Discover Sustainability

Research

Sustainability in the arctic: a bibliometric analysis

Fatma Ahmed[1] · **Oscar Zapata**[1] · **Greg Poelzer**[1]

Received: 18 March 2024 / Accepted: 10 June 2024
Published online: 20 June 2024

Abstract
This paper examines the literature on the Sustainability in the Arctic region, using a bibliometric analysis of 213 English-language articles published between 1980 and 2022 exploiting Bibliometrix, an R package. To find relevant literature using the Web of Science (WOS) database, we searched for documents using mesh terms based on the query of two terms, "Arctic & Sustainability". We used the Boolean operator "AND" to combine the two terms and the Boolean operator "OR" to include synonyms of the terms. The articles retrieved were authored by 724 researchers, published in 98 journals, representing 132 countries, and growing at 5.08% annually. The findings reveal that a substantial portion of the Arctic sustainability literature placed significant emphasis on the examination of climate change, adaptation, and vulnerabilities affecting local communities. Furthermore, the more recent publications in this field concentrate predominantly on exploring perceptions and governance.

Keywords Arctic · Sustainability · Climate Change · Bibliometric Analysis

1 Introduction

The Arctic region has faces multiple challenges climate change, sustainable resource extraction, community infrastructure, transportation development, and environmental degradation [1–3, 7]. These challenges place increasing pressure on the ecological and social sustainability of the Arctic and its inhabitants. As per the GLOBIO Report commissioned by the United Nations Environment Programme, projections indicate that a substantial portion of the Arctic, ranging from 50 to 80%, may encounter significant anthropogenic disruptions by the year 2050. This alarming trend is anticipated to occur even with relatively moderate levels of economic expansion [4]. Given the challenges confronting the Arctic, it is important to take stock of region, progress on sustainability research in the Arctic to understand the trajectory of Arctic research as a basis for further analysis of the potential policy gaps not addressed by current research. This paper aims are modest in scope and provides a first step. It is essential to conduct a bibliometric analysis of the existing literature and synthesize the main findings, as this can help to reveal the current knowledge and challenges of Arctic sustainability, as well as the basis for future assessment of possible recommendations for research priorities to address the urgent challenges facing the Arctic. In particular, a bibliometric analysis can identify the most overlooked or under-studied aspects of sustainability research in the Arctic region.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s43621-024-00312-4.

✉ Fatma Ahmed, fatma.ahmed@usask.ca; Oscar Zapata, oscar.zapata@usask.ca; Greg Poelzer, greg.poelzer@usask.ca | [1]School of Environment and Sustainability, University of Saskatchewan, Saskatoon, Canada.

A bibliometric analysis offers a valuable analytical technique for mapping existing literature concerning a specific research theme broadly used as a trend assessment tool [5]. Bibliometric analysis is a computer-aided scientific review method that uses statistics to analyze the bibliometric publications data such as peer-reviewed journal articles, books, conference proceedings, periodicals, reviews, reports, and related documents [6]. The approach offers robust analytics to facilitate research retrospection, identify the research gaps and assess the publication's evaluation in from different perspectives quantitatively and qualitative [61]. Bibliometric analysis can help researchers map the existing literature on a specific research theme and evaluate the academic quality and impact of journals or authors [8]. By using bibliometric tools, researchers can also explore the connections between authors, frameworks, methodology, and practice [9]. Furthermore, by applying diverse research methodology using Bibliometrics tools in R such as, Top Cited Publications, Co-occurrence, Co-authorship, word frequency, etc., researchers can assess and evaluate scientific research trends, a research topic and determine the relative importance of publications [10]. Bibliometrics provides a holistic perspective of a particular field, including its organizational aspects and notable features such as trends, influential authors and publications, and emerging ideas. Moreover, it serves as a valuable resource for researchers, directing them towards particular domains and specialized research prospects with potential for advancement [9, 11, 62].

Several studies have applied bibliometric analysis to various topics, such as the United Nations sustainable Development Goals (SDGs) [12], political connections [5], Sustainability reporting [8], and artificial intelligence in sustainable development [13]. However, there is a lack of bibliometric studies on sustainability in the Arctic, which is an important and emerging area of research. Therefore, this study aims to fill this gap by conducting the first bibliometric analysis of sustainability in the Arctic based on the Web of Science database from 1980 to 2022. The specific objectives of this analysis are: (1) to identify the growth, publication, and citation trends of sustainability research in the Arctic over time; (2) to rank the most productive and influential countries, journals, authors, institutions and (3) to visualize the most frequently used keywords and the conceptual structure of sustainability research in the Arctic using word-cloud and co-word network methods. This analysis will provide a comprehensive overview and insight into the current state and future directions of sustainability research in the Arctic for the scientific community and policy makers.

2 Methodology

This paper examines the literature on the Sustainability in the Arctic region, using a bibliometric analysis of 213 English-language articles published between 1980 and 2022 exploiting Bibliometrix, an R package. Bibliometrix is an R package for comprehensive science mapping analysis of scientific publications. It provides various functions for importing, analyzing, and visualizing bibliographic data from different sources.

