

## Carbon accounting - literature review at the meso level

The aim of this paper is to present the current state of scientific research in the field of environmental accounting, especially with regard to carbon accounting. To this end, a bibliometric survey of 1,035 WoS-indexed publications was conducted, which included specific organizational and technical activities using the Mendeley Reference Manager and the specialized software VOSviewer. The survey revealed the main contributors to this field according to the criteria of the most productive author, the leading journal, the most cited article, the keywords used in the researched articles, as well as the frequency of their appearance and the geographical locations where the research is focused, highlighting the leading country in the field of carbon accounting. In addition, the analysis identified 9 clusters in two segments from the field of economics, and the results show that the topic of carbon accounting is underrepresented in academic papers and research studies worldwide. Nevertheless, some publishers, researchers and universities have taken a leadership position from the outset by positioning themselves as pioneers of zero tolerance for carbon emissions. This may be the first bibliometric analysis and systematic review of carbon accounting in scientific papers in the context of Croatian research. The theoretical achievements of the paper open new avenues for other researchers in the studied field. The current scientific insights could be deepened by further expanding the original assumptions and incorporating searches in the SCOPUS database and other indexed scientific publications in various world languages.

**Keywords:** carbon accounting, literature review, WoS, VOSviewer, bibliometric review, analysis of cluster

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The paper was received on 21.07.2023. It was accepted for publication on 27.12.2023.

## 1. INTRODUCTION

The European Union instituted an emissions trading scheme based on the Kyoto Protocol, which allows entities to offset their emissions liabilities, among other ways through carbon sequestration (UN, 2022; Bosello and Buchner, 2004; Gagelmann and Hansjurgens, 2002). These emissions trading schemes have created a whole new “carbon economy” (EIB, 2023; Boyd et al., 2011; Manne and Richels, 2000; COM, 1999). In accountancy companies, the discussion on the integration of aspects of climate change mitigation into accounting is often called carbon accounting (Qingliang, 2017; UN and EU, 2014; Stechemesser and Guenther, 2012; Schaltegger and Csutora, 2012; KPMG, 2008; Hesperheide et al., 2010; Radermacher, 2007). Carbon accounting is a key tool for estimating greenhouse gas emissions and developing strategies to combat climate change (UNFCCC, 2001/2005).

In this paper, we present an analysis of a comprehensive theoretical framework for carbon accounting based on assumptions that highlight the importance of the topic and its underrepresentation in broader scientific fields. By using standardized analytical protocols and advanced measurement techniques, we aim to increase the role of literature reviews in the field of carbon accounting. Literature reviews are used to describe current knowledge, justify the need for and significance of new research, explain research findings, and describe the quality of the available research (Fink, 2014). Thus, this article has retrieved all studies related to carbon accounting from WoS sources in order to answer the following questions:

- RQ1: How many articles have been published over the years on the given keywords? The articles in the WoS database were exported to Mendeley Reference Manager and Excel, and a graph was created showing the number of articles by year;
- RQ2: Who are the main authors related to the topic and how many published articles do they have, i.e., what is the citation rate of a single author? To test RQ2, we used Co-authorship analysis (Unit of analysis: Authors) and Citation analysis (Unit of analysis: Authors);
- RQ3: Which countries are the most productive in relation to the topic in terms of number of articles published and citations of articles? In the analysis we used Co-authorship analysis (Unit of analysis: Countries) and Citation analysis (Unit of analysis: Countries);
- RQ4: What are the most important articles published in relation to the keywords, which can be proven using Citation analysis? (Unit of analysis: Documents);
- RQ5: In which sources were the examined articles published, why was Citation analysis applied? (Unit of analysis: Sources);
- RQ6: Which keywords were used in the researched articles? The frequency of occurrence was examined with Co-occurrence analysis (Unit of analysis: All keywords) and
- RQ7: What branches are represented in the field of Economics? Can the existence of clusters be determined?

In testing and analyzing research questions (RQ1 to RQ6) we used VOSviewer as the most popular and promising domain visualization software package available. It is primarily intended for the analysis of academic records and can be used on any type of network data (Aruda et al., 2022). Also, VOSviewer explores co-authorship, co-occurrence, citation, bibliographic merging and co-citation links in one of three possible views: grid, overlay, scatter view or density visualization using import data from SCOPUS (CSV), Clarivate Analytics WoS (plaintext or tab-delimited), Pub-Med/MedLine (MEDLINE) and Dimensions (CSV). Within RQ7 a selected set of scientific papers was analyzed, forming subsets (clusters) in the field of Economics, and appropriate separation of papers in relation to the selected criteria was carried out following Hazaea (2023).

The remainder of the paper is organised as follows: Section 2 presents a literature review on the topic; Section 3 presents the methodology used for this study; Section 4 presents the results using bibliometric data and analysis of cluster; and finally, Section 5 draws the conclusions and identifies the limitations of the research and recommendations for future research.

## 2. LITERATURE REVIEW

Energy has always been considered one of the most important economic inputs, and so-called green growth could provide an alternative to the conventional economic paradigm (Hazaea et al. 2021a; UN, 2014; Drvenkar and Marošević, 2014). Stechemesser and Guenther's (2012) research emphasizes how difficult it is to define carbon accounting. Therefore, they contribute to the definition through a literature review that includes different perspectives and research streams. Moreover, their approach is interesting because they raise the intriguing question of whether carbon accounting is an integral part of environmental accounting, just as environmental accounting is an integral part of accounting.

According to Stechemesser and Guenther (2012), the attempts to streamline the definition of carbon accounting have failed. These authors make a distinction between explicit definitions (Gifford and Roderick, 2003; Ratnatunga, 2007; Kolk et al., 2008; Ascui and Lovell, 2011), implicit definitions (Weaver, 2008; Lovell and MacKenzie, 2011) and alternative terms used at the national level (account for CO<sub>2</sub> emissions, carbon emissions accounting, (GHG) emission accounting), as well as at project level (mitigation accounting, green accounting, physical carbon accounting, emissions accounting, accounting for carbon sequestered).

Recently, scientific research has been showing a significant reassessment of the concept of carbon accounting itself. Over time, according to Ascui and Lovell (2011), a range of actors and disciplines have attempted to measure 'carbon' and its impacts in various ways, for a number of different reasons. They identify five major framings of carbon accounting as scientists (Physical carbon accounting—Högbom, 1895), politicians (Political carbon accounting—Fogel, 2005; MacKenzie, 2009), economists (Market-enabling carbon accounting – Wambsganss and Sanford, 1996), accountants (Financial carbon accounting—KPMG, 2008) and activists (Social i.e. environmental carbon accounting—Gray, 2002; Parker, 2005; Owen, 2008; GRI; GHG Protocol; Carbon Disclosure Project (CDP) in 2000).

