Article

Analysis of Peatland Research Trends Based on BERTopic

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Abstract: Peatlands comprise approximately 3% of the land area worldwide. Peatland exists in most countries, including tropical, subtropical, and boreal regions. Accordingly, peatland has garnered increased research attention as a potential countermeasure against climate change. Therefore, it is necessary to identify and comprise the topics constituting global peatland research. In this study, we applied BERTopic—a topic modeling technique—to analyze relatedness between research topics to classify global peatland research trends, evaluate changes over time, and analyze the relationships between topics. To this end, we searched the keyword "peatland" on ScienceDirect—a global academic publication data platform—and collected the titles and abstracts from 10,158 publications from 1953 to 2022 for dynamic topic modeling and network analysis. Eighty-two peatland research topics were identified, which were combined into 15 main topics. Over time, an increasing trend was observed in topics related to production, management, and fire. In addition, upon analysis of the relationships between topics, three groups centered on fire, peatland value, and carbon were identified. We anticipate that the findings of this study can be expanded to analyze trends in research related to fires in peatlands, regional characteristics of peat soil, prediction of greenhouse gases emission and mitigation due to peatland fires, and prediction of future peatland research topics.

Keywords: BERTopic; peatland; research trend analysis; topic classification

1. Introduction

Peatland, i.e., wetlands with accumulated peat, is estimated to comprise approximately 3% of land area worldwide, with distribution across most geographical regions, including tropical, subtropical, and boreal regions [1–4]. Peatlands are typically defined as regions with ≥30 cm of peat soil depth, or where dead organic material comprises a minimum of 30% of the dry peat weight [4,5]. Peatlands provide various ecological services, including carbon and water storage and biodiversity conservation, and serve as the largest natural carbon store among land ecosystems, making them an important resource for mitigating climate change [2,6,7]. In particular, peatlands have an excellent carbon storage capacity per land area, storing about 40% of the earth's soil carbon [8]. For example, it was reported that the carbon storage of Indonesian peatlands (approximately 20 million ha) is approximately 46 Gt, accounting for 8–14% of the global peatland carbon storage [9]. Through this, peatland restoration has recently received attention as a means of responding to climate change in degraded peatland.

Peatlands have garnered increasing attention throughout the international community, with studies reporting on the relationship between peatland and the climate crisis, reducing greenhouse gases using peatland [10–12], and changes in peatland microbial ecosystems with climate change [13]. Given the surge in peatland research, a need exists for the classification of associated peatland research topics such as climate change, greenhouse gases, and microbial ecosystems, etc. Previous studies that sought to achieve this goal applied topic modeling techniques to classify peatland studies by keywords and identify trends based on topic categories. However, Van Bellen and Larivière [14] were unable to efficiently investigate the significance of relationships between topics due to duplication

issues when keywords were designated as topics. These results were improved upon by Yang et al. [15], who applied Dynamic Topic Modeling (DTM) and network analysis to select topics by keyword groups, enabling them to investigate structural properties and changes over time in topics. However, the study used algorithms based on DTM or Latent Dirichlet Allocation (LDA), which limited the authors to consider the context of the studies. Furthermore, concerns were raised regarding duplication caused by the assumption that text contained various topics. To overcome these limitations, the latest techniques must be adopted, assigning a single topic per text and allowing combinations of topics to be analyzed based on the significance between topics.

Topic modeling is an unsupervised machine learning technique applied to determine abstract topics within large-scale text data. To date, various topic modeling methodologies, including LDA and Probabilistic Latent Semantic Analysis (PLSA), have been suggested. However, these methods adopt the Bag of Words (BoW) technique, which is limited by the word order being ignored and sparse representation caused by the large number of words and dimensions in the data [16]. Moreover, semantic relationships between words cannot be investigated using these methodologies as the text context is not considered. In contrast, BERTopic, based on the Bidirectional Encoder Representations from Transformers (BERT), has been increasingly applied since its development in 2018 as it performs natural language processing using embeddings at the text level. BERTopic boasts excellent performance functionality by applying new techniques, such as embeddings and c-TF-IDF, to extract topics based on context. In fact, it reportedly offers superior technological performance compared to LDA and Non-negative Matrix Factorization (NMF) in terms of Normalized Pointwise Mutual Information (NPMI) [17]. Accordingly, BERTopic has received considerable attention from researchers as a deep-learning classifier in the field of natural language processing, with NMF, Corex, Top2Vec, and others [18,19].

This study is conducted to solve the limitations of previous studies by elucidating the significance and relationships between topics in peatland research. To this end, we applied BERTopic to derive topics from all classes via c-TF-IDF-based clustering and identify the hierarchical structure between topics as well as changes in research trends over time. The specific objectives of this study were to investigate (i) how peatland research topics are classified, (ii) changes in the proportion of peatland research topics over time, and (iii) the core peatland research topics, based on an analysis of the relationships between topics and their significance.

2. Materials and Methods

2.1. Research Framework

We used the deep-learning language model BERTopic to classify peatland-related studies and analyze their trends. After searching "peatland" on the academic publication data platform ScienceDirect, we collected the titles and abstracts of peatland-related papers published between 1953 and 2022. After pre-processing, BERTopic was applied to extract peatland-related topics based on the collected data. We then performed hierarchical clustering of 82 topics classified by BERTopic to extract 15 final main topics. The significance of changes in the 15 main topics over time and the relationships between topics was analyzed (Figure 1).
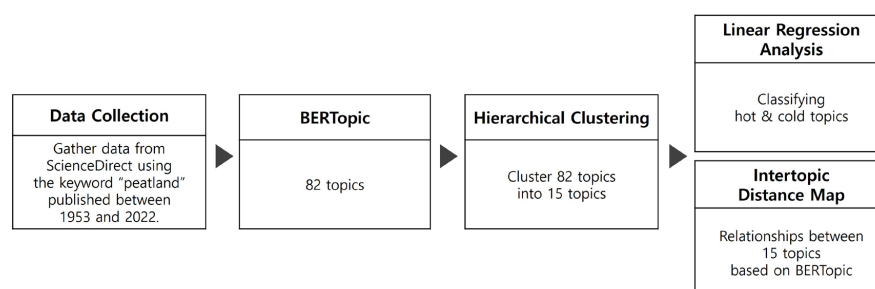

Figure 1. An overall research framework for identifying changes in peatland research trends.