2.1 Research design

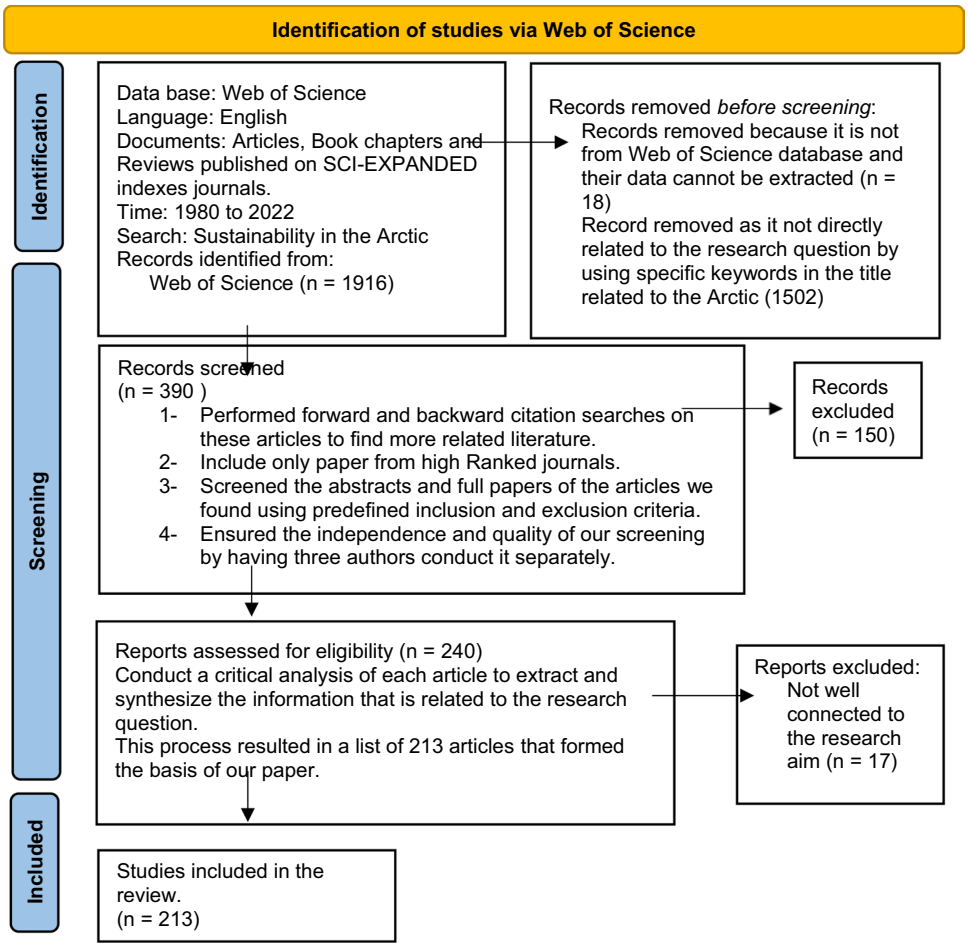
For our literature review, we opted to use the Web of Science database as our source of articles. Previous research [14–16] has demonstrated the numerous benefits of utilizing this database for bibliometric analysis. Adriaanse & Rensleigh [14] found that the Web of Science database provides a more comprehensive range of journals in the social sciences and humanities compared to Scopus and Google Scholar, particularly for older publications. The database also utilizes clear and consistent criteria for selecting and indexing articles, ensuring that the literature's quality and relevance is of high standard. Additionally, the Web of Science database is more user-friendly and flexible than other databases, such as Scopus and Google Scholar, allowing for easier searching, filtering, sorting, and exporting of data. This allows for accurate and reliable citation analysis and bibliometric research, with little to no data cleaning required [7]. Furthermore, Birkle et al. [15] and Mengist et al. [16] also acknowledged that the Web of Science database offers selective and balanced coverage of the world's leading research journals, books, proceedings, and data sets. This is based on expert evaluation and quality criteria, making it a suitable database for conducting a bibliometric analysis of literature on sustainability in the Arctic. Therefore, we believe that utilizing the Web of Science database for our literature review will provide us with high-quality, reliable, and relevant information on this topic.

2.2 Search strategy

The study utilized the Web of Science database as our primary data source. We searched for articles in English language that addressed the topic of sustainability in the Arctic, including articles, book chapters, and reviews published

on SCI-EXPANDED indexed journals. We depend on specific criteria to filter the relevant articles that met our research objectives. Firstly, we used mesh terms based on the query of "Arctic & Sustainability," and we combined the terms using the Boolean operator "AND" and "OR" to include synonyms of the terms. Secondly, the articles had to mention a term related to sustainability in their titles, such as sustainability, climate change, poverty, health, SDG'S or any relevant topic. Thirdly, the articles had to mention a term related to the Arctic in their titles, such as Arctic, North Pole, polar region, circumpolar, or boreal, etc. Fourthly, the articles had to meet our research objectives and provide adequate research perspective, as verified by reading the full text of each article.

We followed a rigorous and transparent search strategy to select the relevant articles following [63–66] as presented in PRISMA flow diagram. We started by retrieving 1910 articles from various disciplines and time periods using the Web of Science database. We then filtered out articles that were not relevant or of high quality for our study using two criteria. The first criterion was selecting articles published in Q1 or Q2 ranked journals by the Journal Citation Reports from 1980 to 2022, which indicated their academic excellence and impact. The second criterion was selecting articles that had a clear focus on the Arctic region, which we determined by checking if their title included a term related to the Arctic. We then performed a citation analysis to identify the most pertinent articles for our research aim and question, using forward and backward citation searches. This allowed us to capture the most influential and recent literature on our topic.