Gibassier and Schaltegger (2015) take the in-depth case study method even further by exam-

ining carbon accounting as an aspect of environmental accounting and carbon management in a multinational company and asking what might be considered an effective carbon management system. This paper shows that different approaches to carbon management accounting can be pursued in parallel in one company. In addition, Gibassier, Michelon, and Cartelthey (2020a) propose four broad lines for further research: (i) climate change as a systemic and social problem, (ii) a multi-layered climate change transition apparatus, (iii) climate vulnerability, and (iv) the future of carbon accounting. Related to the future of carbon accounting, recently many research papers have contributed to raising the profile of the profession of environmental accounting (He et al., 2022; Gibassier et al. 2020a; Gibassier et al., 2020b).

## 3. METHODOLOGY

According to Littell (2008), a systematic review aims to comprehensively locate and summarize research findings on a particular issue, using organized, transparent, and repeatable procedures at each stage of the process. Stechemesser and Guenther (2012) provide an interdisciplinary and an international overview of the current understanding of carbon accounting using Fink (2014) seven steps methodology (synthesized to four by Stechemesser and Guenther (2012)), as well as the structure proposed by Tranfield et al. (2003).

In step 1 we selected research questions, bibliographic and article databases, websites, and other sources i.e. search terms (Fink steps I to III). Scientific papers that examine the reviewed area were searched in the WoS Core Collection database. Once it was decided that the WoS database would be used as a source of papers, keywords were selected to find relevant papers. Based on the article by Stechemesser and Guenther (2012), the following query was used: "carbon\* accounting" or "carbon emission accounting" or "carbon offset accounting" or "carbon management accounting" or "carbon flow accounting" or "corporate-level carbon accounting" or "whole life carbon accounting" or "full carbon accounting" or "partial carbon accounting", which returned 1,278 papers identified through database search-

ing. Then we followed the PRISMA statement flow chart by Fink (2014), which shows the selection process for qualitative (descriptive) review. After entering the search query “carbon\* accounting” into the WoS database, 1,214 papers were found, representing 95% of the papers previously received in the WoS database. It was decided to use this particular term for further analysis, however, we did not use the chemical symbol CO<sub>2</sub> or terms like climate and environmental accounting. In step 2 we applied practical screening criteria. According to Fink (2014), preliminary literature searches always yield many articles, but only a few are relevant. We screened the literature to obtain relevant articles by setting inclusion and exclusion criteria for the review, which included factors such as language in which the article was published, type of article (journal article, part of a book, proceedings paper, unpublished work) and year of publication. The third step implied the application of methodological screening criteria. To perform the analysis, a \*.txt file containing 1,035 articles was downloaded from the WoS database first in Mendeley Reference Manager and then uploaded to VOSviewer, where the analysis was performed. No time limit was set for searching the WoS database.

First, we performed a bibliometric analysis and the WoS database search results were analysed. A descriptive overview of the papers was presented, and then the papers were analysed using the following analyses: Co-authorship analysis, Co-occurrence analysis, Citation analysis. The goal of the paper was to present only scientific articles, which reduced the observed sample to 1,022 articles. We did not fully follow the recommendation by Tranfield et al. (2003) that searches should not be restricted to bibliographic databases. Stechemesser and Guenther (2012) acted similarly. The last step, as proposed by Fink (2014), involves synthesizing the results shown in Table 1.

## 4. EMPIRICAL RESEARCH AND RESULTS

### 4.1. Qualitative (descriptive) review

The results of the literature review can be synthesized descriptively based on the researcher's

experience and quality and content of available literature. No time limit was set for searching the WoS database. The first results show that the oldest article included in this analysis was published in 1991, and that articles have been published continuously until the latest date, which is consistent with Alsaifi et al. (2020) and Ascui and Lovell (2012). Second, the interest in the mentioned field has been growing over the years, as evidenced in the number of published articles. The most articles were published in 2022 (102 articles). This is followed by 2021 with 85 articles and 2019 with 80 articles. All results are presented in Table 1.

Nartey (2018) and Hazaea (2023) emphasized that carbon accounting is considered a part of sustainability accounting, through which it is possible to provide information on emissions in environmental changes that benefit the management of institutions in a way that contributes to achieving sustainability. This may be one of the important indicators to explain the interest of researchers in this topic in recent years. In the period from 1995 to 2019, scientific productivity in the field of carbon accounting is a total of 706 articles. As for 2023, 61 articles were already published by July. The time distribution of works divided into four periods is shown in Table 1, which contains also data on citations in the total observed period, where CRC represents Cited Reference Count, TC<sub>1</sub> is Times Cited (WoS Core) and TC<sub>2</sub> denotes Times Cited (All Databases). The summary results on citations are presented in a hierarchical order starting from the most cited areas, which include *Forestry, Sustainability Science, Soil Science and Remote Sensing*. In the field of Economics, the scientific branch of Management is in the unexpected 5th place in terms of the number of published scientific papers. After the bibliometric analysis presented in chapter 4.1, an analysis of cluster was performed at the meso level within the scientific branch of Management, and the results are described in chapter 4.2.

### 4.2. Bibliometric survey

To determine the most productive authors of the analyzed articles, a Co-authorship analysis (Unit of analysis: Countries) was conducted. The

**Table 1.** Characteristics of the sample

Field	Published works by period				Citation by WOS		
	1990-1999	2000-2009	2010-2019	2020-2023	CRC	TC <sub>1</sub>	TC <sub>2</sub>
Forestry	5	64	213	71	19,613	12,015	12,819
Sustainability Science		8	99	70	9,935	3,879	3,981
Soil Science		30	80	38	8,209	5,35	5,753
Remote Sensing		15	46	23	4,858	3,527	3,72
Management		3	35	33	4,725	1,806	1,835
Environmental Sciences		4	19	13	2,086	809	917
Marine Biology	1		10	20	2,115	658	665
Paper & Wood Materials Science		2	10	1	570	314	317
Oceanography, Meteorology&Atmospheric		6	4	3	741	431	481
Agricultural Policy		1	7	2	523	189	193
Supply Chain & Logistics			4	3	400	55	56
Climate Change			3	4	442	69	70
Nanofibers, Scaffolds & Fabrication			4	2	492	157	158
Energy & Fuels		1	2	3	401	85	85
Ocean Dynamics			3	3	462	179	183
Hospitality, Leisure, Sport & Tourism			5		271	71	77
Power Systems & Electric Vehicles			3	1	126	173	178
Water Resources			3	1	205	92	94
Political Philosophy			2	1	239	23	23
Synthesis			2		128	17	17
Bioengineering			1	1	83	41	43
Political Science			1	1	94	97	97
Mineral & Metal Processing			1	1	67	25	25
Medical Ethics				1	21	4	4
Molecular & Cell Biology	1				37	23	25
Philosophy			1		74	4	5
Physical Chemistry			1		74	13	13
Chemometrics			1		34	11	13
Catalysts				1	77	100	100

