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Review Paper

Mapping World Trends in the Peatland Restoration Literature: An Overview of Bibliometric Analysis

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Abstract

Anthropogenic activities have degraded peatlands in various regions worldwide. To protect and restore peatlands and their ecosystems, sustainable peatland restoration efforts have been undertaken. These efforts have attracted the attention of researchers to assess the success rate, benefits, and protection of restored ecosystems. This study highlights trends, issues, and recent developments through a bibliometric analysis of articles on peatland restoration from an environmental security perspective, published in the Scopus database. The researcher identified 94 journal articles published between 1994 and 2022 and analyzed them using VOSviewer and NVivo 12 Plus software. The results show that research on peatland restoration is playing an important role from an environmental security perspective with increasing recent progress, and has high relevance for rewetting, revegetation, and cost benefits. In contrast, the main issues in peatland restoration are water, ecosystem, and carbon. Experts measure restoration progress through water levels and related issues. Then the peatland ecosystem absorbs about 30% of the world's carbon and vice versa; when degraded, they release carbon. Recommendations for future research focus on harmonizing peatland restoration efforts with an environmental security perspective and educating local communities about the benefits that can increase the success of restoration and preservation of peatland ecosystems, as well as efforts to increase protection through advocacy for these marginal ecosystems.

Keywords

Peatland Restoration, Bibliometrics Analysis, Degraded Peatlands, Peatland Carbon

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1. INTRODUCTION

The aim of this study is to identify trends in peatland restoration research issues worldwide from an environmental security perspective. It intersects with environmental issues that have recently been widely studied by scholars, related to climate change, biodiversity loss, degradation, deforestation, rising carbon dioxide, and the depletion of the ozone layer (Heikkila et al., 2018). The United Nations designated 2021–2030 as the Decade of Ecosystem Restoration (DER) in the agreement. It aims to accelerate the restoration of degraded ecosystems, combat climate change, and improve food security, water availability, and biodiversity. Then reach a common understanding of the Sustainable Development Goals (SDGs) agenda in 2030 by emphasizing efforts to prevent, reduce, and restore degraded land (Elias et al., 2021; Shen et al., 2023).

Therefore, sustainable peatland management is one of the focuses of the UN's decade of ecosystem restoration. It is also based on the significant benefits of peatland in reducing global carbon emissions (UN Environment Programme, 2019). In addition, peat formation from the accumulation of plants for thousands of years; to achieve the appearance of a 1 cm peat takes ten years (Harris et al., 2022; Kalnina et al., 2015). Based on these studies, it can be inferred that plant remains in waterlogged, nutrient-poor, and acidic environments undergo extremely slow decomposition, and over long periods, gradually develop into peat deposits (Ehnvall et al., 2025; Lourenco et al., 2023). Joosten and Clarke view peat as a soil containing 30% organic matter, while Burton and Hodgson peat soils at least 50% organic matter (Rahimpouri et al., 2025). Meanwhile, according to The World Reference Base for Soil Resources (WRB) 2006, histosol, considered peat in many regions, has been defined as a soil containing at least 20% organic matter or at least 18% organic matter. Different interest groups usually use their definitions of "peat" and "peatland" because there is no uniform official definition (Xu et al., 2018).

Meanwhile, global peatlands are estimated to be around

397 to 436.2 million ha, with an average thickness of 80 cm (Anda et al., 2021). Xu et al. (2018), a study conducted with geospatial meta-analysis from various global, regional, and national sources, reported a total international peatland area of around 423 million ha, or 2.84% of the world's land area. Then, the tropical peatland area covers 36–44 million ha (8–11 percent of global peatland area), with 25 million hectares (56 percent) in Southeast Asia (Page et al., 2011; Parish et al., 2008; Terzano et al., 2022).

Happen the underlying uncertainty of peatland areas is influenced by; 1) the repetition of citation source errors caused by the level of accuracy of the data in the past literature that is not confirmed; 2) mapping scale errors; 3) overestimation of peatlands related to simplification of mapping units; 4) classicalization errors in peatland mapping; and 5) different approaches to mapping by different institutions with different objectives (Anda et al., 2021). The importance of geographical data in peatland distribution to plan land use and being used as activity data in calculating greenhouse gas emissions and carbon sequestration for national action plans (Minasny et al., 2024).

Past scholars have been concerned about peatlands because they are essential terrestrial ecosystems for carbon storage (Terzano et al., 2022). Although only 3% of the earth's surface peatlands store as much carbon as the world's vegetation combined and half of the atmosphere (Food and Agriculture Organization of the United Nations, 2020), within an absorption rate of 0.01–0.03 Gt (Gigaton) C/year, peatlands store about 2150 to 2875t C/ha (Widanarko, 2020). On the other hand, tropical peatlands in Southeast Asia are 25 million ha; however, at least 68.5 Gt of carbon stores represent 11-14% of the global carbon (Hoyt et al., 2020). Peatlands are home to unique biodiversity and are even at risk of extinction (such as for orangutans, Sumatran tigers, and Sumatran rhinos) due to deforestation, drainage, and peatland conversion (Choy and Onuma, 2025). Besides that, peatland plays an essential role in regulating water and nitrogen reserves (Yin et al., 2022).

Southeast Asia's deforestation and conversion lead to the loss of peatland forest cover. The transformation of forests and peatlands into Industrial Planting Forests (IPF) causes peatlands to degrade and damages water infiltration, making peatlands flammable (Mishra et al., 2021; Ohkubo et al., 2021). In several countries, such as Ireland, peat is harvested for power generation (Bresnihan and Brodie, 2023; Lempinen and Vainio, 2023). In China, the use of peat for planting media and fertilizer, population increases, and natural changes accelerate degradation (Yang et al., 2017). However, peatland restoration is needed as a trusted step to protect and restore degraded peatland ecosystems and can improve peatland ecosystem services (Glenk and Martin-Ortega, 2018).