2.2. Data Collection and Pre-Processing

After searching for "peatland" on ScienceDirect, we collected the titles and abstracts of 11,519 papers published between 1953 and 2022. We excluded 1361 papers that were missing an abstract or for which the abstract was "unknown". The remaining 10,158 papers were included in our analysis. The "all-mpnet-based-v2" model from Hugging Face was applied to embed the data. Subsequently, additional pre-processing was performed on the collected data to derive significant results. Using Python 3.11.4, we removed stop words using the stop word package provided by the Python NLTK, as well as verbs, adjectives, adverbs, and specific symbols commonly used in academic writing.

2.3. BERTopic Modeling

BERTopic improves research accuracy by performing NLP via document embedding based on the model published by Google in 2018 [19–21]. BERTopic uses a sentence transformer to construct document embedding, and then it clusters based on density using HDBSCAN (Hierarchical Density-based Spatial Clustering of Applications with Noise) after dimensionality reduction of embedded vectors using UMAP (Uniform Manifold Approximation and Projection) (Figure 2). Meanwhile, c-TF-IDF was used to extract important topics and words for each cluster. BERTopic shows high topic coherence and topic diversity [22]. In particular, unlike previous topic modeling techniques, BERTopic can extract accurate topics while accounting for context [22] and can perform hierarchical clustering based on topic similarity. Accordingly, we applied the functionality of BERTopic to identify the topics constituting global peatland research, investigate how these topics change over time, and analyze the relationships between topics.
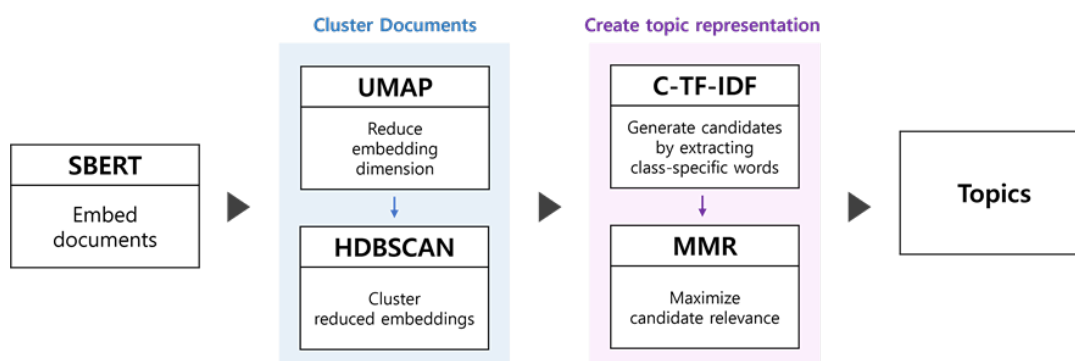

Figure 2. BERTopic algorithm process in which topics are extracted.

We trained a BERTopic model and derived 82 topics. Subsequently, c-TF-IDF was employed to measure the similarity between topics. Via hierarchical clustering, we condensed these 82 topics into 15 main topics, the titles for which were determined based on the top 20 keywords and representative papers for each topic. Additionally, the Python "statsmodel" library was used to perform linear regression analysis and test the significance of annual changes in the 15 main topics. The independent variable was the year of publication, whereas the dependent variables were the number and proportion of each topic. We performed significance testing for the papers published from 2001 to 2022 where all 15 main topics appeared. Using a significance level of 95%, positive (+) regression coefficients were categorized as hot topics that significantly increased over time, while negative (−) regression coefficients were categorized as cold topics that significantly decreased over time. Additionally, we inspected the intertopic distance map using the visualization function to assess the relationships between topics. The intertopic distance map is a visualization of the relationships between topic clusters generated during the modeling process of BERTopic. The distance between the visualized topics on this map indicates the semantic similarity between the topics.

3. Results

3.1. BERTopic Modeling

The 10,158 peatland studies analyzed by BERTopic were classified into 82 topics (Appendix A). After hierarchical clustering based on the similarity between topics (Figure 3), 15 main topics were generated. In the similarity matrix presented in Figure 3, a higher similarity between two topics indicated a closer relationship, causing them to be clustered together. For example, Topic 21 (fire_burned_burning) exhibited the highest similarity with Topic 60 (fire_charcoal_frequency; similarity 0.927) and Topic 61 (fire_wildfire_health; similarity 0.899). This demonstrates the close relationships between these topics; for example, studies investigating fires (fire, burn) on peatland may evaluate the frequency and breath of wildfire spread, the extent of tree burning (charcoal), and effects of smoke generation on health.