Field	Published works by period				Citation by WOS		
	1990-1999	2000-2009	2010-2019	2020-2023	CRC	TC <sub>1</sub>	TC <sub>2</sub>
Electrochemistry			1		42	1	1
Photocatalysts				1	59	0	0
2d Material			1		76	12	12
Herbicides, Pesticides & Ground		1			9	3	3
Plant Pathology			1		53	127	129
Telecommunications			1		45	25	25
Transportation			1		21	18	20
Distributed & Real Time Computing				1	38	0	0
Artificial Intelligence & Machine			1		56	32	32
Nuclear Physics		1			45	14	14
Astronomy & Astrophysics		1			24	2	2
Imaging & Tomography			1		37	52	57
Economics			1		24	40	40
Education & Educational Research		1			52	10	10
Communication		1			0	3	3
Human Geography	1				0	1	1
Metallurgical Engineering	1				0	1	1
Concrete Science			1		70	16	16
Combustion				1	4	4	1
Testing & Maintenance		1			4	5	5
Manufacturing		1			20	20	20
Asphalt			1		76	0	0
Thermodynamics				1	68	12	12
Archaeology			1		75	8	8

Source: Authors (2023).

papers included in the analysis were written by 3,819 authors. In Table 1 it can be seen that the most productive author is *Tang Qingliang*, who published 12 articles that were included in the analysis. By the number of articles published, *Roxburgh* is second with 9 articles, while *Luo* is third with 8 articles published. Other authors

who published 5 or more articles in the analysis are also listed in Table 2.

To determine the most productive countries in terms of the number of published articles included in the analysis and the citation of articles by individual countries, Co-authorship

**Table 2.** The most productive authors

Author	Documents	Author	Documents
Tang, Qingliang	12	Chappell, Adrian	5
Roxburgh, Stephen H.	9	Cook, Garry D.	5
Luo, Le	8	Domke, Grant M.	5
Russell-Smith, Jeremy	7	Dubayah, Ralph	5
Wang, Xiaoke	7	Edwards, Andrew C.	5
Woodall, Christopher W.	7	Fraver, Shawn	5
England, Jacqueline R.	6	Hammond, Geoffrey P.	5
Keith, Heather	6	Hansen, Matthew C.	5
Lu, Fei	6	Li, Mingshi	5
Paul, Keryn I.	6	Luo, Yunjian	5
Rossel, Raphael A. Viscarra	6	Murphy, Brett P.	5

Source: Authors (2023).

and Citation analysis (Unit of analysis: Countries) was performed. The authors who wrote the articles analyzed in this study were from 95 countries. Figure 1 shows that the United States is the most productive country in terms of the number of published articles that are the subject of the analysis - 302 articles, but this finding is contrary to Hazaea et al. (2023). Australia is in second place with 226 published articles, which supports the results of Hazaea et al. (2023).

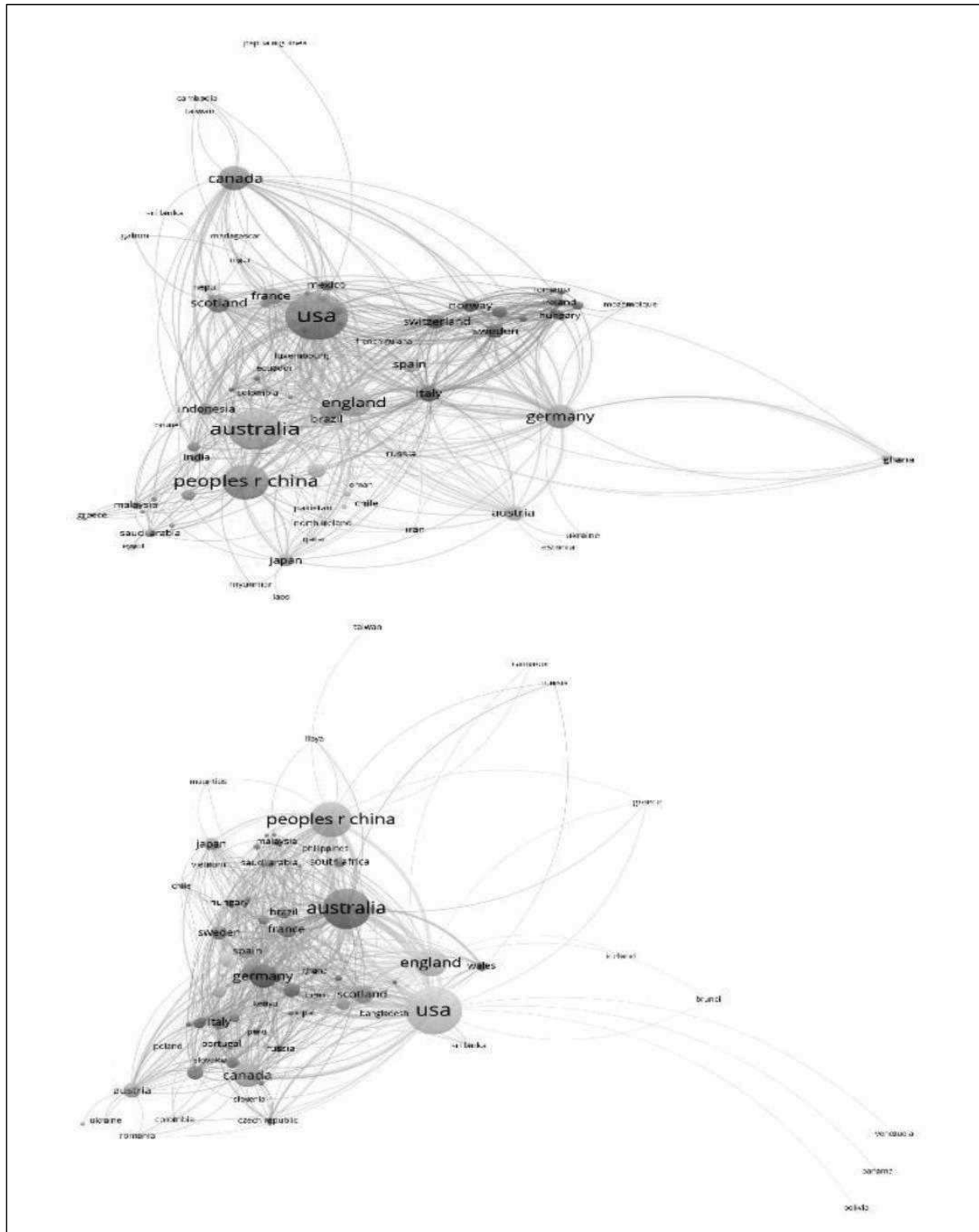
This may be because the Australian government has worked hard to launch many national schemes for emission trading. China ranks third with 166 published articles which is also contrary to Hazaea et al. (2023). It is followed by England (103 articles), Canada (80 articles) and Germany (75 articles).