Next, we screened the articles based on their abstracts and keywords to ensure they addressed aspects of sustainability in the Arctic that were relevant to our research question. Three authors independently reviewed the abstracts of the articles, and we agreed on their inclusion or exclusion. Lastly, we conducted bibliometric and critical analysis using Bibliometrix in R to extract and synthesize information that answered our research question, resulting in a list of 213 articles that formed the basis of our paper.

3 Results

This paper performs a bibliometric analysis of the existing literature on the topic of sustainability in the Arctic region. The objective of this review is to explore and evaluate the research that has been done and identify the main contributors, topics, trends, and challenges that emerge in the literature on this issue.

Bibliometrics is gaining popularity across different fields, especially for science mapping. Science mapping helps organize the vast amount of research being produced, but it's complicated and requires various software tools, some of which aren't free. We exploit a new open-source tool called bibliometrix has been created to simplify science mapping analyses. It's programmed in R, making it flexible and easy to update, which is crucial in a field that's always changing like bibliometrics [5, 17].

We searched for relevant documents in various sources, such as academic journals, books, conference proceedings, and review articles, using keywords that relate to sustainability and the Arctic region. We selected 213 documents that were published between 1980 and 2022 and that satisfied our inclusion criteria based on their relevance and quality. Using descriptive statistics, bibliometric analysis with R software and content analysis techniques, we extracted and analyzed data from these documents. The data covered information on the documents themselves, such as their publication dates, sources, citations, references, and document types; the contents of the documents, such as their keywords; and the authors of the documents, such as their number of authors, single-authored documents, co-authors per document, and international co-authorships and the full abstract. This review offers a comprehensive overview of the current state of knowledge on sustainability in the Arctic region and identifies the gaps and opportunities for future research on this topic.

The document types of the selected documents reflect the diversity and complexity of the literature on sustainability in the Arctic. The most common document type is article, with 142 documents (70.9% of the sample), followed by review, with 51 documents (24.2% of the sample). Articles are original research papers that report new findings and contribute to the advancement of knowledge on a specific topic. Reviews are critical evaluations of the existing literature on a topic, synthesizing and summarizing the main issues, debates, and gaps. Other document types include editorial material, book chapter, book review, letter, proceedings paper, and early access. Editorial material consists of introductions, prefaces, or comments by editors or guest editors of journals or special issues.

3.1 Top cited publications

Table 1 displays the most cited papers with at least 100 citations in the last 40 years from 1980 to 2022. The top five most cited papers are [18–22] with 1053, 673, 515, 493 and 445 citations respectively. Remarkably, four of these papers are related to climate change and its environmental impacts. Hinzman et al. [18] examined the evidence and consequences of recent climate change in arctic terrestrial ecosystems. Similarly, McGuire et al. [19] assessed the status of the current carbon cycle of the Arctic and its vulnerability to climate change. Furthermore, Wassmann et al. [20] analysed the evidence of how climate change has already caused noticeable changes in marine Arctic ecosystems while Stroeve et al. [22] explored the changes and trends in the Arctic melt season and their implications for sea ice loss. However, Armitage et al. [21] investigated the role of knowledge co-production as an institutional factor or mechanism to facilitate learning and adaptation in co-management arrangements in the Canadian Arctic. The result indicates that the research on the environmental aspect of sustainability in the Arctic is extensive.

3.2 Research production and trend topics over years

This section describes the data from the paper sample and gives a preliminary overview of the literature on sustainability in the Arctic. Figure 1 shows the trend of publications over time, from 1980 to 2022. The number of papers on sustainability in the Arctic increased until it reached a peak of 25 publications in 2012 and then started to decline. The reasons for this decline are not self-evident. In 2018, the number of publications began to rise again and remained stable until 2020, when the COVID-19 pandemic affected the world and possibly disrupted the production of sustainability research in the Arctic that relies on field data. As a result, only 5 papers were published in 2021. However, the number seems to recover in 2022. The first papers in the sample focused on human adaptation to Arctic zones

