The number of clusters visualized in the network is determined by the resolution parameter. The higher is its value, the higher is the level of detail and, consequently, the number of clusters. Its value can be set by the user to visualize an appropriate number of clusters on the map (Van Eck and Waltman, 2018). In this study, a resolution equal to 1 for all the analysis was applied.

2.2.Bibliographic research and data collection

Documents were collected on the 6th of November 2023, by research on the Scopus web search engine. The search string used was “environmental accounting”. Results were exported as .csv files after selecting “Citation information”, “Bibliographical information”, “Abstract & keywords”, and “Include references”. The temporal trend of the number of articles published per year was also investigated.

3. Results and Discussion

3.1.Temporal trend analysis

The research in the Scopus database resulted in 1,603 published documents. Figure 1 shows the temporal trend of publications since 1970, expressed by an exponential function (R^2 = 0.87). This outcome highlights the growth of the topic “environmental accounting” in the scientific literature over time. This growth reflects the increasing recognition of the importance of environmental sustainability in both scientific and policy-making contexts. From its early stages as a niche area of research, environmental accounting has evolved into a mainstream topic, also influencing corporate practices and shaping sustainability reporting frameworks.

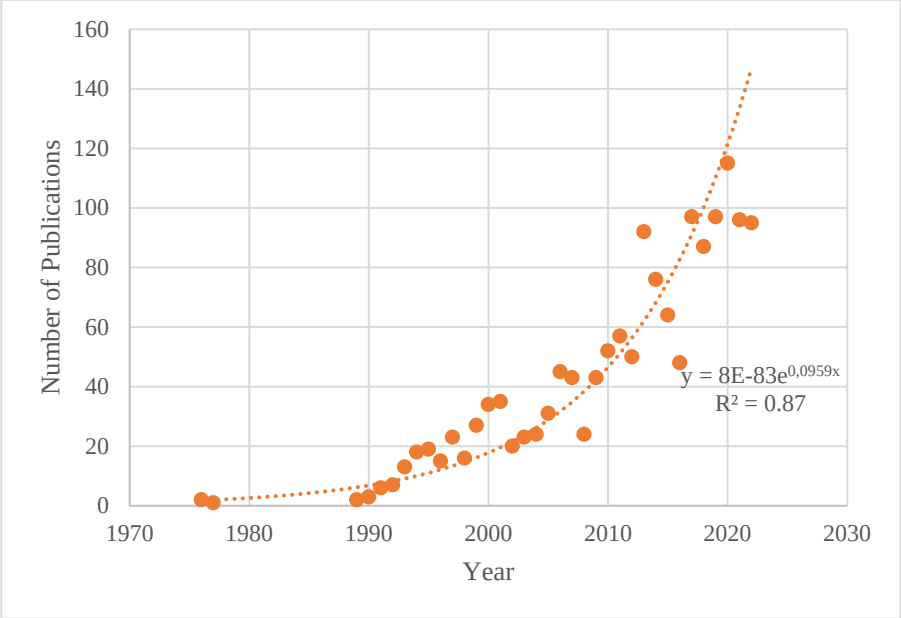

Figure 1. Temporal trend of scientific articles published on the topic “environmental accounting”.

3.2.Bibliometric network analysis

On the base of the documents collected by research on the Scopus web search engine, bibliometric network analysis was applied. Tables 3-7 show items classified according to different weight attributes (citations, number of documents, and "total link strength").

3.2.1 Citation analysis of documents

Table 3 lists the 10 most cited documents dealing with the topic of environmental accounting. The article entitled "The legitimising effect of social and environmental disclosures – a theoretical foundation" published by Deegan C. (2002) stands out as the most cited document in the field of environmental accounting. The paper addressed a gap in the literature. By providing a solid theoretical foundation for understanding the legitimizing effect of social and environmental disclosures in accounting practices, it became a cornerstone for researchers and practitioners. It offers insights into how accounting practices can be used to promote sustainable and responsible business practices and how disclosures can be used by organizations to enhance their reputation, gain stakeholders' trust, and secure their social license to operate. There is robust empirical evidence along with real-world examples provided by the author, which lend credibility to the paper and makes it applicable and valuable for practitioners and researchers.