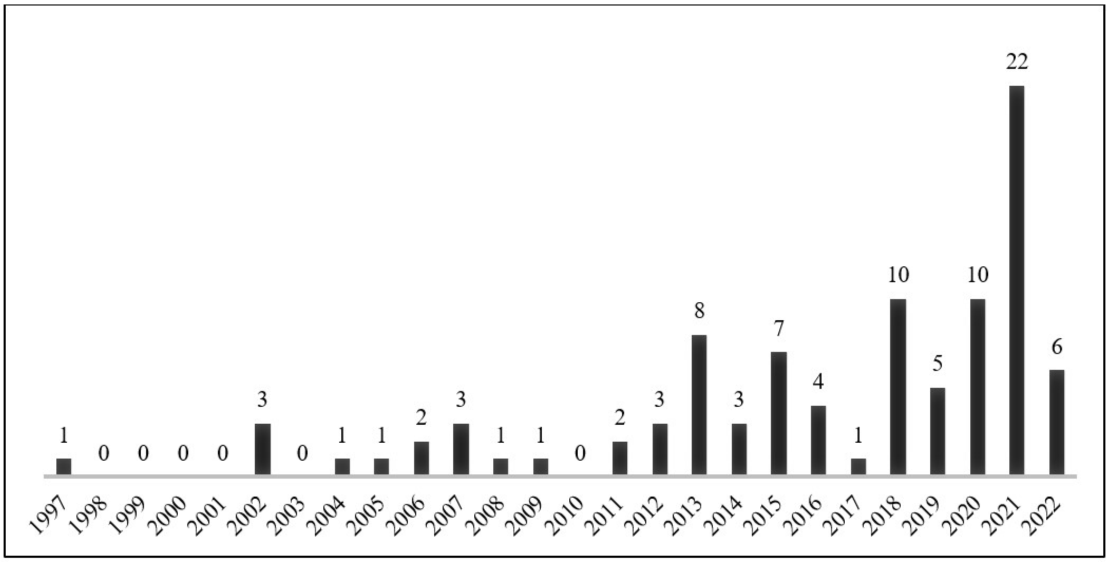
Although the literature on peatland restoration continues to grow, bibliometric studies specifically addressing this topic in a comprehensive, in-depth, and environmental security-oriented manner remain rare. The novelty of this research lies in its explicit contribution to filling this gap by systematically mapping global trends, dominant issues, and emerging sub-themes in peatland restoration research. Using an integrated approach that employs VOSviewer for keyword mapping and collaboration networks, along with NVivo for thematic clustering, this study provides the visual-thematic synthesis of peatland restoration research from 1997 to 2022. The analysis reveals several overlooked sub-themes, such as post-rewetting groundwater table dynamics, self-sustaining peatland ecosystems, and carbon loss mechanisms. This original contribution not only highlights underexplored research areas but also situates peatland restoration within an environmental security framework, thereby offering a solid foundation for future research directions.

2. EXPERIMENTAL SECTION

This study adopts a bibliometric analysis by exploring the scientific literature, highlighting knowledge gaps, and identifying potential differences in sources that can be highlighted from the topic trends. Bibliometric analysis is based on quantitative analytical studies to measure scientific research publications in specific fields, which form the basis for understanding several related studies. The results of bibliometric analysis mapping are generally related to developing research trends based on the keywords used and provide information on countries, research institutions, authors, and the relationships between them (Furoida et al., 2023; Subekti et al., 2025; Taslim et al., 2025).

Data collection was conducted on July 14, 2022, by searching the Scopus database for documents using the keyword "peatland restoration". As the largest academic database and an indexing institution for leading scholarly journals, Scopus was selected as the primary data source for this study for several key considerations. First, Scopus offers extensive coverage and ensures high-quality data, featuring journals that have undergone a peer-review process, making it a reliable source for bibliometric analysis. Second, Scopus is widely recognized in various studies, including bibliometric research, as a credible source, ensuring that the data analyzed reflects trends and findings relevant to the field of study (Baas et al., 2020; Pranckutė, 2021). Additionally, limitations in time and resources constrained the use of multiple databases, making Scopus the most practical and feasible choice for this analysis.

Furthermore, the data is limited to the keyword "peatland restoration" at the final publication stage, with the selected document type being an English journal article; the results found 94 journal articles. The next step is to export the document in CSV file format for analysis using VOSViewer software and in RIS file format for data analysis using Nvivo 12 Plus software. VOSviewer is a data analysis software used to visualize networks and create bibliometric maps that are easy to understand (Van Eck and Waltman,



Source: Academic Scopus Database. Authors' elaboration, 2022

Figure 1. Number of Publications per years (1997-2022)

2019). In this study, the mapping steps or procedures conducted using VOSviewer are as follows:

- Creating maps based on bibliographic data.
- Using data sourced from the bibliographic file of the Scopus database.
- Selecting the type of analysis:
  - Co-Author (this analysis unit is used to visualize the network of countries).
  - Co-Occurrence (this analysis unit is used to visualize the keyword co-occurrence network).
- Setting a threshold for data visualization, particularly for keyword occurrences of three times.
- Verifying the selected data and completing the mapping process.

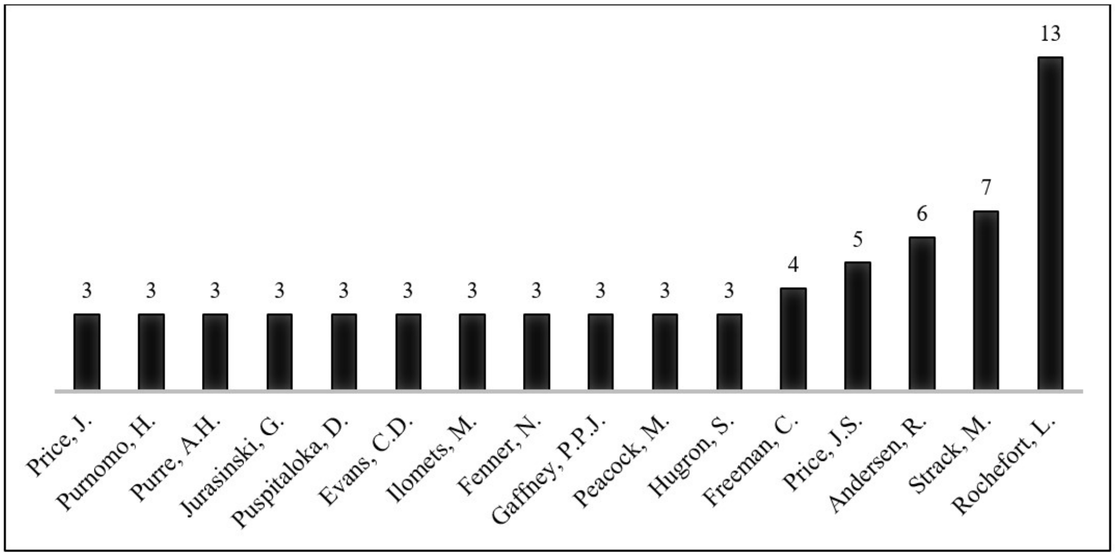
In addition, this study used the Nvivo 12 Plus software. This qualitative data analysis tool makes it easier to collect, categorize, map, analyze, and visualize data in images, graphics, or quantitative data. Nvivo 12 Plus can process qualitative data from journal articles, memos, photo documents, interview transcripts, reports, and laws. The data analysis stage can be explained with Nvivo 12 Plus: data collected in RIS format, import data, auto-code data, data classification, and data visualization. In this study, data analysis from Nvivo 12 Plus uses the cluster analysis tool menu to map the main issues related to peatland restoration (Dalkin et al., 2021; Subekti et al., 2025).