Table 1 The Most Cited papers

Authors	Journal	Year	Total citations	Average per year
Hinzman, et al. [18]	Climatic Change	2005	1053	55.42
Mcguire, et al. [19]	Ecological Monographs	2009	673	44.87
Wassmann, et al. [20]	Global Change Biology	2011	515	39.62
Armitage, et al. [21]	Global Environmental Change-Human And Policy Dimensions	2011	493	37.92
Stroeve, et al. [22]	Geophysical Research Letters	2014	445	44.5
Ford, et al. [23]	Global Environmental Change-Human And Policy Dimensions	2006	295	16.39
Eugster, et al. [24]	Global Change Biology	2000	294	12.25
Moritz, et al. [25]	Science	2002	282	12.82
Stohl, et al. [26]	Atmospheric Chemistry And Physics	2013	249	22.64
Cameron [27]	Global Environmental Change-Human And Policy Dimensions	2012	229	19.08
Comiso and Hall [28]	Wiley Interdisciplinary Reviews-Climate Change	2014	214	21.4
Willox, et al. [29]	Social Science & Medicine	2012	200	16.67
Forbes, et al. [30]	Proceedings Of The National Academy Of Sciences Of The United States Of America	2009	187	12.47
Mistry and Berardi [31]	Science	2016	185	23.13
Bjerregaard, et al. [32]	Scandinavian Journal Of Public Health	2004	185	9.25
Callaghan, et al. [33]	Ambio	2004	159	7.95
Pearce, et al. [34]	Polar Research	2009	156	10.4
Huet, et al. [35]	Journal Of Nutrition	2012	142	11.83
Farre, et al. [36]	Polar Geography	2014	135	13.5
Ford, et al. [37]	Geographical Journal	2008	135	8.44
Bronen and Chapin [38]	Proceedings Of The National Academy Of Sciences Of The United States Of America	2013	133	12.09
Loring and Gerlach [39]	Environmental Science & Policy	2009	129	8.6
Ford, and Pearce [40]	Environmental Research Letters	2010	128	9.14
Chan, et al. [41]	International Journal Of Circumpolar Health	2006	126	7
Ford, et al. [42]	Arctic	2007	122	7.18
Chapin, et al. [43]	Ambio	2004	122	6.1
Descamps, et al. [44]	Global Change Biology	2017	118	16.86
Willox, et al. [45]	Qualitative Research	2013	116	10.55
Stephenson, et al. [46]	Climatic Change	2013	113	10.27
Ford, et al. [47]	Global Environmental Change-Human And Policy Dimensions	2010	112	8
Chapin, et al. [48]	Proceedings Of The National Academy Of Sciences Of The United States Of America	2006	109	6.06
Willox, et al. [49]	Climatic Change	2013	108	9.82
Gearheard, et al. [50]	Climatic Change	2010	105	7.5
Wenzel [51]	Polar Research	2009	105	7
Caine, and Krogman [52]	Organization & Environment	2010	101	7.21
Durkalec, et al. [53]	Social Science & Medicine	2015	100	11.11
Marino [54]	Global Environmental Change-Human And Policy Dimensions	2012	100	8.33

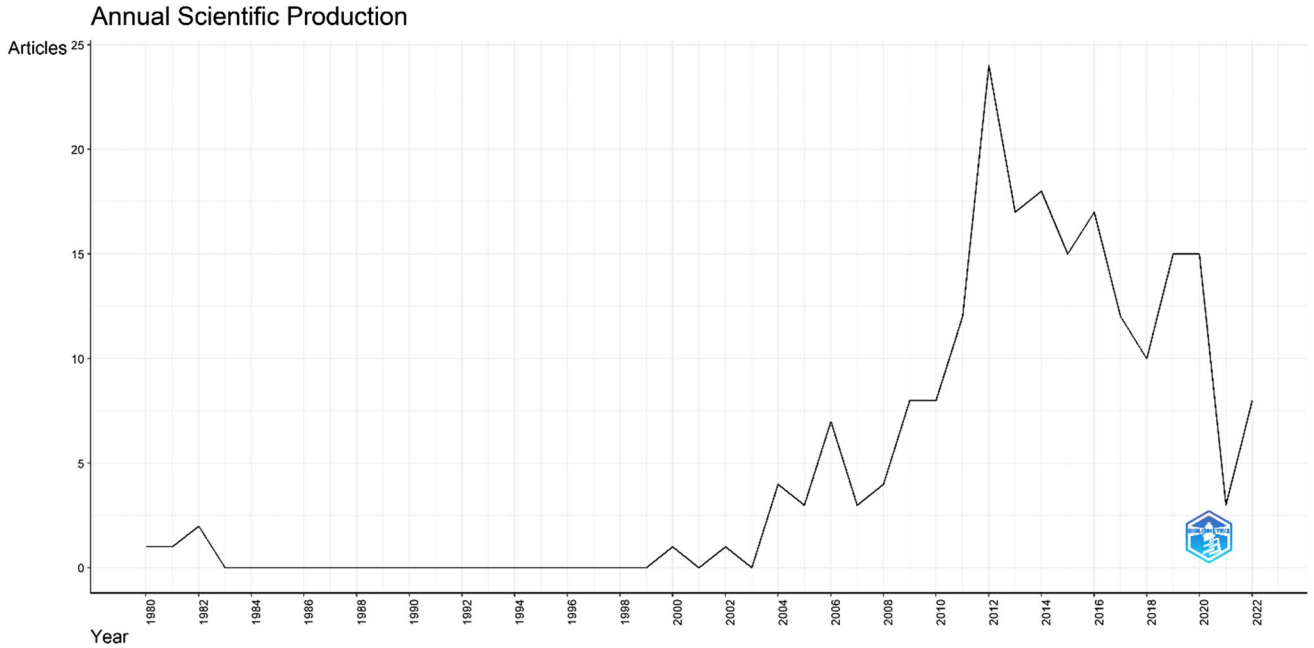


Fig. 1 Annual Scientific Production

[55, 56]. Interestingly, the close connection between social and environmental issues is not new, as Lewis & Thomas [57] examined the social, political, and economic aspects of expanding subarctic agriculture in Alaska and its implications for sustainability, such as land use conflicts, environmental degradation, food security, rural development, and energy consumption.