Table 3. Ten most cited documents on the topic "environmental accounting".

Documents	Citations
Deegan C. (2002)	1922
Boyd J. and Banzhaf S. (2007a)	1445
Cho C.H. and Patten D.M. (2007)	1097
Wiedmann T. (2009)	850
Laufer W.S. (2003)	729
Gray R. (2010)	722
Guthrie J. et al. (2004)	697
Buckley R. (2012)	635
Crossman N.D. et al. (2013)	541
Parker L.D. (2005)	482

3.2.2 Co-authorship analysis of authors

The co-authorship analysis of authors produced 3,116 results. Among them, 177 authors met the default threshold of a minimum of 3 published documents, while documents having a number of co-

authors greater than 25 were excluded (Figure 2). The largest set of connected authors shown in the network map consists of 47 authors, divided into 9 clusters. The top 10 authors ranked by number of citations are reported in Table 4.

Table 4. The table shows the first 10 items of the co-authorship analysis of authors ordered by number of documents.

Authors	Documents	Citations	Total link strength
Franzese P.P.	24	863	37
Bebbington J.	23	2344	23
Gray R.	19	1797	11
Schaltegger S.	14	872	7
Cho C.H.	13	1678	12
Ulgiati S.	13	1070	11
Brown J.	11	1353	8
Patten D.M.	9	1670	8
Boyd J.	4	1758	0
Deegan C.	3	2179	0

The results of the co-authorship analysis of authors show well-defined small clusters. Moreover, the results show that researchers publishing on environmental accounting belong to different disciplines, among which ecology, environmental science, and economics. Most authors cited are European, American, or Australian. Historically, these regions have been at the forefront of scientific research and have well-established academic institutions and research infrastructures. Consequently, scholars in these regions have greater access to resources, funding, and collaboration opportunities, contributing to higher research output and visibility.

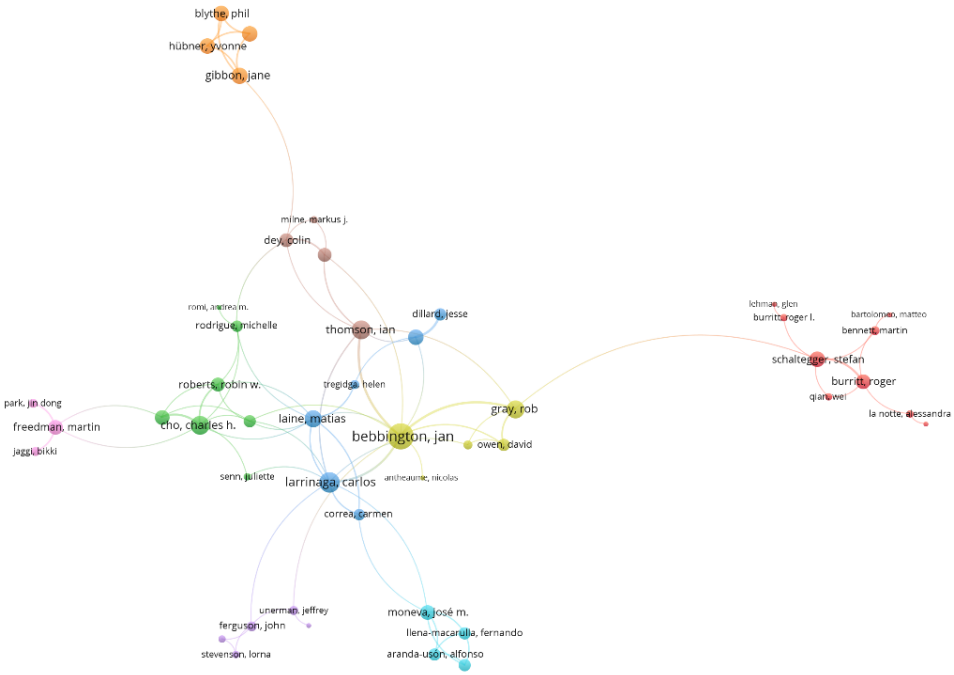

Figure 2. Co-authorship network map of authors publishing on environmental accounting (the size of the items is based on the number of citations).