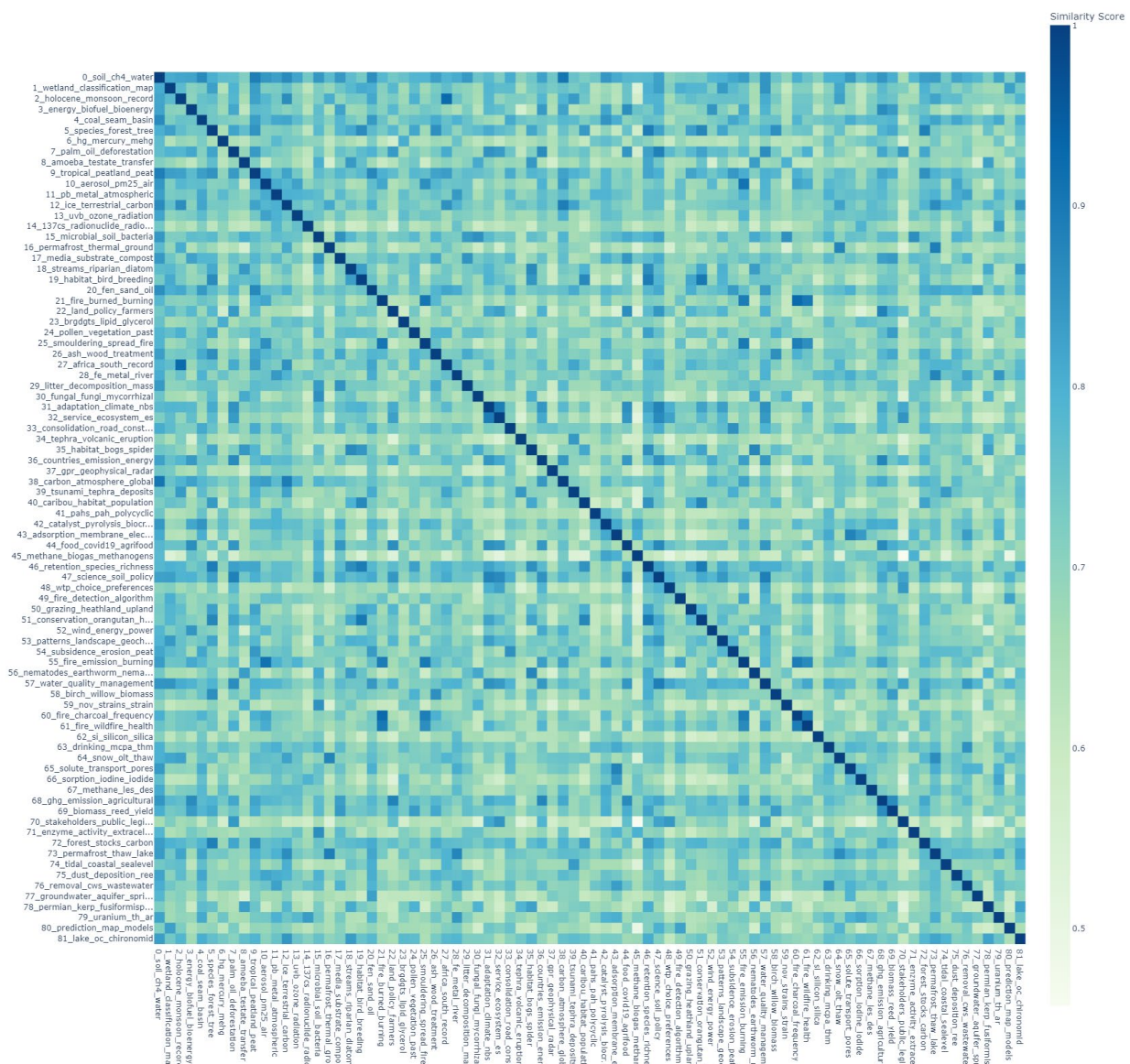**Figure 3.** Similarity matrix between 82 topics. The x and y axes represent 82 topics; the darker the color, the higher the similarity score between topics.

BERTopic can use hierarchical clustering to elucidate the relationships between topics based on their similarity (Figure 4). For example, Topic 21 (fire_burned_burning) and Topic 60 (fire_charcoal_frequency) showed high similarity with Topic 61 (fire_wildfire_health),

causing them to be clustered together. Similarly, Topic 10 (aerosol_pm25_air) was clustered with Topic 55 (fire_emission_burning). The cluster containing Topics 10, 55, 60, 21, 61, and 49 formed one main topic (fire_detection_algorithm). Thus, by exploiting the strengths of BERTopic, hierarchical clustering was performed between highly similar topics, ultimately producing 15 main topics for peatland research.
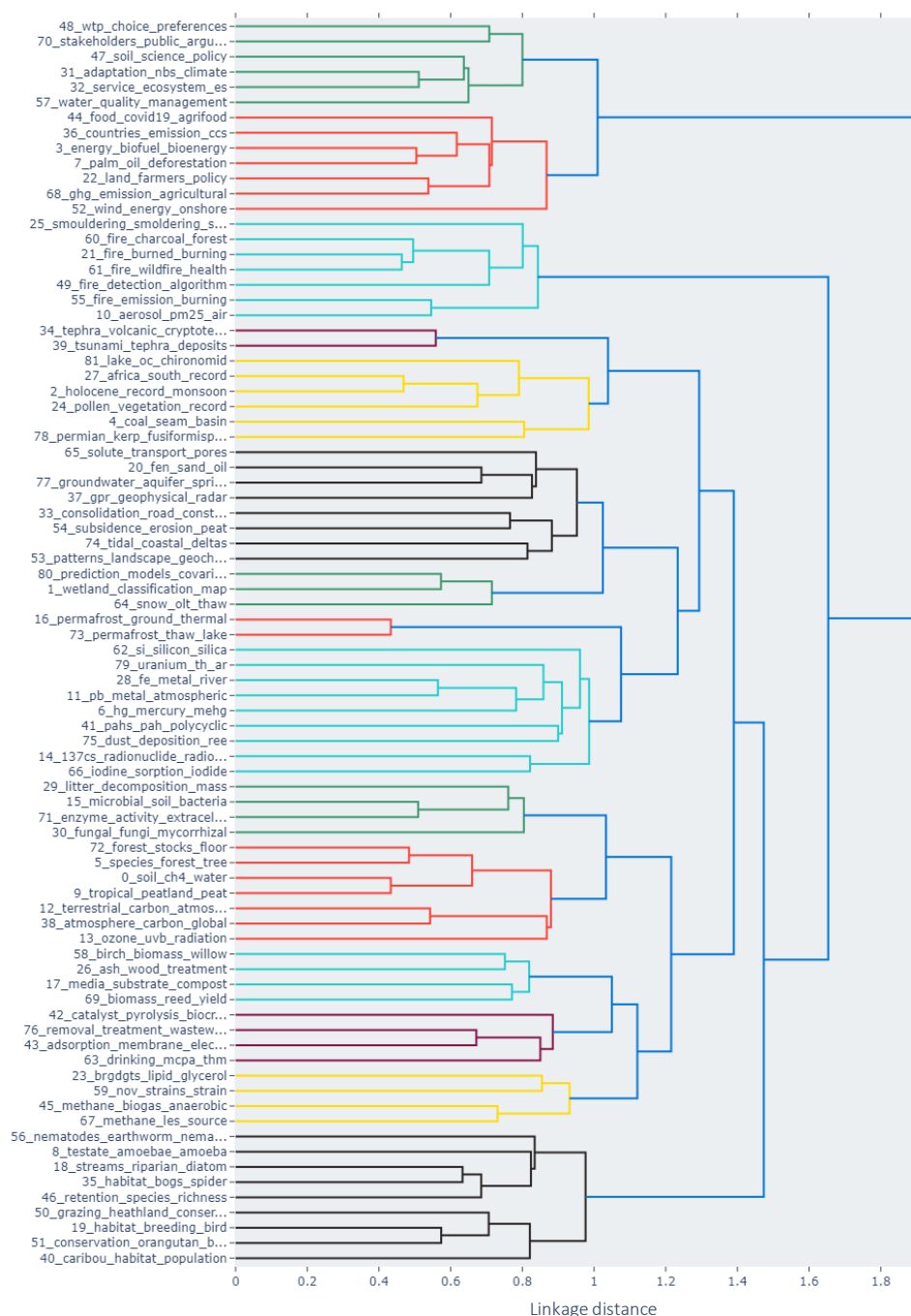
Figure 4. Hierarchical clustering of 82 topics. The linkage distance required to merge two clusters and used to measure inter-cluster similarity. Lower values indicate higher similarity, while higher values indicate greater difference. The color line connecting each other show clustering into highly similarity topics.