3.3 Trends topic over time

To investigate the evaluation and the trends of the sustainability topics in the Arctic over years, the study exploited R bibliometrix software to analyses the abstracts, references, sources and all the data extracted of all the 213 papers

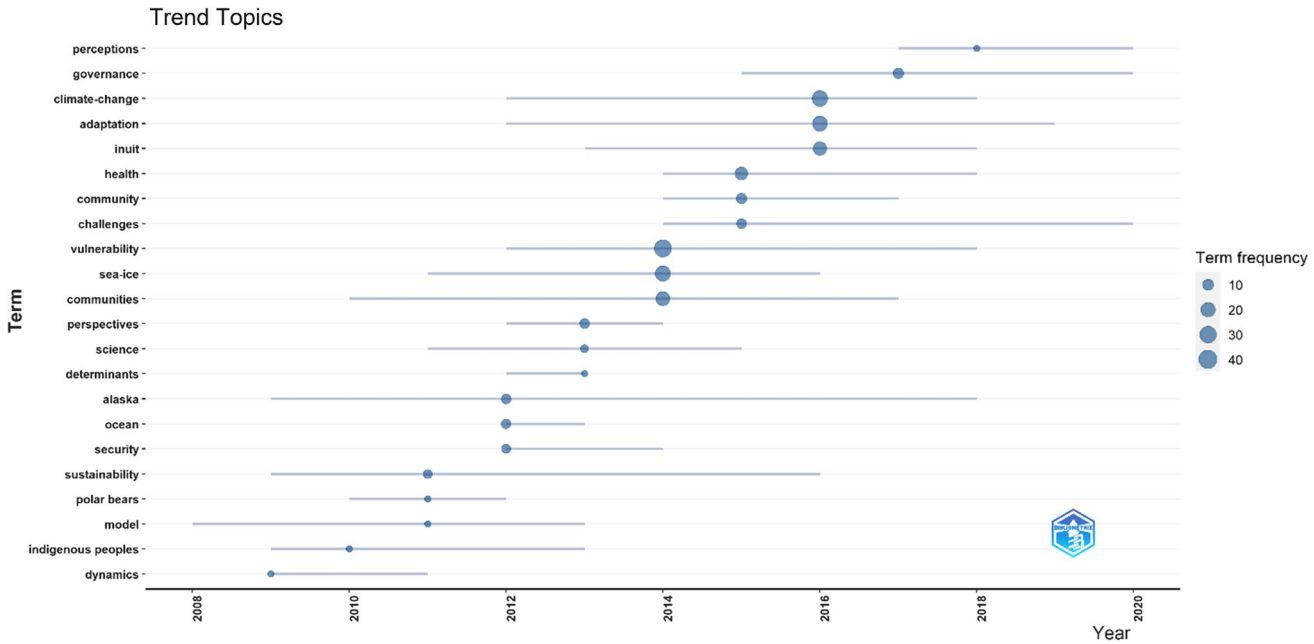


Fig. 2 Trend topics on Sustainability in the Arctic

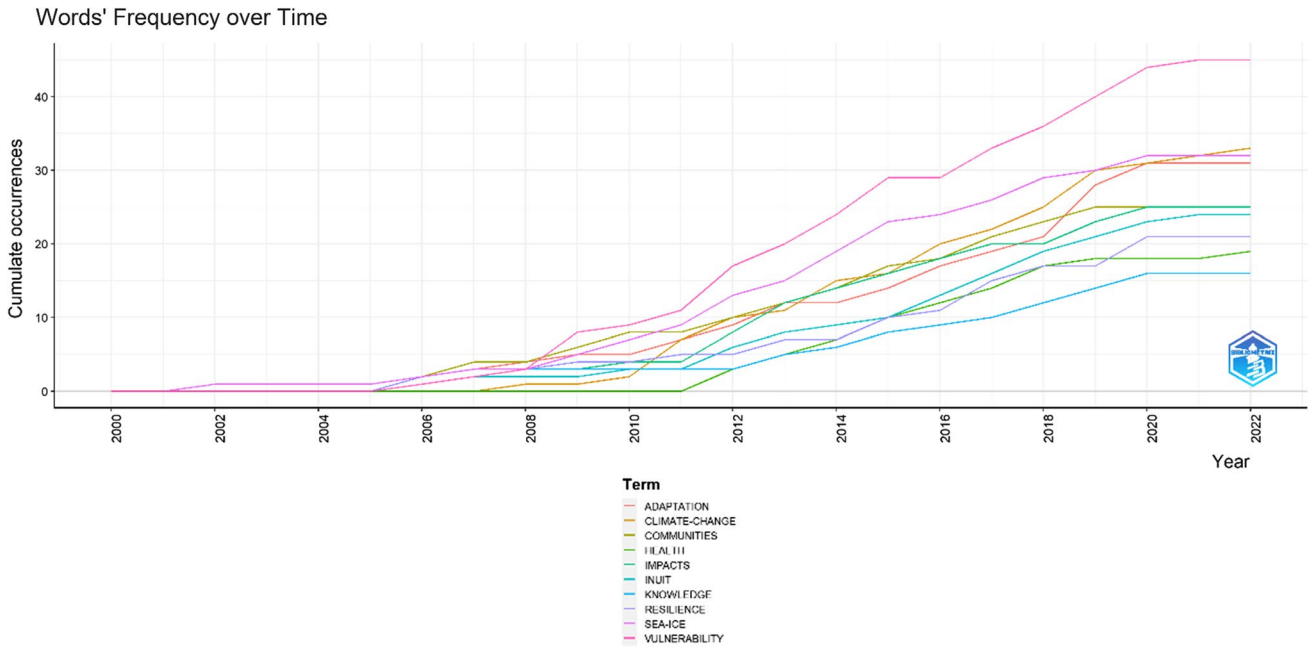


Fig. 3 Word frequency over time related to Sustainability in the Arctic

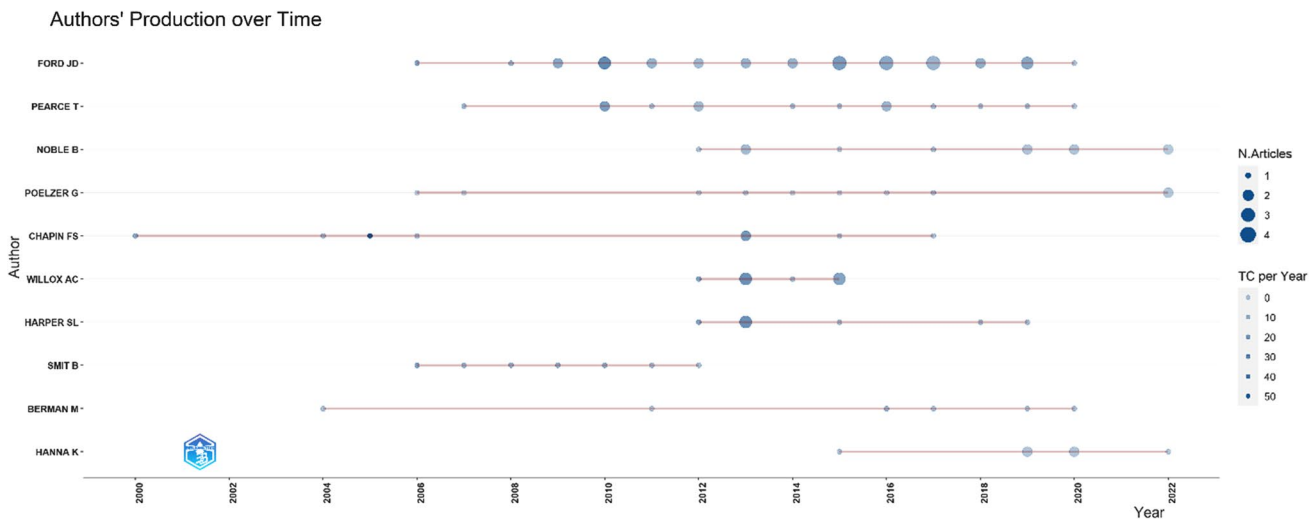


Fig. 4 Authors production over Time

and correlate the topics. The results in Fig. 2 show that the Arctic sustainability literature from 2014 to 2018 heavily investigated climate change, adaptation, and vulnerabilities for the communities. Additionally, the most recent literature focus on perceptions and governance.

3.4 Word frequency over time

There is an increase in the word frequency for all the terms starting from 2004 to 2022 highlighting the evaluation of the sustainability literature over years. As shown in Fig. 3 the term vulnerability is the most influential term whose frequency increased dramatically over the years, followed by sea ice.