3.2.3 Co-authorship analysis of countries

Documents with no more than 25 countries per article were considered for the co-authorship analysis of countries. The results revealed that out of 103 countries, 53 published at least 5 articles on environmental accounting. The network map shows the selected countries divided into different clusters (Figure 3). Among them, 8 clusters are connected and include different countries belonging to different geographical areas. This reflects the awareness that environmental challenges transcend national borders, and collaborations are needed. By sharing knowledge, best practices and resources, collaborative efforts enable countries to work jointly towards sustainable solutions.

Table 5 shows the first 10 countries ordered by “total link strength”. The United Kingdom and United States emerged as leading countries working on the environmental accounting theme. In these countries, the environmental impact on public health, economics and well-being is widely recognized. Therefore, they have invested substantial resources in establishing renowned academic communities and research institutions focused on environmental accounting. These institutions have worked on developing comprehensive environmental accounting frameworks. For instance, the United Kingdom has been a leader in environmental accounting, as demonstrated by the introduction of the Environmental Reporting Guidelines in 2013. The United States has also made significant steps in this field, with the Environmental Protection Agency (EPA) playing a major role in promoting environmental accounting practices. Furthermore, both countries have strong diplomatic relations

with countries around the world and, therefore, they played an important role in global environmental initiatives, such as the Intergovernmental Panel on Climate Change (IPCC) and the United Nations Framework Convention on Climate Change (UNFCCC).

Table 5. The table shows the first 10 results of the co-authorship analysis of countries ordered by "total link strength".

Countries	Documents	Citations	Total link strength
United Kingdom	236	10900	129
United States	227	12028	114
Italy	183	7034	100
Australia	171	9873	79
Germany	61	3043	66
China	132	1344	57
Spain	87	4006	54
Netherlands	42	2892	47
France	46	1217	45
New Zealand	51	4038	43