The 15 main topics were assigned names based on the top 20 keywords for each topic indicated by BERTopic, and 3 representative papers (Table 1, Figure 5, Appendix B). BERTopic assigns topic numbers to the topics associated with the higher number and

proportion of papers. Topic 1 (carbon dynamic) applied to approximately half of all papers (47.7%), whereas Topic 15 (deposit) applied to only 0.8%. Additionally, the number of papers in all topics is increasing every year (Figure 5).

Table 1. Top 20 keywords with high probability appearing in each topic calculated using BERTopic modeling in peatland research from 1953 to 2022.

No.	Topic 1 Carbon Dynamic	Topic 2 Past Environmental Change	Topic 3 Production	Topic 4 Metal	Topic 5 Management	Topic 6 Microbe	Topic 7 Soil Organic Matter	Topic 8 Surface Fire (Flaming)
1	soil	coal	energy	Hg	service	species	soil	fire
2	water	Holocene	oil	concentration	ecosystem	habitat	microbial	burning
3	carbon	pollen	palm	Pb	policy	amoeba	litter	aerosol
4	wetland	record	emission	mercury	land	testate	enzyme	wildfire
5	peat	climate	production	metal	management	community	activity	forest
6	peatland	vegetation	policy	MeHg	biodiversity	conservation	decomposition	emission
7	forest	region	biofuel	deposition	climate	forest	community	burned
8	CH_4	changes	land	peat	water	population	bacteria	air
9	organic	lake	sustainability	atmospheric	use	diversity	fungal	PM25
10	area	China	use	soil	conservation	area	plant	biomass
11	emission	basin	environmental	elements	environmental	peatland	organic	smoke
12	ecosystem	monsoon	sustainable	sediment	soil	caribou	fungi	soil
13	concentration	sediment	forest	Fe	area	assemblages	effect	area
14	CO_2	Ka	fuel	source	ES	biodiversity	carbon	haze
15	vegetation	peat	bioenergy	river	framework	richness	nutrient	severity
16	effect	seam	food	lake	benefits	abundance	diversity	charcoal
17	plant	conditions	ghg	dust	agricultural	used	increased	health
18	changes	temperature	biodiesel	^{137}Cs	impacts	sites	species	carbon
19	sites	precipitation	development	trace	approach	ecological	treatment	concentration
20	species	climatic	deforestation	Cd	quality	taxa	temperature	region

No.	Topic 9 Hydrology	Topic 10 Global warming	Topic 11 Forest	Topic 12 Peat fire (smoldering)	Topic 13 Biomarker	Topic 14 Permafrost	Topic 15 Deposit
1	groundwater	carbon	ash	smoldering	methane	permafrost	tephra
2	fen	global	growth	peat	lipid	soil	volcanic
3	peat	ozone	biomass	removal	brGDGTs	layer	eruption
4	water	UVB	substrate	spread	bacteria	thaw	tsunami
5	sand	CO_2	growing	fire	temperature	warming	cryptotephra
6	oil	climate	media	water	glycerol	ground	layer
7	soil	emission	wood	treatment	GDGTs	active	record
8	wetland	atmospheric	peat	combustion	branched	temperature	deposits
9	reclamation	terrestrial	treatment	catalyst	source	thermal	volcano
10	region	SI	plant	adsorption	acid	climate	Holocene
11	area	atmosphere	production	wastewater	microbial	ice	ash
12	surface	radiation	nutrient	pyrolysis	sediment	frozen	Ka
13	flow	cycle	compost	content	tetraethers	degradation	sediment
14	peatland	plant	biochar	moisture	production	arctic	island
15	constructed	effect	control	solid	dialkyl	freezing	new