3. RESULT AND DISCUSSION

In this section, we analyze publication documents related to peat restoration research to map and analyze the data sources. Each data and item are displayed based on the search results and filtering of the academic Scopus database, using Nvivo 12 plus and VOSviewer features. In this study, analyze and classify data to be visualized in a discussion consisting of publications by year, number of publications by author, authors by number of citations, number of documents by country, subject area of research, number of articles from journal article publishers, keyword visualization analysis, keyword frequency query, sub-theme relationships, and sub-theme issues. Figure 1 shows the trend of peatland restoration study publications from 1997 to June 2022, with as many as 94 documents.

Figure 1 shows the number of publications on "Peatland Restoration" from 1997 to 2022 has fluctuated. There were no publications of journal articles from 1998 to 2001, 2003, and 2010, which may be due to a lack of focus and consistency among academics on the issue of peatland ecosystems that are starting to be degraded due to conversion, fires, and drainage. Furthermore, the peak of the increase in publications occurred in 2021, with as many as 22 journal articles, even though published research can be a reference for scholars as well as a reference for the government in policy making in the protection and restoration of peatland for the benefits of carbon sequestration and storage (Ekardt et al., 2020; Harrison et al., 2020). Next, this study highlights the authors who have contributed the most to scientific research on peatland restoration, as seen in Figure 2.

This study highlights the contributions of authors of scientific journal articles with at least three documents related to peatland restoration. Based on Figure 2, the most contributing author is Rochefort L, with 13 journal articles published from 2002 to 2022, focusing on topics of Bryophyta, Fens, and Peatlands, with a Weighted Citation



Source: Academic Scopus Database. Authors' elaboration, 2022

Figure 2. Article Publications by Author

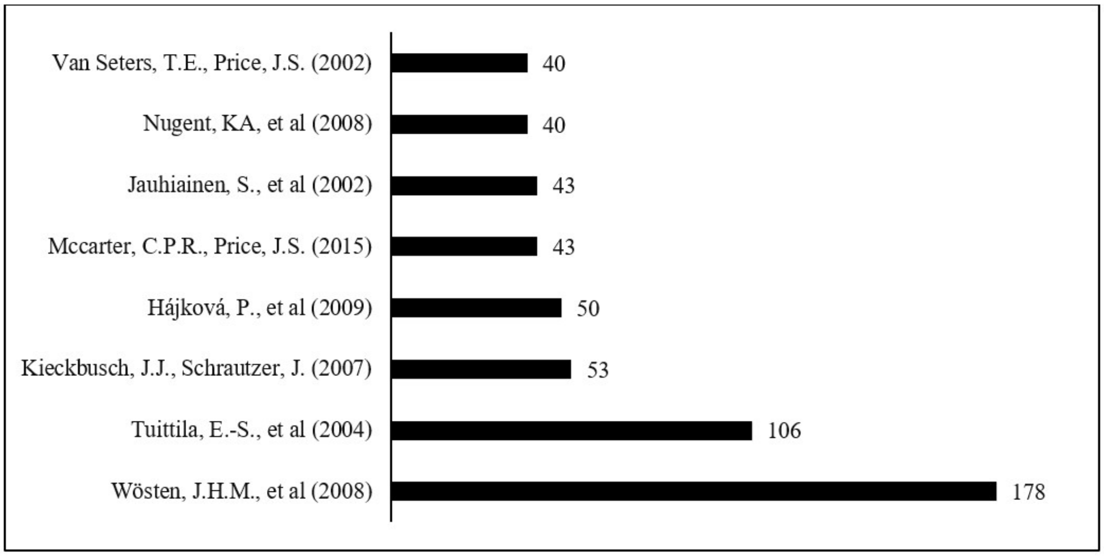
Impact of 0.74. One of his articles, "Multi-year net ecosystem carbon balance of a restored peatland reveals a return to carbon sink," has been cited 40 times by scholars and has become a scholarly reference for measuring peatland carbon sequestration (Nugent et al., 2018). Furthermore, Strack M contributed seven documents, followed by Andersen R with six documents, and Price J contributed five documents. Figure 3 displays the citations for the author's journal articles contributing to another scientific research.

The citation of journal articles reflects how scientific research impacts a scholar's research scope of interest. In addition, it can be interpreted as a transfer of knowledge for development and seeing research gaps for innovations that can be applied in future research (Wang et al., 2019). Figure 3 shows 94 journal articles on peatland restoration, visualizing the authors with their scientific journal articles, which scholars widely cite. The journal article that was most cited was written by Wösten J.H.M. et al. entitled "Peat-Water Interrelationships in a Tropical Ecosystem in Southeast Asia," which has been cited 178 times for journal articles published in Scopus. Citations occurred from 2009–2022, with a Weighted citation impact of 1.87. The article explains that the wise and sustainable use of peatlands must pay attention to a critical element, namely water management, with a hydropedological modeling approach. The relatively intact peatland demonstrated resilience, but When its hydrological integrity was disturbed, the damaged peatland was more prone to fire (Wösten et al., 2008). The journal article has become a reference for scholars to measure peat moisture levels for fire risk studies and the relationship between peatlands and water for sustainability in peatland management.

Furthermore, a journal article written by Tuittila et al. (2004) entitled "Sensitivity of C sequestration in reintroduced Sphagnum to water-level variation in a cutaway peatland" was published in 2004 and has been cited 106 times since 2006–2021, with a Weighted citation impact of 2.37. This article describes the effect of water level on sphagnum CO_2 exchange in cut and rewetted peat. It becomes a reference for scholars looking at vegetation development after peatland restoration and the relationship between water and vegetation in peatland carbon sequestration.

Next, the publication of journal articles with citations 53 times from 2007 to 2022 was written by Kieckbusch J.J. et al. in 2007 entitled "Nitrogen and phosphorus dynamics of a rewetted shallow-flooded peatland" with a Weighted citation impact of 1.09 (Kieckbusch and Schrautzer, 2007). Conclusions in the article explained Flooded peatlands should have constant water flow and steady water levels to avoid high ammonium and phosphate concentrations and to take advantage of the potential for nitrate retention. Flooding in degraded peatlands can only be seen as a quick technological fix to preserve peat mineralization and lay the groundwork for the peatland's future transformation into a more effective nutrient-retention system. This article has become a reference for scholars to look at fluctuations in water, nutrients, nitrogen, and phosphorus in peatlands. Furthermore, this study identifies countries' contributions to journal articles on peatland restoration.

Figure 4 is a network visualization of ten countries contributing to scientific journal articles from 94 documents about peatland restoration. The identification of state contributions is visualized through contributions and collaborations by authors affiliated with institutions in a country.