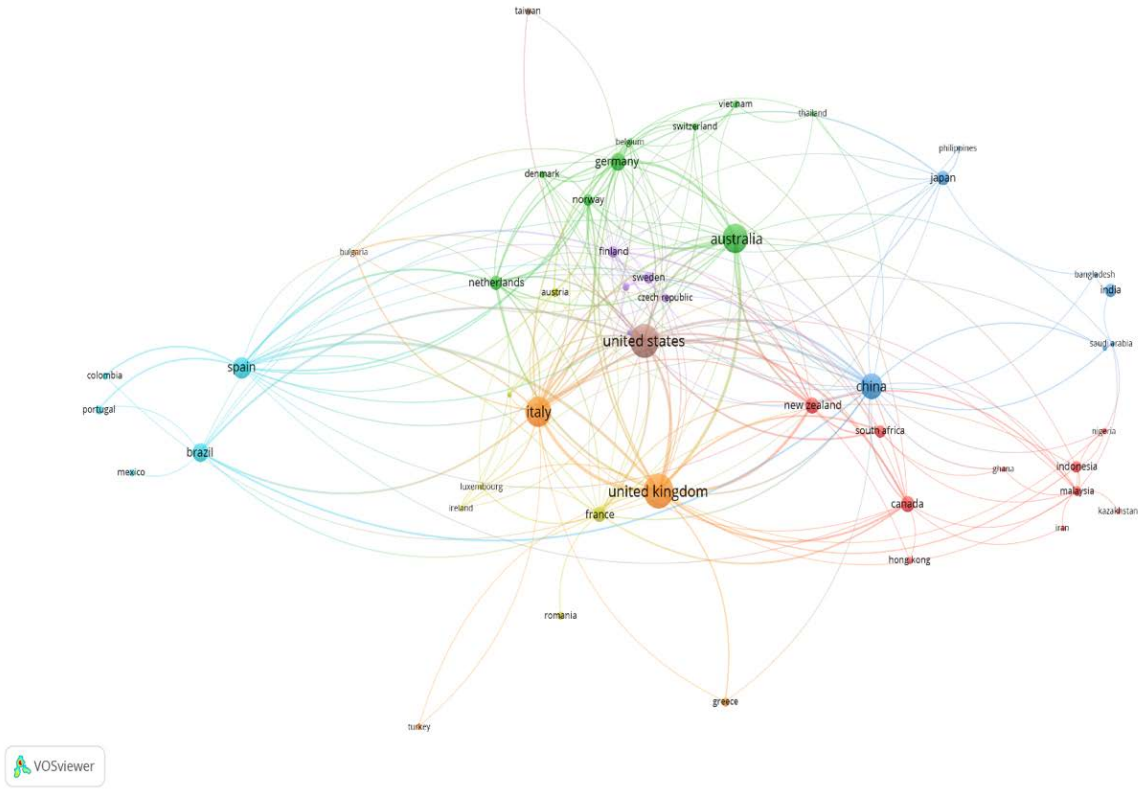

Figure 3. Co-authorship network map of countries publishing on environmental accounting (the size of items is based on the "total link strength").

3.2.4 Citation analysis of journals

The results of citation analysis of journals showed that out of 673 journals, 53 met the threshold of minimum 5 articles published on environmental accounting. Table 6 shows the first 10 journals ranked by number of published documents on the topic. Social and Environmental Accountability Journal ranked first. This journal covers new approaches, advancements, and diverse fields within environmental accounting, providing a broad overview of the field. The high number of environmental accounting documents published by this journal confirms the high commitment of authors to this topic (Figure 4).

Table 6. The table shows the first 10 results of the citation analysis of journals ordered by number of documents.

Journals	Documents	Citations
Social and Environmental Accountability Journal	82	812
Journal of Cleaner Production	59	2948
Accounting, Auditing and Accountability Journal	53	3980
Ecological Economics	45	4469
Critical Perspectives on Accounting	40	2940
Ecological Modelling	35	2059
Sustainability Accounting, Management and Policy Journal	29	650
Sustainability (Switzerland)	25	244
Accounting Forum	23	1292
Journal of Industrial Ecology	19	926