Table 1. *Cont.*

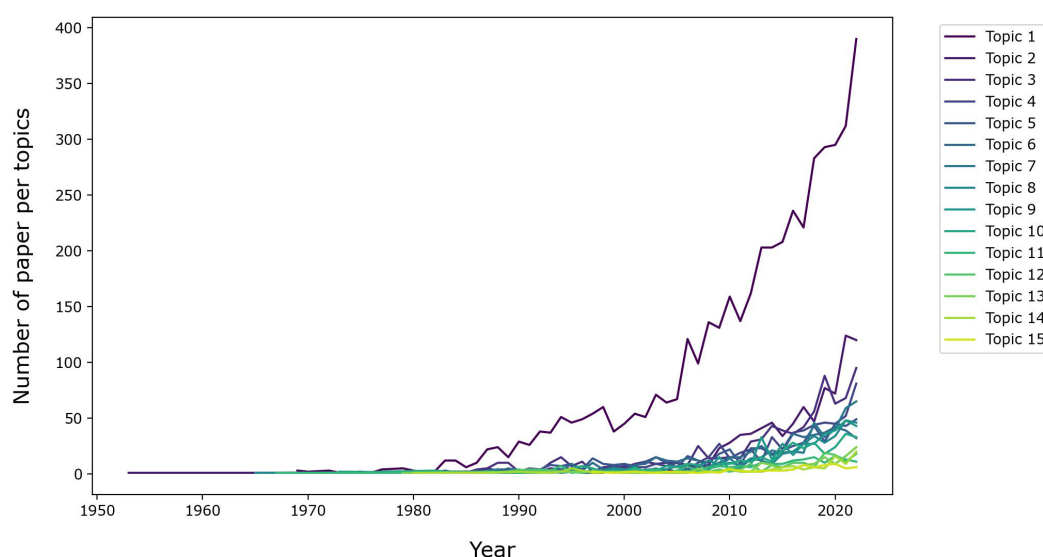| 16	subsidence	changes	effect	using	anaerobic	thermokarst	region
17	concentration	elevated	soil	fuel	soil	thawing	MIS
18	GPR	temperature	birch	ignition	environments	discontinuous	explosive
19	athabasca	O_3	fertilization	organic	distribution	region	age
20	solute	isoprene	seedlings	conditions	archaeal	peat	tephrochronology

Figure 5. Change in number of papers per topic from 1953 to 2022 (*n* = 10,158).

Topic 1 was "carbon dynamic", comprising various carbon dynamics studies that analyzed the flow of carbon. This included studies on regulating the release of CO_2 and CH_4 greenhouse gases through peatland management and rewetting [23], the stability of carbon in tropical peatlands assessed based on the flow and cycling of greenhouse gases [24], and changes in soil organic matter and vegetation with increasing CO_2 concentration due to climate change [25].

Topic 2 was "past environmental change" and included studies on estimating changes in vegetation, climate, and landscape throughout the Holocene based on sedimentary matter records [26–28].

Topic 3 was "production" and included studies on the sustainability of peatlands for production, such as the environmental sustainability of biofuels (biodiesel, biochar, etc.) produced on peatlands and used in palm oil plantations [29], greenhouse gases released during palm oil production [30], and bioenergy production systems [31].

Topic 4 was "metal" and included studies on sedimentary heavy metals in peatlands, focusing on Hg, Pb, 137Cs, and Cd. One such research evaluated changes in the concentration of sedimentary heavy metals from the atmosphere and nearby rivers and lakes over time [32], whereas another research reported changes in the primary productivity of heavy metal sediments [33]. Additionally, the characteristics of heavy metal isotopes in peatland were investigated and compared [34].

Topic 5 was "management" and comprised studies focused on peatland sustainability through suitable management strategies. This included a research on improving air quality and biodiversity via ecological services provided in peatlands [35]. Another research proposed solutions for how to cooperate and resolve conflicts related to the positive benefits of peatlands and the need to increase the profitability of agriculture as the major peatland use [36,37].

Topic 6 was "microbe," comprising studies on the biodiversity, species diversity, and species abundance of microbial communities in peatlands. Others evaluated the potential of testate amoebae as an ecological indicator [38–40].

Topic 7 was "soil organic matter" and included studies on changes in carbon and nitrogen stores at different soil depths due to root addition with climate change [41]. Another evaluated the activity of soil organic matter with pH change [42] and the rate of soil organic matter decomposition by different microbial communities [43].

Peatland fire can be broadly divided into two types [44]: surface fire (flaming), in which flames are visible above the surface and easier to be extinguished, and peat fire (smoldering), referring to the burning of organic matter in peat soil under the surface, hard to detect and producing thicker smoke and haze. Topic 8 was "surface fire (flaming)" and included studies on substances produced during peatland surface fires above the surface (atmospheric pollutants, greenhouse gases, particulate matter, etc.) [45], changes in peat forest vegetation due to fires during the Holocene [46], and the effects on tree species and parts according to fire frequency [47].

Topic 9 was "hydrology" and comprised studies on changes in the underground water level with peatland drying and wetting due to the effects of coastal water, rivers, and lakes [48], hydrological trends and the concentrations of dissolved materials [49], and changes in cation concentrations in underground water based on soil conditions [50].

Topic 10 was "global warming", focusing primarily on changes in ozone concentration, UV-A, and UV-B due to the effects of global warming on peat soil, and how these effects influence greenhouse gas emissions [51–53].

Topic 11 was "forest" and included studies on the tree growth in peatland forests, changes in microbial communities after wood ash fertilization in drained peatland forests [54], changes in tree growth following wood ash fertilization [55], and the effects of these processes [56].

Topic 12 was "peat fire (smoldering)", encompassing peatland fires that burn below the surface and deep surface. This topic primarily included studies on greenhouse gas emissions. For example, one research evaluated the smoke generated in peat fires and the effects of soil moisture content on fire spread [57]. Others reported the effects and physicochemical changes in fires at different soil depths [58] and the effects of smoldering fires on atmospheric oxygen [59].

Topic 13 was "biomarker" and primarily included studies that monitored past environmental changes using lipids extracted from the cell membranes of microbes living in peatland. For example, one research evaluated the changes in the distribution and abundance of Glycerol Dialkyl Glycerol Tetraethers (GDGTs) at different soil depths due to microclimate warming [60,61]. Meanwhile, another assessed seasonal changes in GDGTs [62].

Topic 14 was "permafrost" and comprised studies on the role of peatland in preventing freezing and melting. For example, a research reported on the stabilization and changes in organic carbon in peatland soil located in permafrost [63]. Others assessed the effects of permafrost destruction due to global warming on the structure and function of peatland ecosystems [64], and the characteristics of the permafrost [65].

Topic 15 was "deposit", including studies on the effects of volcanic eruption on the tephra ecosystem [66], the types and composition of sedimentary layers due to volcanic ash deposition in coastal peatlands [67], and the classification of volcanic ash deposited during the Holocene [68].