Note: Author with A Minimum Number of 40 Citations
Source: Academic Database Scopus. Author Elaboration's, 2022

Figure 3. Author with Number of Citations

There is generally more than one author with different country affiliations in one journal article document. For example, in 1 journal article document, there are three authors, two affiliated with the United Kingdom and one affiliated with Indonesia. So, it will be calculated that there are two different country affiliations in one journal article document. Thus, each of these countries will be said to have 1 document even though with the same title.

Figure 4 shows the author collaboration visualization network specified by country affiliation, with A total of 27 scientific journal articles documents from contributions from Canada and the United Kingdom, followed by Germany (12 documents), Indonesia and the United States (10 documents), Finland (6 documents), and France, Ireland, the Netherlands, and Switzerland (4 documents). Then, we can see the collaborative network of writer's affiliate United Kindom collaborating with affiliated writers from Canada, Germany, Indonesia, the United States, Ireland, and the Netherlands. Meanwhile, Indonesian-affiliate writers only collaborated with writers affiliated with the United Kingdom, Germany, the United States, and the Netherlands. In addition, this study also displays the number of journal article documents written in collaboration with cross-country affiliates (see table of total link strength). For example, Canada has 27 documents, but only five documents in their authorship collaborate with authors affiliated with other countries. It can be involved through the LS (Link Strength) network, which shows the number behind it. For example, Canada, with the United Kingdom's Link Strength network showing LS 4, means four documents of collaborative result journal articles author affiliated with that country. Then, Canada with the Link Strength network Ireland shows LS 1, so there is one journal article document of collaborative result author affiliated with that country.

Canada's dominance in peatland restoration publications reflects the vast area of peatlands it possesses, approximately 170 million hectares (25% of the world's total peatlands). However, approximately 2% of this land has been degraded, including 1.3 million hectares that have been drained for agricultural purposes (Agus et al., 2020). The high volume of publications is directly linked to Canada's substantial investment in peatland restoration research, amounting to $20 million (Canadian Sphagnum Peat Moss Association, 2024). Additionally, $1.4 billion in funding from the Smart Climate Solutions initiative and $12.8 million from the Ministry of Environment and Climate Change for programs involving Indigenous communities further strengthen this commitment (Environment and Climate Change Canada, 2024).

The concern scholars have highlighted is that peatlands are degraded due to being cut for fuel for power plants and horticultural extraction, causing loss of surface vegetation and drying of peatlands. Meanwhile, peatland ecosystems have been trusted to provide global carbon sequestration services as a crucial nature-based solution to combat climate change. So, to restore the ecosystem, peatland restoration is carried out by converting the water level by blocking ditches, restoring vegetation by spreading sphagnum, and phosphorus fertilization (Grand-Clement et al., 2015).

While the UK plays a key role in peatland restoration research, particularly due to more than 80% of its peatlands, which cover 3 million hectares, having been degraded (Minasny et al., 2024). The restoration approaches pio-

Table 1. The Most Used Peatland Restoration Keywords

Issues	Cluster	Links	*TLS	Occurrences
Peatland restoration	3	100	668	94
Restoration ecology	2	92	287	32
Sphagnum	4	69	212	25
Restoration	1	78	246	22
Carbon sequestration	5	59	120	11
Rewetting	2	64	126	13
Revegetation	1	48	69	6
Cost-benefit analysis	3	22	29	4
Carbon emission	2	37	45	3
Land use change	2	25	31	3
Ditch blocking	1	39	60	4
Catchments	1	41	65	4
Drainage	1	36	48	7
Agricultural land	2	25	30	3
Climate change	3	56	118	14
Environmental restoration	3	70	146	16
Greenhouse gas	3	55	110	12
Eriophorum vaginatum	5	33	55	7
Soil moisture	4	25	40	4

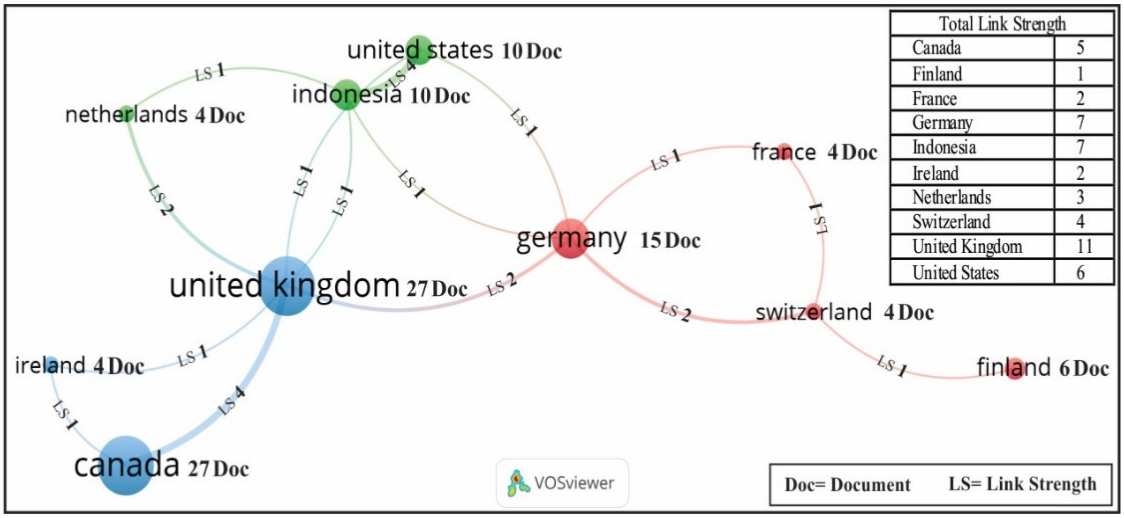
Source: Data is Processed Using VOSviewer on Network Visualization Mapping
Note: The Number of Occurrences of Keywords is at Least Three Times, with a Total Link Strength (*TLS) of at Least 29

neered by the UK, such as drain blocking and revegetating degraded peatlands, have become global models (Howson et al., 2023). The UK Peatland Strategy 2018-2040, supported by substantial funding from the government and leading research organizations like the Natural Environment Research Council (NERC), drives the development of globally applicable peatland restoration techniques (IUCN UK Peatland Programme, 2024). Strengthened by research from leading universities, the UK not only serves as a role model in peatland restoration but also as a key partner in research collaboration for academics and practitioners worldwide.

Meanwhile, Germany's research on peatland restoration reflects significant efforts to address environmental challenges. Although Germany does not have as large a publication volume as Canada or the UK, it plays a crucial role in developing a comprehensive, multi-faceted sustainable peatland restoration policy to help achieve its climate neutrality target by 2045 (Willenbockel, 2024). Germany launched the National Peatland Protection Strategy, which aims to protect and restore degraded peatlands with an ambitious target to reduce carbon emissions from drained peatlands. This policy is critical given that more than 90% of Germany's total 1.786 million hectares of peatlands have been degraded, primarily due to agricultural activities, which now contribute significantly to the country's carbon emissions (approximately 42.5 million tons of CO_2 equivalent in 2020) (Meyer-Jürshof et al., 2025). To address this, peatland restoration efforts focus on restoring water levels, re-establishing hydrological functions and vegetation, and promoting carbon accumulation. Key methods include inundating sites, blocking and backfilling canals, and replanting bare peatlands (Schneider et al., 2024; Zak et al., 2022).