Other important countries to mention are Scotland, the Netherlands, France, and Italy with 42, 41, 37, and 31 published articles, respectively. The results indicate that European countries are researching carbon accounting more than other countries around the world because global climate change impacts Europe in many ways: changes in average and extreme temperature and precipitation, warmer seas, increasing sea

level, and declining snow and ice cover on land and sea, as concluded by Hazaea et al. (2023). Other countries published 30 or fewer articles. It is also important to note that of the 95 countries observed, 4 countries are not connected to any other country, namely Turkey, Latvia, Cameroon and Mauritius. According to Hazaea et al. (2023), the absence of studies that discuss carbon accounting in countries that have a bigger impact on environmental changes is surprising and scary.

Looking at countries by the citation frequency of their articles, it can be seen that the same countries hold the first and second place as in the ranking by productivity. The USA ranks first with 11,538 citations, while Australia ranks second with 7,933 citations. It should be noted that there has been a rank reversal between the following countries: England (5,039 citations) and China (3,373 citations), Canada (1,999) and the Netherlands (2,614), and Scotland (1,705) and France (2,318). Germany and Italy are in the same places - Germany in 6th place with 2,556 citations and Italy in 10th place with 1,506 citations. Other countries have fewer than 1,500 citations. In terms of the number of citations, 81 countries are connected to the network as

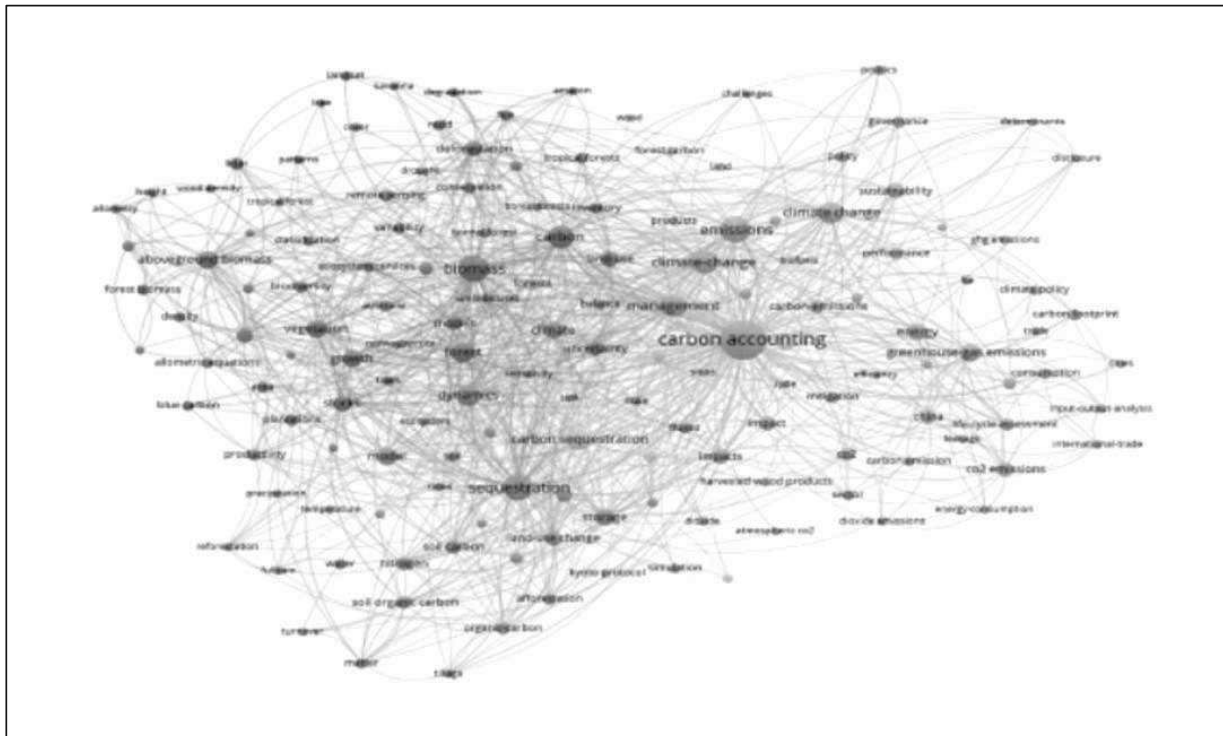
**Figure 1.** The most a) productive countries and b) cited countries



Source: Authors according VOSviewer (2023).



**Figure 2.** Relationship networks and total link strengths of the keywords



Source: Authors according VOSviewer (2023).

shown in Figure 1, while 14 countries are not connected to any other country.