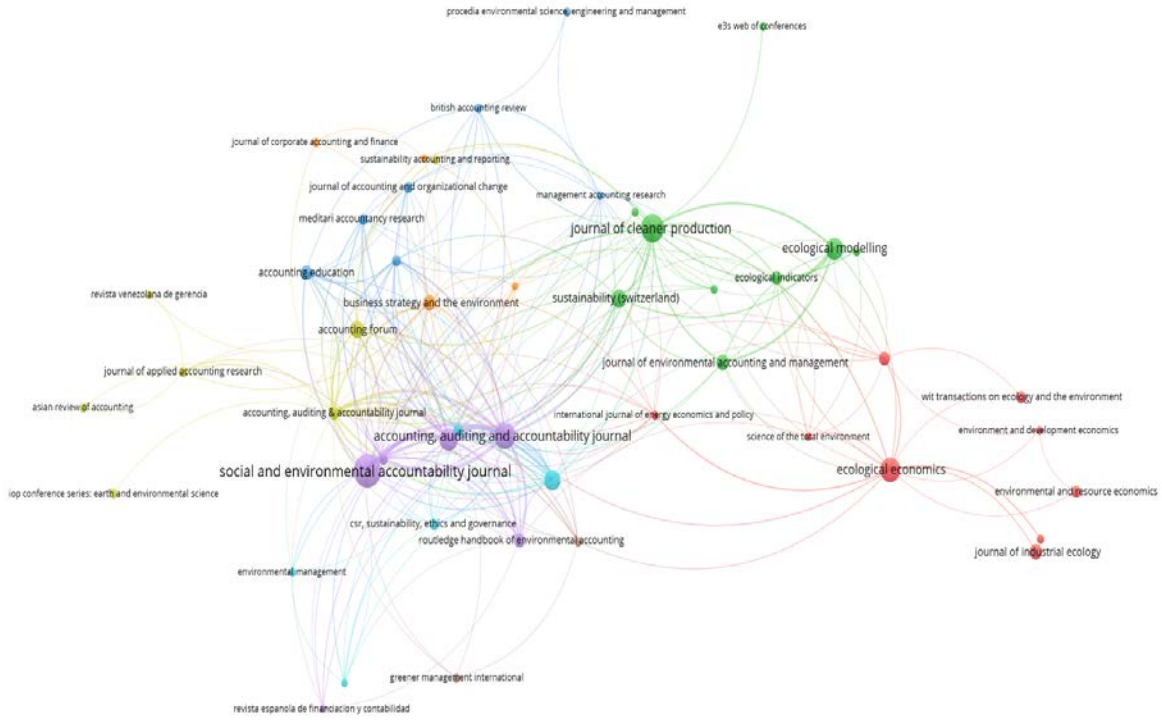

Figure 4. Citation network map of journals publishing on environmental accounting (the size of items is based on the number of documents published on the topic of environmental accounting).

3.2.5 Co-occurrence analysis of keywords

The analysis of the co-occurrence of keywords showed that out of 5,815 keywords, 400 met the threshold of minimum 5 occurrences and were grouped in 7 clusters (Figure 5). These clusters are related to different research areas on environmental accounting among which ecosystem services assessment, tools for environmental accounting (e.g., life cycle assessment and emergy), and environmental economics. Table 7 lists the first 20 keywords by "total link strength". Environmental accounting research results are closely linked to sustainability topics. Indeed, the keyword "sustainable development" highlights the importance of environmental accounting as a tool for achieving sustainable development goals.

Table 7. The table shows the first 20 results of the co-occurrence analysis of keywords, ordered by "total link strength".

Keywords	Occurrences	Total link strength
Environmental accounting	661	3590
Sustainable development	240	1927
Environmental economics	137	1332
Sustainability	170	1193
Environmental management	162	1179
Environmental impact	120	1083
Emergy	111	963
Environmental protection	90	887
Decision making	90	758
Ecosystem	63	685
Economics	65	671
Life Cycle Assessment (LCA)	77	616
Natural capital	44	473
Accounting	80	457
Ecosystem services	51	455
Italy	36	450
Ecology	40	444
Cost-benefit analysis	42	420
Policy	37	414
Environmental impact assessment	39	402