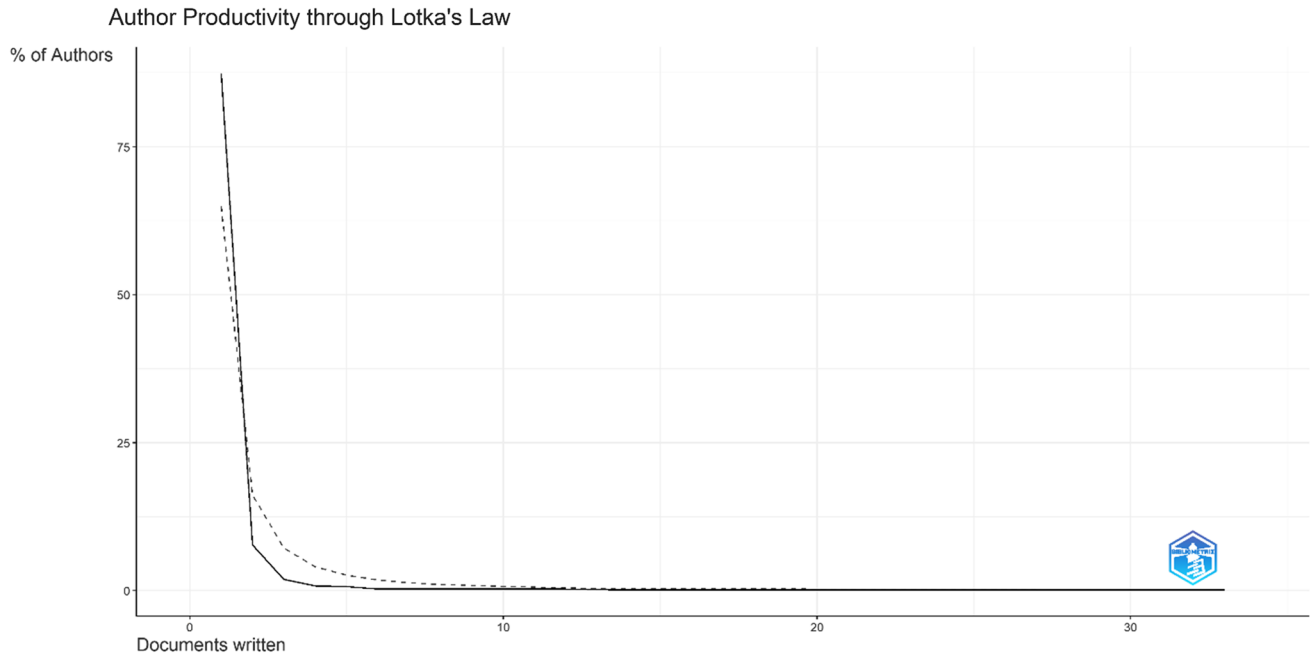


Fig. 5 Authors productivity through Lotka's Law on Sustainability in the Arctic

Table 2 Authors productivity through Lotka's Law on Sustainability in the Arctic

Documents written	N. of Authors	Proportion of Authors	Expected
1	633	0.874	0.72
2	56	0.077	0.19
3	14	0.019	0.08
4	6	0.008	0.04
5	5	0.007	0.03
6	2	0.003	0.02
7	2	0.003	0.01
8	2	0.003	0.01
12	2	0.003	0
14	1	0.001	0
33	1	0.001	0

3.5 Productive and influential authors

The bibliometrix analysis of the most effective authors in the sustainability field in the Arctic shows how many articles each researcher has published from 1980 to 2022. For example, Fig. 4 shows the frequency and citation impact of academic papers written by different authors in different years. The figure shows that Ford has contributed with 37 papers used in this study about sustanability in the Arctic between 2006 and 2020, followed by Pearce, with 12 papers between 2007 and 2020. The author with the highest total citations is Chapin who received 1,869 citations for eight papers only between 2000 and 2017, followed by Ford who has 1,839 citations for 37 papers between 2006 and 2020.

To identify the most influntial authors in sustainbility in the Arctic, we use Bibliometrix on R to produce a graph that shows the frequency of publication by authors in studing the sustainability in the Arctic to explain the productivity of the authors using Lotka's Law as showen in Fig. 5. Lotka's law is a formula that shows how many authors publish how many papers in a specific field.

It calculates the fraction of authors who publish n papers is 1/n^a times the fraction of authors who publish one paper. The graph compares the real (black line) and the predicted (fitted line) fractions. For instance, 0.874 means that

almost 9 out of 10 authors publish one paper only which is a little bit higher that the expected value of Lotka's law. All the results are reported in Table 2. However, 0.077 means that less than 1 out of 100 authors publish two papers, indicating a low level of expertise among most authors. Only a few authors, such as Ford, Pearce, Noble and Poelzer, have published several papers and can be considered as experienced researchers in studing sustainabilty in the Arctic.

3.6 Co-authorship network

The analysis of the co-authorship network shows how different researchers work together to write research about Sustainiabilty in the Arctic. The researchers are represented by circles with their names. The circles have different colors and sizes. The colors show which researchers work with each other more often than with others. The sizes show which researchers are more important and influential in the network. The lines between the circles show how many articles the researchers have written together. The more lines, the more articles. The information helps us understand the patterns and levels of collaboration among the researchers in Arctic studies. The graph shows the collaboration network between the researchers based on their co-authorship of articles. The data was analyzed using bibliometrics in R and depends in four measures of centrality: cluster, betweenness, closeness, and PageRank, that extracted from the data and used to generate the graph. Cluster indicates the group of nodes that are more connected to each other than to other nodes. Betweenness measures how often a node acts as a bridge between other nodes. Closeness measures how easily a node can reach other nodes. PageRank measures how important a node is based on the number and quality of its connections.

The results in Fig. 6 shows that James Ford is the most central and influential node in the network, with the highest values of betweenness and PageRank. He belongs to cluster 5, which also includes Pearce, Smit, and Willox. They are the second most connected group after cluster 2, which consists of Noble and Poelzer. Cluster 2 has the highest values of closeness, indicating that they can access other nodes quickly. Cluster 4 includes Forbes, Huntington, and Walker. They have moderate values of centrality, except for Walker who has a high betweenness. The graph suggests that there are different patterns and levels of collaboration among the researchers in Arctic studies, and that some researchers play more prominent and bridging roles than others.