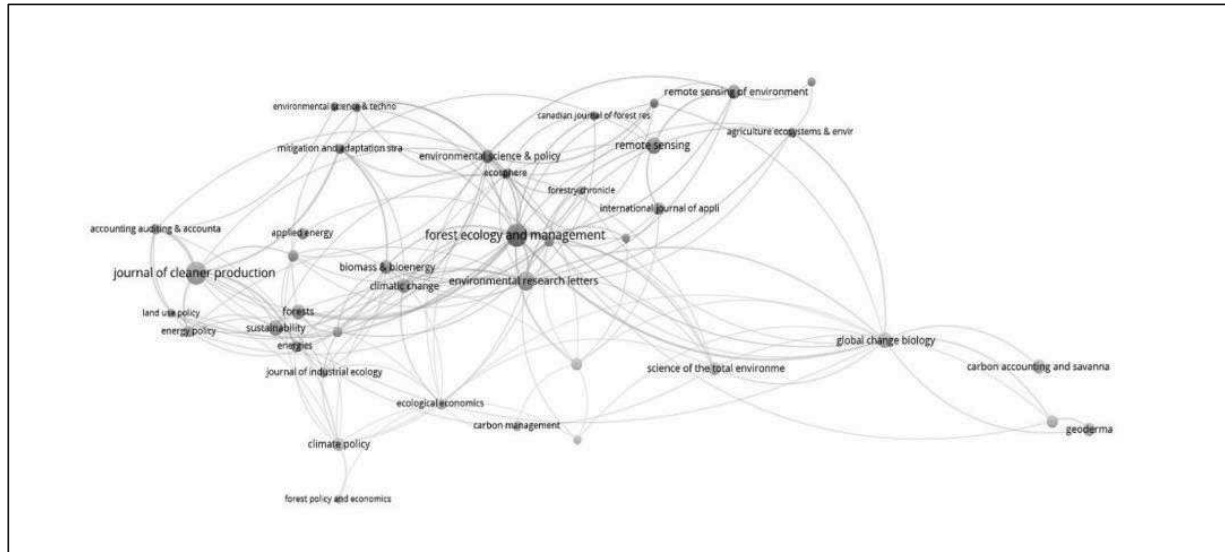
To find out which words/phrases were used in the keywords of the researched articles and how often they occur, a Co-occurrence analysis (Unit of analysis: All keywords) was performed. The 'minimum number of occurrences of a keyword' was set to '5' to obtain an optimal network. Of the 4,882 keywords identified, 390 met the threshold and were included in the resulting network. Keywords in the studied articles are shown in Figure 2.

Since we wanted to group the keywords of the analyzed articles around the keywords that have the highest frequency of occurrence but also the highest total link strength, this was achieved after setting the "minimum number of occurrences of a keyword" to '11'.

As can be seen in Figure 2, the most frequently used word is carbon accounting, which appears 284 times in the keywords of the studied arti-

cles. The second, third, and fourth most frequently used words are "emissions," "biomass," and "sequestration", whose occurrences in the keywords of the studied articles do not reach even half of the first-ranked keyword (123, 121, and 120 times, respectively). The keyword "carbon accounting" is most strongly linked to the other keywords in the researched articles (TLS 3,038). This is followed by keywords whose total link strength is more than 50% lower than the total link strength of the mentioned keyword, namely the keywords "sequestration" (TLS 1.468), "biomass" (TLS 1.379), and "emissions" (TLS 1.146). The Total link strength (TLS) attribute indicates the total strength of the co-authorship links of a given researcher with other researchers (van Eck and Waltman, 2022).

The colours indicate that the keyword "carbon accounting" occurs in the searched articles together with the keywords "emissions", "climate change", "management", "greenhouse gas emissions", "energy", but also with other words written in green. The second cluster consists of key-

**Figure 3.** Citation analysis at the journal level

Source: Authors according VOSviewer (2023).

words that occur in the researched articles with the keyword “biomass”. These are the keywords “forest”, “aboveground biomass”, “vegetation”, “growth”, but also other words written in red. It is also possible to see which keywords are connected in a cluster around the keyword “sequestration” (keywords written in blue), but also keywords written around the keyword “carbon sequestration” (keywords written in yellow).

Citation analysis (Unit of analysis: Sources) was performed to determine the number of journals in which the articles that are the subject of the analysis were published, in which journals the articles were published, and how many articles were published in each journal. The aforementioned analysis also showed the citation rate of the articles in a particular journal. Thus, the analysis showed that the analysed articles were published in 377 journals. The “minimum number of documents of a source” was set to “6” to obtain an optimal network (41 journals grouped in 7 clusters), which can be seen in Figure 3.

As shown in Table 3, most of the articles studied were published in the *Journal of Cleaner Production* (IF: 11.072) - 41 articles. The impact factor is an indicator for the scientific impact

represented by citations where the higher the impact of the journal on other journal articles, the higher the estimated quality of the journal (Stechemesser et al., 2012). As for the number of citations of the published articles, the journal mentioned above ranks fourth with 1,083 citations. The journal *Forest Ecology and Management* (IF: 4.384) comes second, both in terms of the number of articles published - 38 - and the number of citations - 1,609. In third place in terms of the number of published articles is the journal *Environmental Research Letters* (IF: 6.947) with 26 articles, while the third in terms of citations of published articles that are the subject of analysis is the journal *Remote Sensing of Environment* (IF: 13.850) with 1,333 citations. Other journals that have published 10 or more articles that are the subject of the analysis, along with the corresponding impact factors and also the journal citations, can be seen in Table 3.

Citation analysis (Unit of analysis: Documents and Authors) was carried out to determine which are the most cited works among the articles studied, but also which are the most cited authors. As shown in Table 3, the paper published in the journal *Global Change Biology* (IF: 13.212) entitled *Critical analysis of root: shoot*