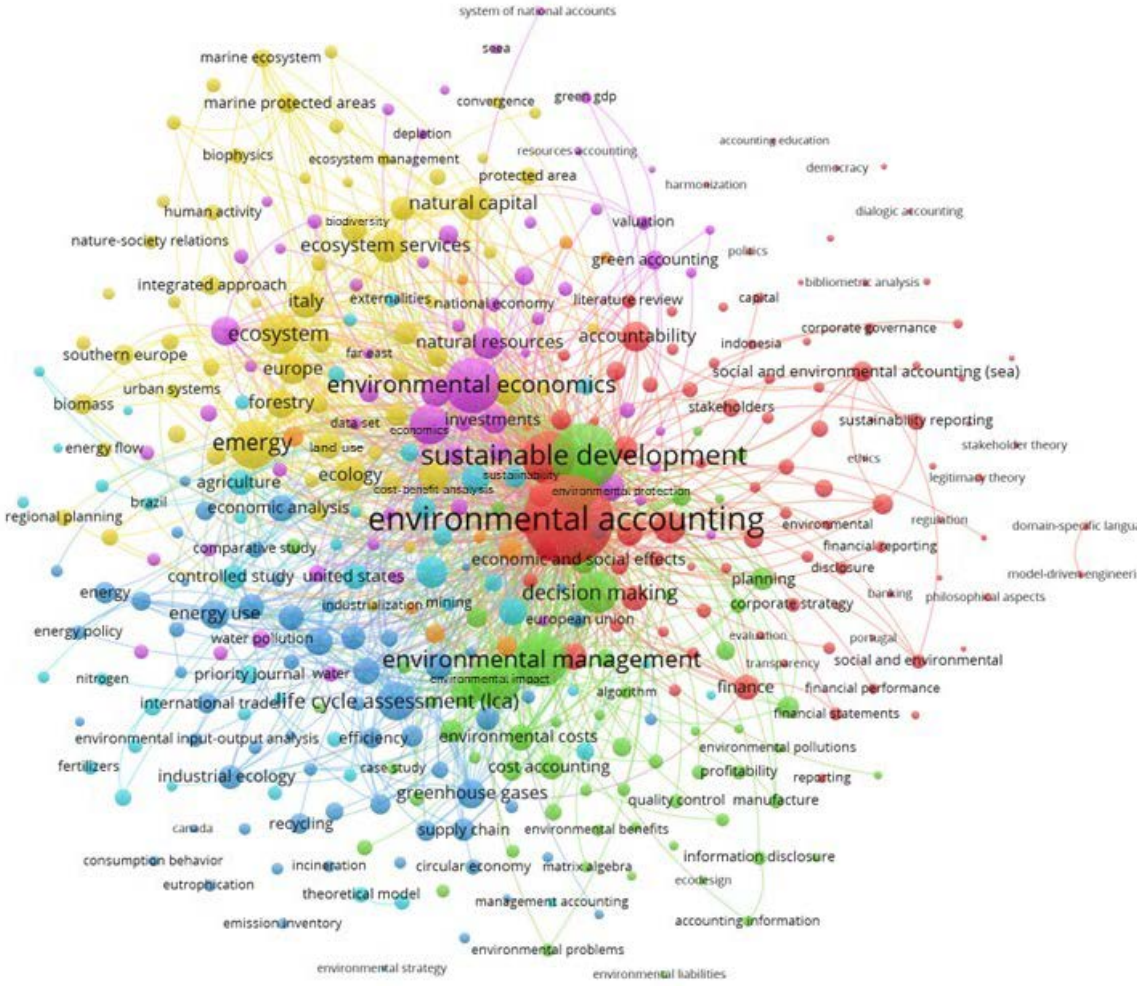

Figure 5. Co-occurrence network map of keywords of published articles on environmental accounting (the size of the items is based on the "total link strength").

Figure 6 shows the overlay visualization map based on the year of documents publication, providing a temporal perspective for the interpretation of the co-occurrence network map of keywords. The distribution of the keywords along a temporal gradient allowed for the understanding of the evolution in the environmental accounting scientific research, identifying the most recent topics and research paths. The overlay visualization map shows a shift of the attention of the environmental accounting research over topics such as governance, sustainability reporting, and information disclosure. This trend highlights the importance of the environmental accounting tools for implementing practices and schemes aimed at promoting environmental sustainability in the context of firms and productive activities.