3.2. Changes in the Number and Proportion of Papers for Each Topic

To analyze the trends in peatland studies over time, we assessed the significance of changes in the number and proportion of papers for each topic. First, considering that topics appear at different times, the same starting publication year was applied throughout to ensure that the order of appearance did significantly affect the proportion. Accordingly, for all 15 main topics, the significance of changes was evaluated based on papers published between 2001 and 2022 (Table 2).

Table 2. Regression coefficients and *p*-values of topic number and proportion over time from 2001 to 2022 (*n* = 9002). 'Hot' indicates topics where the number and proportion changes significantly increase (*p* < 0.05), while 'Cold' represents topics where the number and proportion changes significantly decrease (*p* < 0.05). '-' is not statistically significant.

Topic	Paper Number (2001 to 2022)	Topic Number (Frequency)			Topic Proportion		
		Coefficient	*p*-Value	Hot/Cold	Coefficient	*p*-Value	Hot/Cold
1	4240	16.50706	2.56×10^{-13}	Hot	−0.00683	4.48×10^{-6}	Cold
2	789	3.935065	1.38×10^{-8}	Hot	0.000716	0.363856	-
3	723	4.506502	3.11×10^{-9}	Hot	0.004454	1.39×10^{-5}	Hot
4	468	1.673631	5.38×10^{-8}	Hot	−0.00177	0.005069	Cold
5	505	3.220215	5.18×10^{-8}	Hot	0.002769	7.36×10^{-7}	Hot
6	467	1.61773	2.26×10^{-8}	Hot	−0.00203	0.001801	Cold
7	350	1.80463	7.93×10^{-9}	Hot	0.000443	0.240627	-
8	306	1.847524	5.93×10^{-8}	Hot	0.001644	0.00179	Hot
9	264	1.162055	2.21×10^{-7}	Hot	−0.00026	0.52559	-
10	224	0.721626	3.97×10^{-6}	Hot	−0.0007	0.066037	-
11	172	0.587239	1.53×10^{-8}	Hot	−0.00055	0.025334	Cold
12	155	0.952136	6.33×10^{-6}	Hot	0.000592	0.010549	Hot
13	136	0.68323	9.85×10^{-7}	Hot	0.00019	0.352263	-
14	126	0.81147	3.45×10^{-5}	Hot	0.000443	0.076562	-
15	77	0.361341	2.05×10^{-5}	Hot	−0.00015	0.328624	Normal

We classified topics for which the number of papers increased significantly (*p* < 0.05) over time as hot topics. Of these, Topic 1 (carbon dynamic) showed the largest rate of increase in number, whereas Topic 15 (deposit) exhibited the lowest rate of increase.

An additional four hot topics exhibited a significant increase (*p* < 0.05) in paper proportion over time: Topic 3 (production), Topic 5 (management), Topic 8 (surface fire (flaming)), and Topic 12 (peat fire (smoldering)) (Figure 6a). Conversely, there were four cold topics with a significant decrease in proportion over time (*p* < 0.05): Topic 1 (carbon dynamic), Topic 4 (metal), Topic 6 (microbe), and Topic 11 (forest) (Figure 6b). The proportion of other topics did not exhibit significant trends over time.
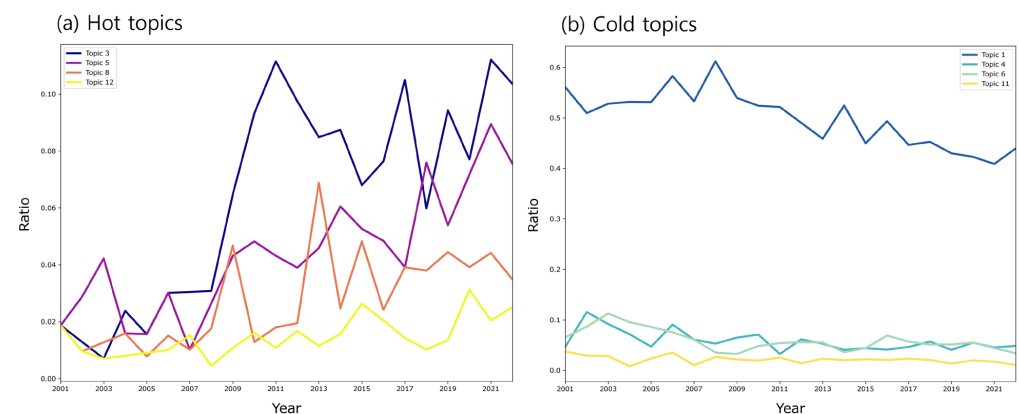

Figure 6. Proportions of topics which significantly (**a**) increased (hot topics) or (**b**) decreased (cold topics) from 2001 to 2022.

3.3. Analysis of Relationships between Topics

A distance map was derived, demonstrating the relationships between the 15 main topics, which were further divided into three groups (Figure 7).
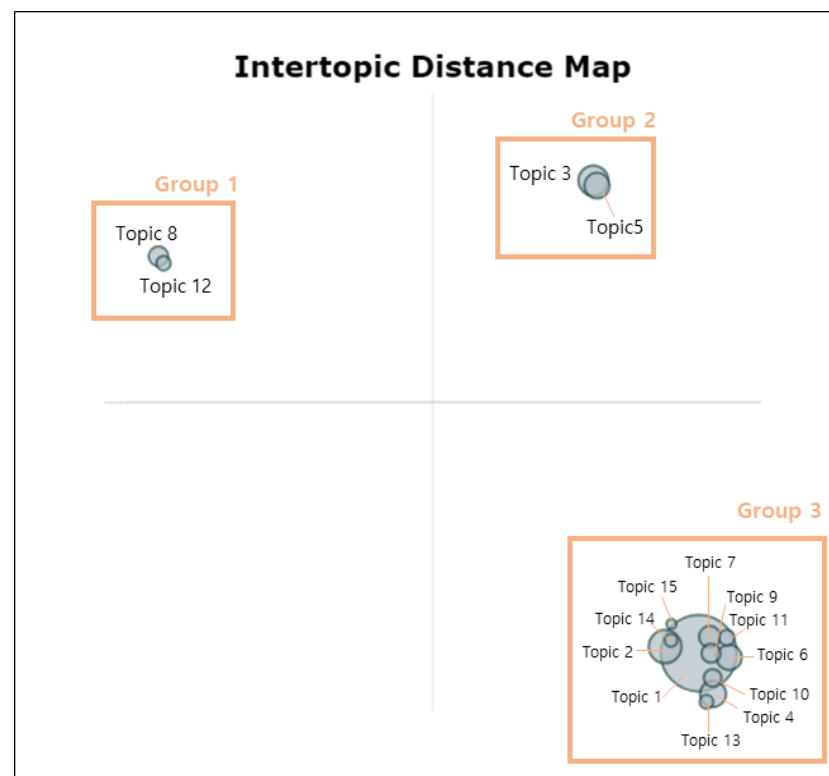
Figure 7. Intertopic distance map of 15 topics. The size of the circles represents the paper number for each topic, and semantically similar topics are positioned in closer proximity to one another.