**Table 3.** List of journals (with their impact factor) and conferences, number of published papers and citations

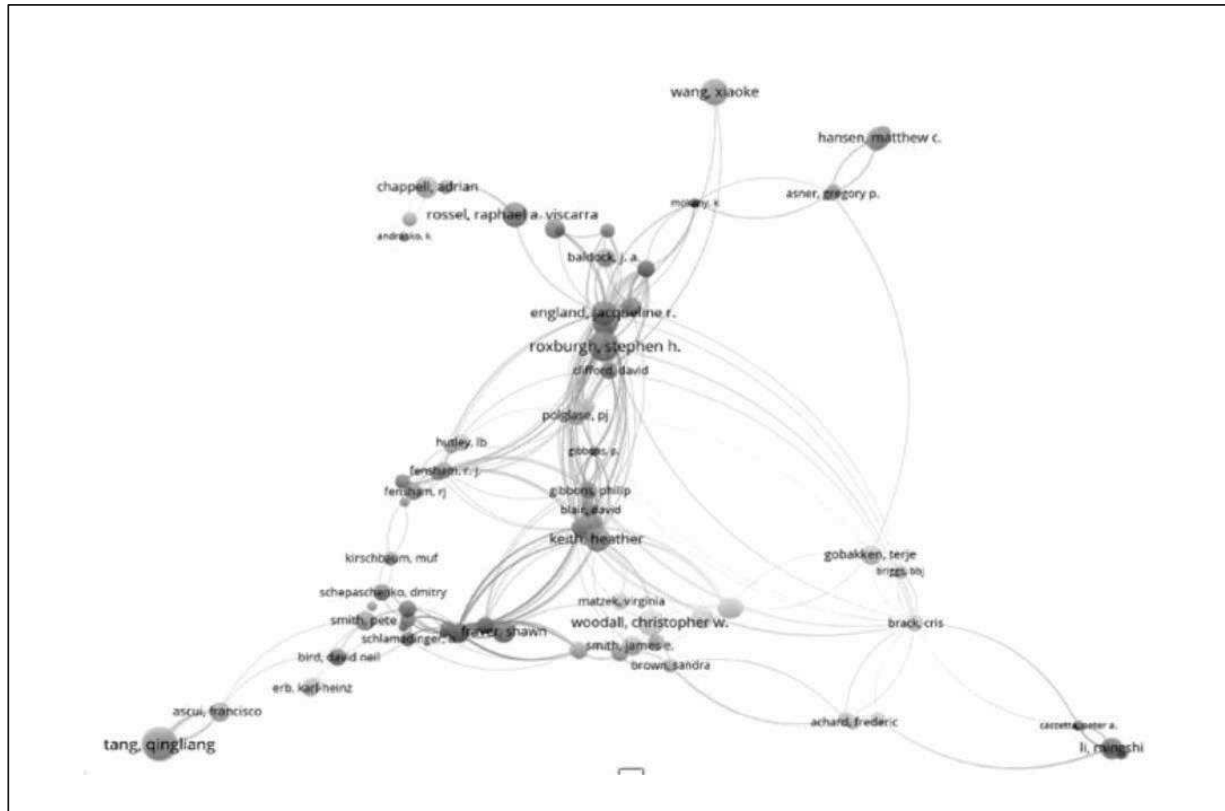
Journal	Impact (2022-2023) (Accelerator, 2023)	Articles	Citations
Journal of Cleaner Production	11.072	41	1,083
Forest Ecology and Management	4.384	39	1,609
Environmental Research Letters	6.947	26	824
Remote Sensing	5.349	20	484
Global Change Biology	13.212	18	2,137
Sustainability	3.889	18	164
Forests	3.282	16	122
Biomass and Bioenergy	5.774	15	544
Carb. Acc. and Savanna Fire Manag.	/	15	79
Climatic Change	5.174	15	619
Remote Sensing of Environment	13.850	15	1,333
Climate Policy	7.750	14	212
Environmental Science and Policy	6.424	13	519
Geoderma	7.422	13	675
Science of the Total Environment	10.754	13	105
Carbon Balance and Management	4.356	12	144
IJ of Applied Earth Observation and Geoinformation	7.672	12	352
Soil Research	1.878	12	315
Energy Policy	7.576	11	392
Applied Energy	11.446	10	306
Ecological Economics	6.536	10	341
Energies	3.252	10	109
Journal of Environmental Management	8.910	10	122

Source: Authors (2023).

*ratios in terrestrial biomes* by Mokany, Raison and Prokushkin (2006) is the most cited paper among the papers included in the analysis, and its authors are the most cited authors among those who wrote the papers included in the analysis - 972 citations (total link strength 16).

Following the group of authors, in terms of number of citations, is Rossel (2011-2018) with 662 citations (6 articles).

In second place is the paper published in *Ecological Applications* (IF: 6.105) entitled *Regional*

**Figure 4.** The most cited authors

Source: Authors according VOSviewer (2023).

and phylogenetic variation of wood density across 2456 neotropical tree species by Chave, Muller-Landau, Baker, Easdale, ter Steege and Webb (2006) – 972 citations and total link strength 7. In third and fourth place are the authors Zhang (2013) and le Toan et al. (2011) with 482 i.e. 447 citations. They are followed by Kolk, Levy, Pinkse (2008) – 388, Gomez, Rossel, McBratney (2008) – 381, Kurz et al. (2009) – 335 and Gifford (2003) – 300 citations. At the end of the scale are Carlson et al. (2013) and Richards and Stokes (2004) with 289 and 275 citations, respectively. The authors most frequently cited in the articles studied can be seen in Figure 4.

### 4.3. Analysis of cluster

We reviewed some previous studies (mainly Hazaea et al., 2023) to build on the results of the bibliographic analysis and explicitly answer

RQ7. The final step was to identify and analyze clusters in the field of Economics. Considering the results of Table 4, two research areas - Business Finance (34 articles) and Management (14 articles) - were included in further analysis based on the criterion of the largest number of published articles without chronological classification. The other two areas (Business and Economics) were excluded from further analysis because the timing of article publication in this area is unsteady (gap from 2014 to 2020) and the results from WOS Metrics are less critical. Several common characteristics were observed, grouped into 9 homogeneous clusters, and these were filtered out.

Cluster 1 explores the relationship between carbon accounting and the theoretical assumptions based on the keywords in the article. In contrast to Hazaea et al. (2023), the majority

**Table 4.** Characteristics of the sample in field Economics

Research Areas (by WOS)	WOS Metrics			Publication Year													
	CRC <sup>a</sup>	TC <sub>1</sub> <sup>b</sup>	TC <sub>2</sub> <sup>c</sup>	2008-2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	½ Q <sub>23</sub>	Σ
Business Finance	2464	1185	1206	6	1	1	1	3	2	1	2	2	3	2	6	4	34
Enviromental Sciences	798	427	433		4	1		1			2	2		1	1	2	14
Green Sustainable Science Tehnology	65	468	474		5		1	2				2	3			1	14
Management	871	144	149	2		1	1	1		1	1		2	1	4		14
Enviromental Studies	777	156	157	1		1	1	1			3		2	1	2	1	13
Engineering Enviromental	0	0	0														0
Business	354	34	34			1								2	2	1	6
Economics	196	28	28			1								2		1	4
Energy Fuels	0	0	0			1								1		1	3
Public Administration	186	31	31	1							1				1		3
Geography	142	42	42					1			1						2
Regional Urabn Planning	180	23	23		1						1						2
Development Studies	94	20	20		1												1
Transportation	37	7	7								1						1
Ecology	39	5	5											1			1
Religion	23	0	0			1											1
Social Issues	40	0	0										1				1
Womwn S Studies	44	1	1												1		1
Ethics	78	1	1													1	1
Σ	6388	2572	2611	10	12	8	4	9	2	2	12	6	11	11	17	12	116