Meanwhile, Indonesia's contribution to scientific publications is in line with the area of peatlands, reaching 13,430,517 ha or 47% of the global tropical peatland area (Anda et al., 2021; Rieley and Page, 2016). Degradation, deforestation, and peatland drainage are triggered by industrial forest plantations (pulpwood, oil palm) and forest and peatland fires (Harrison et al., 2020). So it becomes the focus of scholars to observe tropical peatlands in Southeast Asia, namely Indonesia, which causes biodiversity loss and carbon reserves (Wilcove et al., 2013). In addition, efforts to restore peatland ecosystems are carried out using the approach of rewetting, revegetation, and socio-economic revitalization of the community (Harrison et al., 2020).

The dominance of publications from Canada, the UK, and Germany in peatland restoration research reflects the significant influence these countries have in shaping the global research agenda. With their extensive boreal peatland ecosystems, all three countries have developed practical restoration approaches for temperate and boreal environments. Techniques such as drain blocking and revegetation of degraded peatlands in the UK and Canada have now become widely adopted models. However, despite the sig-



Note: Countries with A Minimum of 4 Journal Article Documents
Source: Academic Database Scopus, Processed with VOSviewer, 2022

Figure 4. Document Identification Based on Countries

nificant contributions of these countries in the context of boreal ecosystems, this publication dominance may create a research gap in countries with tropical peatland ecosystems, such as Indonesia, Malaysia, and Congo, which face different challenges (Page, 2024). Tropical countries face unique challenges, including peatland fires, land conversion, and accelerated degradation, which necessitate distinct research approaches (Girkin et al., 2022). Approaches developed in developed countries are often less relevant to the conditions of tropical peatlands. Additionally, the dominance of research from high-capacity research countries results in a concentration of international research funding. In contrast, tropical peatland countries often lack the resources to develop research that addresses their local challenges. Therefore, to address these challenges, a more inclusive international collaboration between developed and tropical countries is needed to ensure that peatland restoration solutions are more relevant and applicable across diverse peatland ecosystems worldwide.

Apart from the area of peatland owned, the number of scientific journal article publications in each country is determined by several factors: first, the quality of human resources and educational institutions as well as the state or government which is very concerned about climate change due to damage to environmental ecosystems and peatlands. Second, the level of attention and concern for global warming elaborated by scholars to fight climate change is one of them with conservation, restoration, and sustainable management policies. It is seen as a practical and actual effort to absorb and store global carbon. Third, the financial factor that supports research quality, developing countries tend to wait for funding from other countries to produce research and scientific publications, especially on marginal ecosystems such as peatlands. Other factors that are still quite relevant are equipment, including research equipment, level of experience, and cross-country collaboration which also affect the limitations of scientific publications on environmental issues (Djalante, 2018; Furoida et al., 2023,?; Minasny et al., 2020). Next, this study presents the subject area of the publication of scientific journal articles on peatland restoration.

Figure 5 provides a visualization of the subject area of scientific journal articles on peatland restoration. It can be observed that this study shows that peatland restoration studies are dominated by subjects in the Environment Science area (47%), agriculture and Biological Sciences (31%), Earth and Planetary Sciences (8%), Social Sciences (4%), Medicine (3%), Biochemistry, genetics, and Molecular Biology (1%), Economics, Econometrics, and Finance (1%), and energy (1%). In addition, this visualization also explains the complexity of peatland restoration studies that cross the subject areas or fields of a scientific research study so that the issue of peatland restoration is no longer just an issue of environmental science. It is because peatland ecosystems indirectly impact life, especially humans (Grand-Clement et al., 2015; Harrison et al., 2020).

Understandably, the study of peatland restoration is indeed a subject area of Environmental Science, which can be illustrated through studies on damage to peatland ecosystems, carbon sequestration, and water regulation. Because of the complexity of efforts to accelerate peatland restoration, the perspective of scholars from various subject areas of science is needed. For example, in the subject area of social science from research by Januar et al. (2021), highlighting the implementation of peatland restoration policies from the point of view of stakeholders in the regions shows that there are limitations made by the government for restoration

Table 2. Value Jaccard's Coefficient

Code A	Code B	Jaccard's Coefficient
Nodes\peatland restoration\water	Nodes\peatland restoration	0.925926
Nodes\peatland restoration\ecosystem	Nodes\peatland restoration	0.814815
Nodes\peatland restoration\carbon	Nodes\peatland restoration	0.814815
Nodes\peatland restoration\soil	Nodes\peatland restoration	0.790123
Nodes\peatland restoration\measurements	Nodes\peatland restoration	0.753086
Nodes\peatland restoration\vegetation	Nodes\peatland restoration	0.740741
Nodes\peatland restoration\water table	Nodes\peatland restoration	0.716049
Nodes\peatland restoration\plant	Nodes\peatland restoration	0.703704
Nodes\peatland restoration\bog	Nodes\peatland restoration	0.666667
Nodes\peatland restoration\sphagnum	Nodes\peatland restoration	0.567901

Source: Processed with Nvivo 12 Plus Using the Cluster Analysis Menu

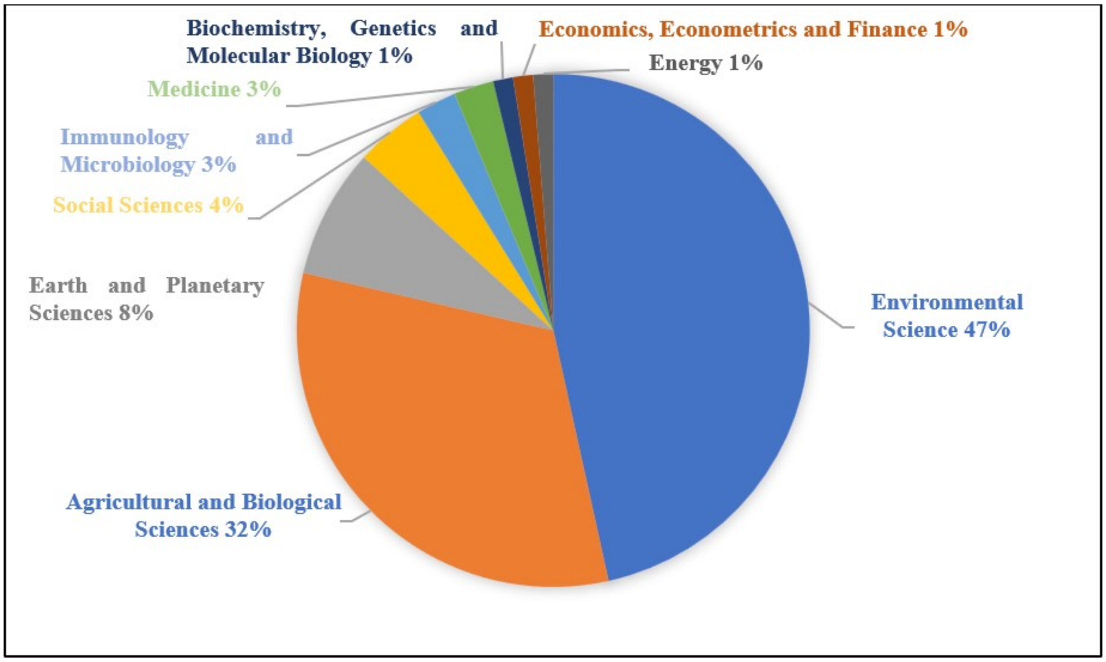
actors, as well as governance in the areas which is not good enough to cause overlap.