Group 1 comprised Topics 8 and 12, focused on fires. This group inevitably shows high relatedness, given that the two topics focus on peatland and peat fires, as well as the resulting effects on atmospheric pollution, greenhouse gas emissions, and human health.

Group 2 comprised Topics 3 and 5, focused on the value obtained from peatlands. This group demonstrates the high relatedness between the value and scale of production (e.g., biofuel, bio-oil, bioenergy, etc.) from peatlands that differ depending on how peatlands are managed.

Group 3 was the largest cluster, including Topics 2, 4, 6, 7, 9, 10, 11, 13, 14, and 15, and centered on Topic 1 (carbon dynamic). This group exhibited the highest paper number of the 15 main topics. Semantically, the similarity between topics was higher than in Groups 1 and 2, demonstrating that the other topics were clustered around this topic. Through this, it can be seen that past environmental changes can be inferred based on the cycling of accumulated materials in peatland, and that basic scientific research fields related to peatlands are interconnected with a focus on carbon.

4. Discussion

In this study, we investigated global peatland research trends using BERTopic to analyze 10,158 papers retrieved by searching "peatland" on ScienceDirect. Initially, 82 topics were derived, which were subsequently reclassified into 15 main topics based on hierarchical clustering. The "hot topics" with significantly increased paper proportions over time were Topic 3 (production), Topic 5 (management), Topic 8 (surface fire (flaming)), and Topic 12 (peat fire (smoldering)), related to peatland management, usage, protection, and conservation. Conversely, the cold topics with a decreasing research proportion over time were Topic 1 (carbon dynamic), Topic 4 (metal), Topic 6 (microbe), and Topic 11 (forest), related to the basic ecology, chemistry, and matter cycles of peatlands. This shows that peatland research trends are shifting from basic studies to fields relating to utilization and applications. In previous studies analyzing peatland research trends, van Bellen and Larivière [12] and Yang et al. [13] also reported significant increases over time in keywords

such as management, climate change, restoration, production, and biodiversity. This likely reflects the current circumstances in that the importance and utility of peatland are increasing due to the changes associated with human settlement, including its roles in habitats and its overall utility [69–71].

Upon analysis of the relationships between topics, three groups were divided. By combining the analysis of relatedness with changes in the proportion of papers over time, Topics 3 and 5 (hot topics) formed Group 2, whereas Topics 8 and 12 (hot topics) formed Group 1. Meanwhile, the remaining 11 topics, which were either cold topics or showed no change in paper proportions, formed Group 3. Topics 8 and 12 in Group 1 focused on fires, with the studies evaluating the effects of peat and surface fires, including atmospheric pollution, friction with neighboring countries due to smoke, the release of organic carbon stored in peatland soil in the form of greenhouse gases, and negative effects on human health [45–47,57,58].

Group 2 is particularly important to evaluate as it exhibited the fastest increase in the proportion of papers. This is similar to a report by Yang et al. [15], which not only considers peatland as a target for conservation or development but also emphasizes the importance of sustainable peatland management as a countermeasure to climate change that can mitigate greenhouse gases. Thus, we can conclude that the value and scale of ecosystem services and products (e.g., biofuel, bioenergy, etc.) from peatland may differ based on management, and effective peatland management is important to improve peatland productivity and sustainable use [29–31,35–37].

Topic 1 (carbon dynamic), which is the center of Group 3, had the highest number and proportion of papers from 1953 to 2022. Although this topic exhibited an annual increase in the raw number of papers, the proportion of total papers showed a decreasing trend. This result shows that other topics such as Topic 3, 5, 8, and 12 than Topic 1 are increasing over time. Based on the keywords and research content for Topic 1, overall, this topic is related to the basic flow of carbon within peatlands. Moreover, Topics 2, 4, 6, 7, 9, 10, 11, 13, 14, and 15 are centered on Topic 1, indicating that the circulation of accumulated materials in peatland and the associated basic science studies focus on carbon. This supports previous reports that peatland is closely related to carbon [1,72–74]. In fact, the United Nations Framework Convention on Climate Change (UNFCCC) and the Convention on Wetlands (Ramsar Convention) advised that peatlands should be included in Nationally Determined Contributions (NDCs); accordingly, countries with peatlands are adopting these guidelines as a means of achieving their target NDC [3,10,12,75–77]. However, before expecting all countries with peatlands to implement these practices, given the different characteristics of each country and region, it will first be important to precisely ascertain and map the global peatland area [3].

Although previous studies on peatland research trends simply analyzed the keywords that received the most attention [14] or the structural relationships between topics using network analysis [15], the current study performed hierarchical clustering based on similarities between global peatland studies, deriving 15 main topics that were arranged into three groups by analyzing the relationships between topics. Additionally, the significance of these findings has been discussed. In particular, although several studies have previously highlighted that the topics of fire and carbon are inseparable from peatlands in global research [78–81], this was supported through the results of this study.

Most topic modeling techniques are limited by the nature of unsupervised learning in that the modeling results differ depending on the algorithms used and hyperparameter tuning. To overcome these limitations, we performed several rounds of BERTopic hyperparameter tuning and interpreted the results based on the learning capabilities of the researchers, including the contents of each topic and the naming of topics. Nevertheless, one limitation of this study is that BERTopic assumes that each text only corresponds to a single topic, thus restricting the consideration of multiple topics. To overcome this, the development and supplementation of new topic modeling techniques, the combined use of topic modeling techniques, and improvements in the review capacity of peatland research

experts will be necessary. Moreover, based on our findings, further research is warranted to fully explore the composition of the fire-related topics (Topics 8 and 12), which are important in peatland research, as well as to differentiate the characteristics of peatland soil types in different regions.