<sup>a</sup> Cited Reference Count; <sup>b</sup> Times Cited (WoS Core); <sup>c</sup> Times Cited (All Databases)

Source: Authors (2023).

of the articles examined do not rely on more or less well-known theories, but on homogeneous approaches within the research field. However, among several authors, two theories stand out - Signaling Theory and Resource-based View Theory. According to the Signaling Theory, the disclosure behavior of companies in today's capital market can be viewed as an external signal, for example, by disclosing information about carbon emissions. Companies with better business conditions can communicate their competitive advantages and good development prospects to external stakeholders through signaling (Clarkson et al., 2008). The second theory is that a company will adopt an increasingly proactive environmental management strategy if it has or can acquire resources and convert them into competencies that are critical for competitive advantage and higher returns (Backman et al., 2015). Other theories represented include Contingency Theory (Nartey, 2018), Institutional Theory Approach (Bowen et al., 2011), and Transition Management Theory (Chen et al., 2023).

Cluster 2 shows unexpected results regarding the focus of the organization. The focus of the organization is divided into public, private or mixed sector. While 92% of all papers in the field of economics focus on the public sector, not a single study examined the private sector. The results obtained are consistent with those of Hazaea et al. (2023, 2021b). However, the authors' comparative study warns that research efforts in the economic sector based on data from public reports of international organizations and institutions need to be further increased, especially in countries with pronounced industrialization characterized by significant environmental impacts.

Cluster 3 examines the methodologies used for carbon accounting, such as categorizing emissions into Scope 1, 2, and 3. It discusses the importance of assessing direct emissions from stationary sources (Scope 1), indirect emissions from purchased electricity (Scope 2), and other indirect emissions along the value chain (Scope 3). In the Management research area, most of the papers relate to the generalization of carbon accounting issues, while the Business Finance research area focuses on systematizing and devel-

oping carbon accounting methodologies. There are no surprises in cluster 4. In the observed research areas, researchers most often use various statistical methods and certain econometric models—OLS regression in research papers and case studies that can be linked to the WoS database (cluster 8).

Based on the type of journal, we distributed the literature to be studied in cluster 5 of Table 5. The research focus was directed primarily to the areas of accounting and auditing, finance and management, sustainability, and policy. According to the above criteria, the journals were divided into three types. The dual distribution of journals within the observed fields confirms the exceptional focus of the researchers, which can be explained by the application of Hazaea et al. (2023) and similar methodologies of other authors. In addition, this could be an indication of the link between carbon accounting and the field of accounting in economic and financial terms, since the results of some studies and the application of carbon accounting are mainly related to emissions without linking them to the economic aspect, as concluded by Hazaea et al. (2023). In the field of corporate finance, the top ranked journals are *Accounting, Auditing and Accountability Journal*, *Australasian Accounting, Business and Finance Journal*, while *Sustainability Accounting, Management and Policy Journal* is a joint selection of 18 papers and studies in both research areas.

Cluster 6 includes 48 papers divided into 6 categories, demonstrating the heterogeneity of research questions and topics. For example, most authors in two research clusters explore the issue of disclosure (He et al., 2022) and reporting (Olson, 2010; de Silva Lokuwaduge et al., 2022) on carbon accounting. Transparent reporting is essential to ensure credibility and comparability of carbon accounting results globally, which is ensured by the use of standardized reporting frameworks such as the Greenhouse Gas Protocol and the need for third-party verification to increase data accuracy. It also highlights the role of new technologies such as secure and verifiable carbon accounting. Accurate measurements are critical to sound carbon accounting. Several themes were identified and supported in this study, such as rising carbon emissions, measure-

**Table 5.** Analysis of cluster

Cluster	Number in Business Finance 34	Number in Management 14	Ukupno 48
<b><u>CLUSTER 1. Theory</u></b>	9	1	10
One theory	0	1	1
Two theories	26	11	37
Mixed theory			
<b><u>CLUSTER 2. Organization Focus</u></b>	32	12	44
Public	0	0	0
Private	2	2	4
Mixed			
<b><u>CLUSTER 3. Types of Carbon</u></b>			
Carbon accounting (generely)	8	8	16
(definitions, calculations, converegence)			
Carbon accounting (emissions)	21	1	22
Climate change accounting	5	3	8
Environmental management accounting	0	2	2
<b><u>CLUSTER 4. Types of Articles</u></b>	25	11	36
Case (research) study	0	0	0
Questionnaire/other practical	0	0	0
Interviews/Reports	1	3	4
Contet analysis and observatiom	8	0	8
Theoretical/review			
<b><u>CLUSTER 5. Types of Journal</u></b>			
Accounting and auditing	24	1	25
Finance	4	0	4
Management, sustainability and policy	6	12	18
Others	0	1	1
<b><u>CLUSTER 6. Themes</u></b>			
Disclosure and reporting	9	5	14
Management, governance and sustainability	8	4	12
Performance and policy	4	2	6
Assurance and efficiency	8	1	9
Capital market	3	1	4
Others	2	1	3

Cluster	Number in Business Finance 34	Number in Management 14	Ukupno 48
<b>CLUSTER 7. Publisher</b>			
Routledge Journals, Taylor & Francis	2	1	3
Emerald Group Publishing	19	8	27
Wiley	4	1	5
Springer	0	1	1
Elsevier	1	0	1
Others	8	3	11
<b>CLUSTER 8. Web of Science Index</b>			
SSCI	20	7	27
ESCI	14	6	20
BKCI-SSH	0	1	1
<b>CLUSTER 9. Author's Home Affiliations</b>			
EU	6	3	9
USA	1	2	3
Great Britain	3	0	3
Australia	8	2	10
Africa and Asia	2 (1)	1 (1)	3 (2)
Cross-country	13	5	18

Source: Authors (2023).

ment uncertainty, comparability deficiencies, the need for policy and integrated decision making, budgeting, reporting, disclosure processes, and the ability of accounting professionals to contribute, which is consistent with the findings of Marlowe and Clarke (2022). At the same time, there is growing interest among publishers for a variety of carbon accounting topics.