In addition, in the subject area of Economics, Econometrics, and Finance, research by Puspitaloka et al. (2021) highlights the empirical assessment of the financing and challenges of restoration peatlands, which reveals that financing depends on international and private donors and that half of the funding is an indirect part of the total restoration costs. Meanwhile, conversion to plantations is a reason for the economic needs of local communities. This study proposes an opinion to increase the contribution and collaboration of scholars across science subject areas in scientific research published in reputable journals that will provide a broader perspective for the community and stakeholders to achieve a degree of sustainability of the peatland ecosystem. On the other hand, the findings of this study in Figure 5 can serve as a reference for scholars to see research gaps from the point of view of the scientific subject area so that it becomes a reference for future scientific research updates. For example, it still needs to be found to produce articles in scientific journals in social science, economics, and energy.

There is a significant gap in peatland restoration research, with most focus remaining on ecological techniques and land management. At the same time, the socio-economic aspects tend to receive less attention. It poses a significant challenge in meeting practical needs, which should include the impact of restoration on local communities, indigenous peoples, and farmers who rely on peatlands for their livelihoods. This gap can be filled through more integrative research collaboration, combining socio-economic studies to assess the long-term benefits of peatland restoration, including fire reduction, improved water quality, and alternative income sources, such as ecotourism or non-timber products. Thus, integrating socio-economic research will not only expand the scope of research but also bridge the knowledge gap and provide practical solutions that can be implemented in peatland management and policy for sustainable land use. Next, this study presents the results of a network keyword visualization analysis of peatland restoration.

Figure 3 shows the mapping and network of keywords for Peatland Restoration based on the collected documents from 94 journal articles. All keywords are used as the unit of analysis in co-occurrence mapping. Still, in this study, some limitations are applied to analyze them, with a minimum of three times occurrences of keywords as a limiting factor. So, of the total, there are 1095 keywords, so only 123 meet the threshold. Then, the color indicates clusters to gain insight into grouping in bibliometrics. At the same time, the labels on the images show keywords or terms that appear frequently and meet the specified threshold. So, from Figure 3, the keywords with the highest co-occurrence are peatland restoration (cluster 3 is blue), restoration ecology (cluster 2 is green), sphagnum (cluster 4 is yellow), restoration (cluster 1 is red), and carbon sequestration (cluster 5 is purple). Meanwhile, the circle dimension represents the number of occurrences and the proximity of relatedness (the number of documents that occur together) (Van Eck and Waltman, 2019). Table 1 is presented to complement the legibility limitations of Figure 3.

A keyword frequency query (Table 2) also shows the most frequently used issues or objects of study in the 94 journal article documents. Apart from some of the main keywords (tables 1–5), several important issues have relevance to be discussed in peatland restoration, such as Rewetting, Revegetation, Cost-benefit analysis, and carbon emission. Rewetting is a technical approach to restoring peatlands through constructing infrastructure such as canal blocking, canal backfilling, and drilled wells as an alternative to peat-wetting springs. The rewetting approach is seen as an initial technical step to prevent and improve the hydrology of degraded peatlands, with one of the indicators being an increase in the groundwater table (Dohong et al., 2018). However, in several scholarly studies, the cost and effectiveness of peatland restoration are often questioned



Source: Academic Scopus Database. Authors' elaboration, 2022

Figure 5. Subject Areas of Scientific Journal Article Documents

(Darusman et al., 2023; Osaki and Tsuji, 2016).

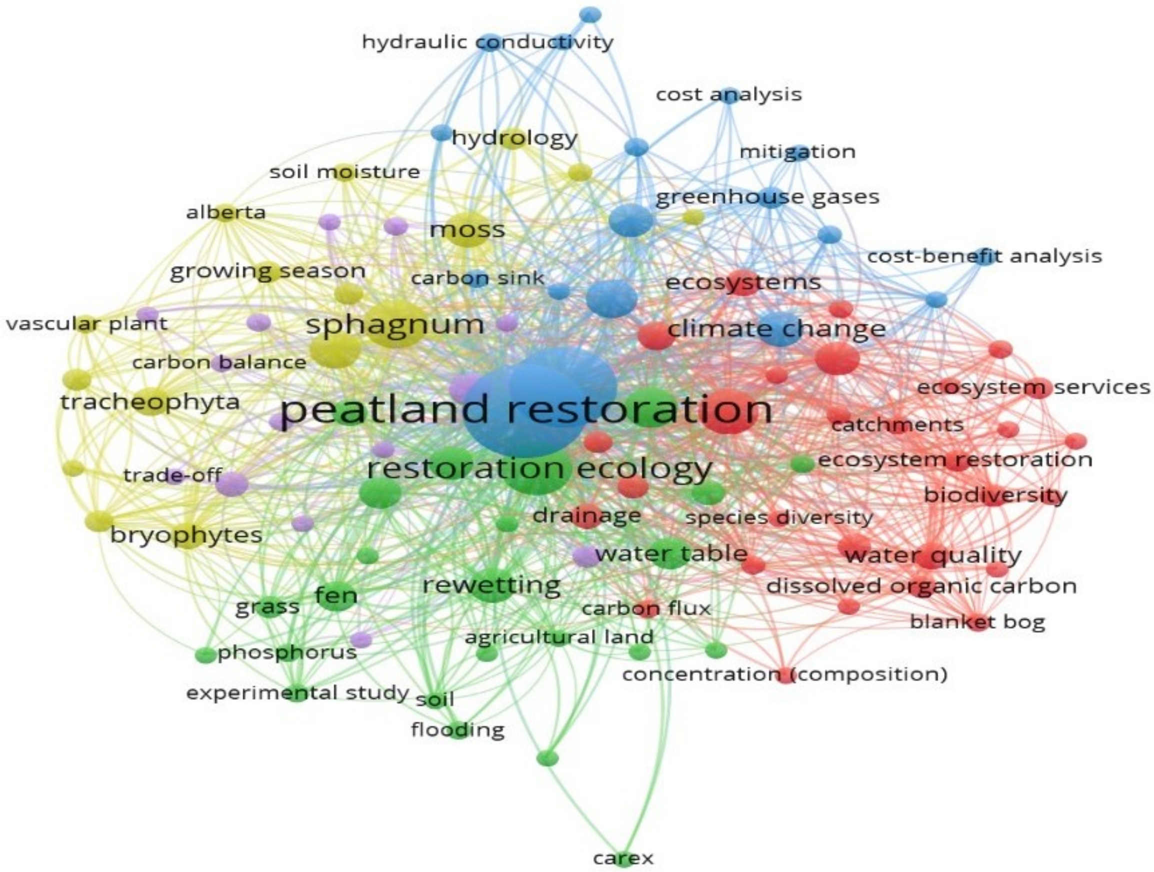
Meanwhile, Revegetation is an advanced effort from the rewetting stage to restore degraded forest cover and peatland through planting trees with native types of peatland ecosystems (Dohong et al., 2018; Terzano et al., 2022). However, scholars consider that Revegetation is determined mainly by the success of wetting and other factors such as climate, quality of seedlings, and maintenance or monitoring. In addition, several Southeast Asian countries (Indonesia and Malaysia) face conflicts over peatland ownership and overlapping restoration policies and actions (Harrison et al., 2020; Januar et al., 2021; Puspitaloka et al., 2021; Terzano et al., 2022).