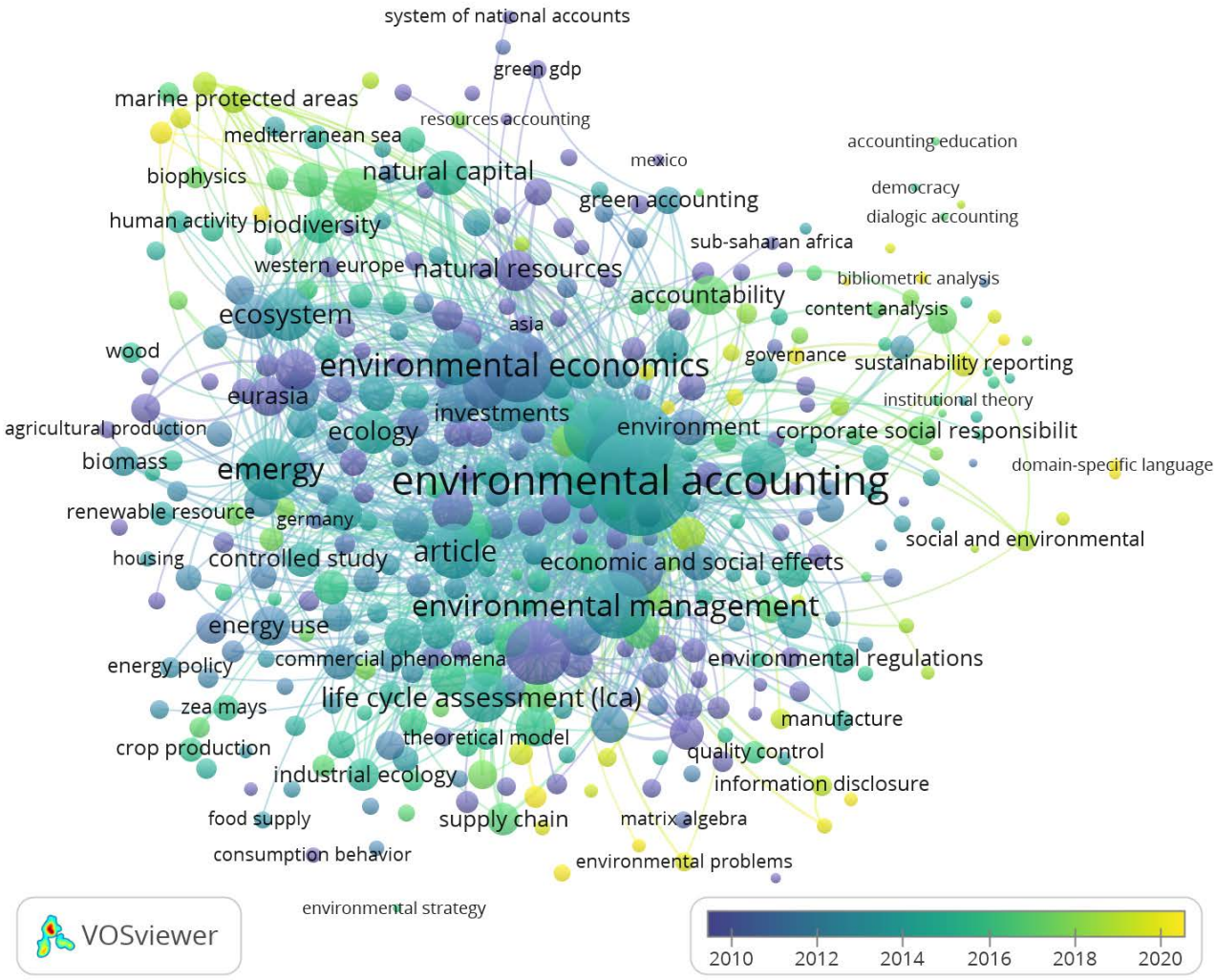

Figure 6. Overlay visualization of the co-occurrence network map of keywords. Keywords are represented based on the average year of publication of documents they occur in, on a color gradient from blue (older publications), to green (publications equally distributed across the timespan), to yellow (more recent publications).

4. Conclusions

In this study, the scientific literature on environmental accounting was explored using bibliometric network analysis. The investigation of authors, journals, countries, and keywords allowed a comprehensive overview of the global scientific literature on the topic. The temporal analysis of publications showed the increasing attention given to this topic worldwide in both scientific and policy context.

The application of systems thinking in bibliometric science to explore the scientific literature resulted a valuable approach for a broader investigation of the research on environmental accounting capturing research trends and gaps while exploring the interdisciplinarity of the topic.

In particular, a strong link was found between environmental accounting and sustainability, highlighting that environmental accounting is an important tool to assess environmental sustainability and build suitable plans for achieving sustainability goals.

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