5. Conclusions

In this study, we used BERTopic, a recent topic modeling technique, to analyze relatedness between topics, with the aim of classifying global peatland research trends into topics, examining the change in topics over time, and identifying core themes in peatland research trends and their significance. We classified global peatland research trends into 15 main topics and observed an overall increase in research related to production, management, and fire. When we analyzed the relationships between topics, three groups were divided, focusing on fire, peatland value, and carbon. Through these research results, we anticipate that, in the future, our findings can be expanded to analyze trends in research related to fires in peatlands, regional peat soil properties, the prediction of greenhouse gases emission and mitigation due to peatland fires, and the prediction of future peatland research topics, among others.

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Data Availability Statement: Publicly available datasets were analyzed in this study. These data can be found here: https://www.sciencedirect.com/ (accessed on 4 May 2023).

Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A. The Name of 82 Topics

No.	Topic Name	No.	Topic Name
1	soil_ch4_water	42	pahs_pah_polycyclic
2	wetland_classification_map	43	catalyst_pyrolysis_biocrude
3	holocene_monsoon_record	44	adsorption_membrane_electrocoagulation
4	energy_biofuel_bioenergy	45	food_covid19_agrifood
5	coal_seam_basin	46	methane_biogas_methanogens
6	species_forest_tree	47	retention_species_richness
7	hg_mercury_mehg	48	science_soil_policy
8	palm_oil_deforestation	49	wtp_choice_preferences
9	amoeba_testate_transfer	50	fire_detection_algorithm
10	tropical_peatland_peat	51	grazing_heathland_upland
11	aerosol_pm25_air	52	conservation_orngutan_habitat
12	pb_metal_atmospheric	53	wind_energy_power
13	ice_terrestrial_carbon	54	patterns_landscape_geochemistry
14	uvb_ozone_radiation	55	subsidence_erosion_peat
15	137cs_radionuclide_radiocaesium	56	fire_emission_burning

No.	Topic Name	No.	Topic Name
16	microbial_soil_bacteria	57	nematodes_earthworm_nematode
17	permafrost_thermal_ground	58	water_quality_management
18	media_substrate_compost	59	birch_willow_biomass
19	streams_riparian_diatom	60	nov_strains_strain
20	habitat_bird_breeding	61	fire_charcoal_frequency
21	fen_sand_oil	62	fire_wildfire_health
22	fire_burned_burning	63	si_silicon_silica
23	land_policy_farmers	64	drinking_mcpa_thm
24	brgdgts_lipid_glycerol	65	snow_olt_thaw
25	pollen_vegetation_past	66	solute_transport_pores
26	smouldering_spread_fire	67	sorption_iodine_iodide
27	ash_wood_treatment	68	methane_les_des
28	africa_south_record	69	ghg_emission_agricultural
29	fe_metal_river	70	biomass_reed_yield
30	litter_decomposition_mass	71	stakeholders_public_legitimacy
31	fungal_fungi_mycorrhizal	72	enzyme_activity_extracellular
32	adaptation_climate_nbs	73	forest_stocks_carbon
33	service_ecosystem_es	74	permafrost_thaw_lake
34	consolidation_road_construction	75	tidal_coastal_sealevel
35	tephra_volcanic_eruption	76	dust_deposition_ree
36	habitat_bogs_spider	77	removal_cws_wastewater
37	countries_emission_energy	78	groundwater_aquifer_springs
38	gpr_geophysical_radar	79	permian_kerp_fusiformisporites
39	carbon_atmosphere_global	80	uranium_th_ar
40	tsunami_tephra_deposits	81	prediction_map_models
41	caribou_habitat_population	82	lake_oc_chironomid

* The 82 topic names were automatically combining the top 3 keywords named by Python.

Appendix B. Number and Proportion of Papers Classified by Topic from 1953 to 2022 (n = 10,158)
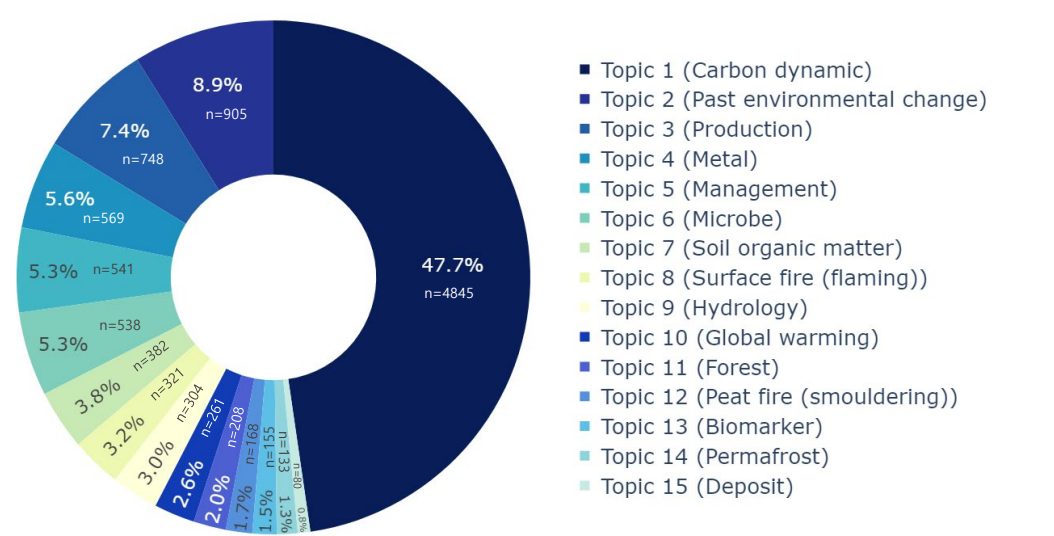
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