Meanwhile, several scholars have highlighted the efficiency and effectiveness of financing peatland restoration (Horsburgh et al., 2022). The Benefit that local communities have received from restoration is the main topic of discussion. However, the general view is that restoration is more cost-effective than peatland degradation's consequences. At the same time, another factor is the approach and method used to analyze restoration financing (Moxey, 2016). The views of Evans et al. (2021) and Kiely et al. (2021) state that the restoration costs incurred to reduce greenhouse gas emissions are comparable and even cheaper than afforestation. Another view suggests accelerating restoration to reduce emissions in the land use sector. On the other hand, carbon trading is an alternative for long-term financing for peatland restoration as a business strategy involving trade in ecological services, especially carbon credits (Glenk and Martin-Ortega, 2018; Horsburgh et al., 2022; Puspitaloka et al., 2021). Furthermore, in Table 2, this study presents the relationship between the main issues and the keyword peatlands restoration.

Table 2 presents the ten main issues related to peatland restoration. Data were processed from 94 journal article documents with the Nvivo 12 Plus software through the toll cluster analysis menu with the results of the jaccard's coefficient value, which explains that the closer to 1.00, the stronger the relationship: conversely, the closer to 0.00, the weaker the issue relationship. Based on Table 2, the highest jaccard's coefficient value for water issues is 0.925, while ecosystem and carbon issues are simultaneously 0.814. This study highlights the three main issues to see the sub-themes.

Referring to Figure 7, in this study, to maximize our discussion, we only highlight three main issues, each of which has five related sub-themes. Based on the cluster analysis results and the value of Jaccard's coefficient, which is sorted based on the relationship from highest importance to lowest importance, The issue of water is related to five sub-themes, namely, water table depth with a value of 0.2, issues of pre-restoration water tables, blocking ditch water, and fen water supplies simultaneously with a value of 0.028, and post-rewetting water table rise with a value of 0.027.

The issue of water and its sub-themes was highlighted by scholars related to measuring the progress of peatland restoration by measuring the water level and the peat pores in the peat swamp, with the note that the water level in the degraded peat swamp reached 53 cm. A study Gaffney



Source: Academic Scopus Database, Processed by VOSviewer with Keyword Network Visualization Tools

Figure 6. Peatland Restoration Keyword Network Mapping

et al. (2018) and Gatis et al. (2020) emphasized in their findings that degraded peatlands significantly affect the decrease in the water level, which causes dry peatlands so that purple moor grass will grow (Molinia caerulea), such as in England and western Europe, while in some countries on the southeast Asian continent, peatlands will grow fern grass (Pteridophyta). So that in these conditions, peatlands will quickly burn. Therefore, various countries have adopted policies to rewet peatlands by building canal blocking and closing/backfilling canals (Gaffney et al., 2018; Isselin-Nondedeu and Gaucherand, 2020).

Furthermore, ecosystem issues have several sub-themes, namely, peat ecosystem (0.314), ecosystem restoration (0.114), degraded peatland ecosystems (0.57), financing ecosystem restoration, and self-sustainable peatland ecosystem (0.028). Peat ecosystem refers to the arrangement of peat elements with unique and fragile characteristics constituting a complete and comprehensive unit with the peat hydrological unit, which influences each other in forming balance, stability, and productivity (Turmudi et al., 2022). Scholars emphasize all the elements that make up and function in peat. Still, in various literature, definitions used vary, and all refer to a peatland ecosystem with the meaning of a terrestrial wetland area where waterlogged conditions prevent plant material from decomposing completely (Andersen et al., 2013; Lindsay et al., 2014; Parish et al., 2008; Rieley and Page, 2016).

Meanwhile, the ecosystem restoration sub-theme relates to peatlands intended to restore air quality, water availability, storage of oxygen-producing carbon reserves, climate balancing, and biodiversity (Food and Agriculture Organization of the United Nations, 2020; Horsburgh et al., 2022). In general, scholars emphasize the action of wetting, followed by revegetation and strengthening of the law, in several Southeast Asian countries emphasizing the socio-economic revitalization of communities around peatlands (Andersen et al., 2017; Dohong et al., 2018; Grand-Clement et al., 2015). Relates to degraded peatland ecosystems (sub-themes) that occur due to anthropogenic activities such as conversion, drainage, and fires which cause carbon release (Grand-Clement et al., 2015; Terzano et al., 2022).