Cluster 7 recognizes leading publishers whose editors place particular importance on the green agenda and environmental awareness, regardless of the research area studied. *Emerald Group Publishing* has published the most scientific papers, analytical studies, theoretical reviews and quantitative research papers to date (56%), followed by *Wiley&Routledge Journals, Taylor&Francis*. However, it is noted that the oth-

er publishers (11 different publishers or 23%) follow the trend of representing carbon awareness in the topics of editorial publications as described by Hazaea et al. (2023).

The results for cluster 8 included in Table 5 demonstrate that these are high quality scientific papers, given the specificity of the topic in the global framework. The last cluster analyzes the author's affiliation with university institutions. The aim of this cluster was to detect the universities with the highest scientific productivity and visibility in the field of carbon accounting. Universities are classified according to geographical criteria, with the exception of the United Kingdom (England and Scotland). In addition, institutional collaboration is presented as cross-national collaboration, which plays a leading role in cluster



9. The most frequent collaboration is with Australian universities (Melbourne, Sydney, Western Australia, Victoria), including researchers from New Zealand. The almost national recognizability of the topic can be explained by the increasing industrialization, accelerated technological development, and recent ideological commitment of the islands' universities, while French universities play a leading role in the EU. English and Canadian universities prefer cross-national cooperation with Australia.

## 5. CONCLUSIONS

The objective of this paper was to examine the current state of scientific research in the field of environmental accounting, particularly in relation to carbon accounting. To this end, a bibliometric analysis of 1,035 articles indexed at WoS was performed, including an analysis of the main authors, articles, journals, and geographic distribution of scientific articles, keywords, and a citation analysis using VOSviewer and Mendeley Reference Manager. The oldest article examined dates from 1991, and over the years additional articles have been published continuously to date, showing that interest in the area studied has increased over the years (RQ1).

The paper identified the following elements: (i) the main contributors to the field, i.e. the most productive author is *Tang* with 12 papers that are the subject of research in this paper, while *Mokany*, *Raison* and *Prokushkin* are the most cited authors with 972 citations (RQ2), (ii) the leading journal in the field is the *Journal of Cleaner Production* with an impact factor of 11.072, in which 41 research papers were published, while the journal *Global Change Biology*, impact factor: 13.212, with 2,137 citations, is the most cited (RQ5), (iii) the leading article (Critical analysis of root: shoot ratios in terrestrial biomes) was published in the most cited journal *Global Change Biology*; the authors were previously listed as the most cited authors (RQ4), (iv) geographic locations where research in the studied area is concentrated, with the U.S.A. being the leading country by number of articles published—302 articles, but also by number of citations—11,538 citations (RQ3), (v) keywords used (carbon accounting, emission, biomass, seques-

tration—RQ6). On the other hand, analysis of cluster identified 9 clusters in two specialized areas. This analysis (RQ7) suggests that the topic of carbon accounting is underrepresented in academic papers and research studies in the field of economics, especially in the observed areas of Business Finance and Management. The leading topics by researchers in Economics most often cover areas of interest related to carbon accounting disclosure and reporting, while *Emerald Group Publishing* is the leading publisher in the field of carbon accounting. Most research studies come from Australian universities, and Australia again takes a leading role in cross-national research studies. In third place are scientific studies from the EU, with researchers from French universities playing a leading role.

This could be the first bibliometric analysis and systematic review of research on carbon accounting in accounting studies in the Croatian research context. The theoretical achievements of the work open new avenues for other researchers in the field of carbon accounting. The current scientific insights could be deepened by extending the research to SCOPUS and other indexed publications. He et al. (2021) emphasize the development of four foci or lines of research that define the current research direction: “carbon data”, “carbon management”, “carbon insurance” (Hazaea et al., 2021b), but also, as pointed out above, carbon accounting as a profession in its own right.

The limitations of the paper are very similar to those of Stechemesser and Guenther (2012). Therefore, we did not include in the original search articles that focus on, for example, emissions trading or carbon footprints with direct and indirect impacts. Like Stechemesser and Guenther (2012) and other researchers, we are aware that there are numerous publications in other fields that might address similar questions. However, our research questions aimed to evaluate the relevance of the selected topic and its representation in scientific publications in the field of economics, while Stechemesser and Guenther primarily aimed to understand the primary and alternative ways of defining the concept of carbon accounting. It should be emphasized that we intentionally selected Eng-

lish-language articles in the search criteria because we initially assumed that the selected topic was underrepresented in other languages and secondary databases such as Google Scholar. However, an extension of the original assumptions to other world languages and scientific databases could lead to a different distribution of results in the observed segments (bibliometric review and analysis of cluster) compared to the results of the present work.

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## Računovodstvo ugljika – pregled literature na mezo razini

### Sažetak

*Ovaj rad ima za cilj istražiti trenutno stanje istraživačkih znanstvenih radova vezanih za računovodstvo okoliša, posebice u vezi s računovodstvom ugljika. U tu svrhu, provedeno je bibliometrijsko istraživanje 1,278 WOS-indeksiranih publikacija što uključuje specifične organizacijske i tehničke aktivnosti pomoću Mendeley Reference Manager-a i specijalnog softvera VOSviewer-a. Prvo, rad je identificirao glavne doprinositelje ovom području prema kriteriju najproduktivnijeg autora, vodećeg časopisa, geografske lokacije u kojima je koncentrirano istraživanje izdvajajući vodeću zemlju u području računovodstva ugljika. Drugo, dodatnom analizom utvrđeno je 9 klastera u dva segmenta iz područja ekonomije te dobiveni rezultati ukazuju kako je računovodstvo ugljika nedovoljno zastupljena tema akademskih radova i istraživačkih studija, globalno gledajući. Ipak, pojedini izdavači, znanstvenici i Sveučilišta a priori zauzimaju lidersku poziciju pozicionirajući se kao predvodnici nulte tolerancije emisije ugljika. U konačnici, ovo bi mogla biti prva bibliometrijska analiza i sustavni pregled istraživanja o računovodstvu ugljika u znanstvenim radovima hrvatskog istraživačkog okvira. Teorijska postignuća rada otvaraju nove putove drugim istraživačima u istraživanom području produbljujući aktualna znanstvena dostignuća što bi se moglo ostvariti dodatnim proširenjem početnih pretpostavki i obuhvata istraživanja na SCOPUS i druge indeksirane publikacije uključujući i druge svjetske jezike.*

**Ključne riječi:** računovodstvo ugljika, pregled literature, WoS, VOSviewer, bibliometrijski pregled, analiza klastera