On the other hand, the sub-theme of financing ecosystem

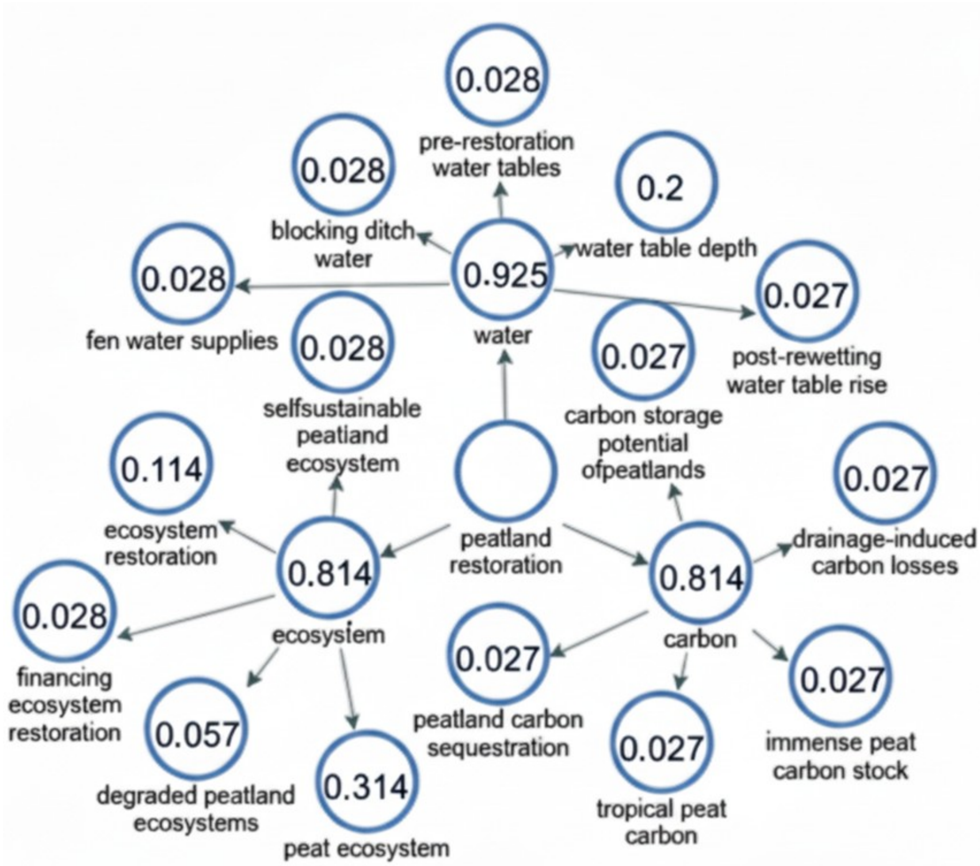


Figure 7. The Three Main Issues Related to the Sub-Themes

restoration is related to peatland. In general, scholars in their studies refer to the costs incurred and alternative financing for peatland ecosystem restoration. In the research by Sari et al. (2020), alternative financing for restoration apart from the state budget can be through the peatland restoration business, such as paludiculture farming, carbon trading, green bonds, and financing through compensation by companies with a history of deforestation. In the research of (Glenk and Martin-Ortega, 2018), it can be concluded that the results of the costs incurred for peatland restoration can contribute to climate change mitigation and provide ecosystem services to the community (Glenk et al., 2021).

Furthermore, the self-sustainable peatland ecosystem sub-theme relates to restoration activities through rewetting, revegetation, and revitalization, which are the first steps in returning the ecosystem to its natural state. It takes approximately 100 years to restore a degraded ecosystem to its natural state (Andersen et al., 2013). Meanwhile, in their research, Budiman et al. (2020) highlighted the restoration of peatland ecosystems through paludiculture as a sustainable ecosystem management step to maintain peat bodies and maintain ecosystem services. Thus, scholars' notes on peatland restoration techniques show how effective and efficient it is to restore peatland ecosystems to their natural state.

Next, the carbon issue has several sub-themes, namely the carbon storage potential of peatland, peatland carbon sequestration, immense peat carbon stock, tropical peatland carbon, and drainage-induced carbon losses. Peatlands are estimated to absorb 0.37 Gt of CO_2 annually and store around 2150 to 2875t C/ha of carbon, or 30% of the world's soil carbon. Meanwhile, peatlands are drained of an estimated 1.9 Gt of CO_{2e} annually. Research by Li et al. (2018), suggests that peatland is degraded due to burning, conversion for agriculture, and industrial forestry, which releases 80.8 Gt of carbon and 2.3 Gt of nitrogen, equivalent to an annual greenhouse gas emission of 1.91 (0.31-3,38) Gt CO_{22e} (Leifeld and Menichetti, 2018). Meanwhile, tropical peatlands store 152-288 Gt Carbon, estimated to be half the carbon emissions of global peatlands. Therefore, in the study, Humpenöder et al. (2020) estimate that tropical and boreal peatlands will be degraded if re-wetting is carried out at least 60% over several decades, and peatland ecosystems will become a global net carbon sink by 2100. So, protection and restoration of Peatlands are the keys to carbon absorption and storage and can potentially mitigate climate change and reduce greenhouse gas emissions.

The presentation of the three main issues with sub-themes related to peatland restoration that this study highlights highlights the main points of view as a review to find research gaps for scholars. So that the sub-themes that are still minimally studied in published journal articles can be explored more deeply for research renewal. As with the water issue, the post-rewetting water table rising sub-theme, while ecosystem issues are found in the self-sustainable peatland ecosystem sub-theme, while on the carbon issue, almost all sub-themes tend to have low scores meaning that interest in the study is still very minimal.

4. CONCLUSIONS

This study aims to fill gaps and generate new research opportunities in peatland restoration through bibliometric analysis, mapping trends, issues, and new ideas. The results of this study are expected to provide practical implications for policymakers and peatland restoration agencies in designing more inclusive and evidence-based policies. Additionally, this study can serve as a practical guide in expanding more ecological peatland restoration strategies, while enhancing insights into sustainable peatland management. On the other hand, this study also emphasizes the importance of considering the socio-economic impacts of peatland restoration, as well as creating alternative livelihoods for communities that depend on peatlands.

Journal articles on peatland restoration were found from 1997 to 2022. This research was conducted, and there were 94 Scopus-indexed documents. Meanwhile, data management analysis uses Nvivo 12 Plus and VOSviewer software to provide amplifying and attractive visuals. The conclusion of this study can be explained by the fact that there has been an increase in published articles on peatland restoration, but so have fluctuations over the years. With Rochefort's most contributing authors, 13 journal articles were published from 2022–2022. Wösten et al. (2008) wrote a high-impact article, cited 178 times, and serves as a reference for measuring peat moisture levels for studies of fire risk and the relationship between peatlands and water for sustainable management.

Meanwhile, authors affiliated with institutions from Canada and the UK produced 27 journal articles; this contribution is related to the quality of human resources, financial, and other technical support. Then the study of peatland restoration crosses scientific disciplines, which are mainly in the subject area of environmental science, while a minor contribution is in the subject area of social science and energy. On the other hand, the most dominant issue of peatland restoration relates to the water, ecosystem, and carbon subthemes. The researchers previously directed their subsequent research on peatland restoration for the socio-economic community by demonstrating the effectiveness and efficiency of the restoration techniques used. Although this study has been able to explain trends in peatland restoration research, it recognizes several limitations, such as the range of subject areas studied is too broad, so it is not enough to focus specifically on the studies of interest. Then, Scopus-indexed only journal article documents can discourage insight, necessitating reviewing more comprehensive database sources such as the Web of Science.

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