3.7 Most active sources

Figure 7 to illustrate the main journals that publish on sustainability in the Arctic. The journals were ranked according to the g-index, which is a measure of the citation impact of a set of articles. The g-index is defined as the largest number g such that the top g articles in the set have received at least g^2 citations in total. As Fig. 7 shows, the most influential journals in this field are The Journal of Climatic Change, Arctic Journal, Global Environmental Change:

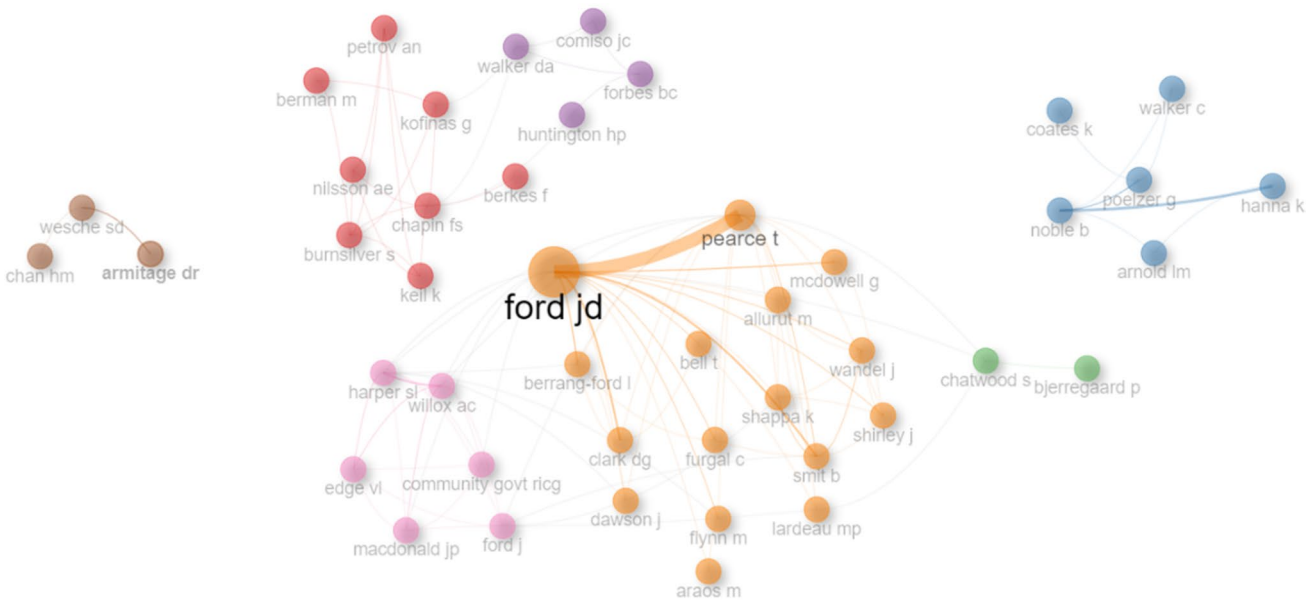


Fig. 6 Co-authorship Network

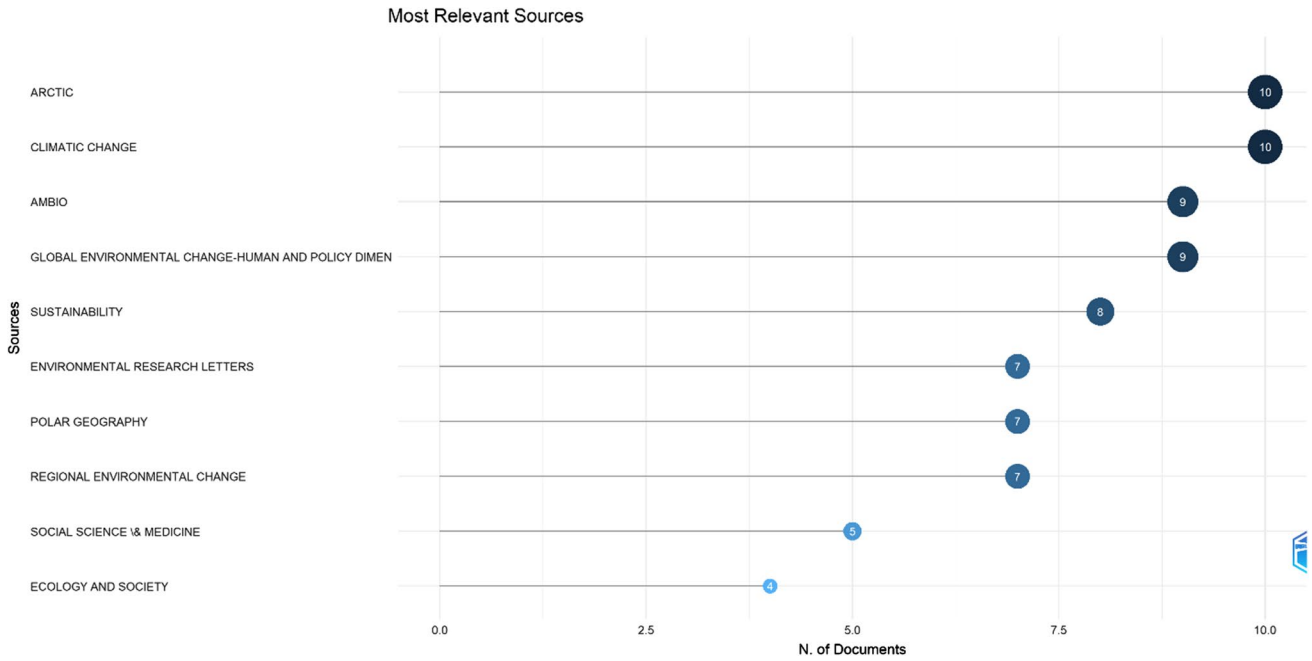


Fig. 7 Relevant Sources

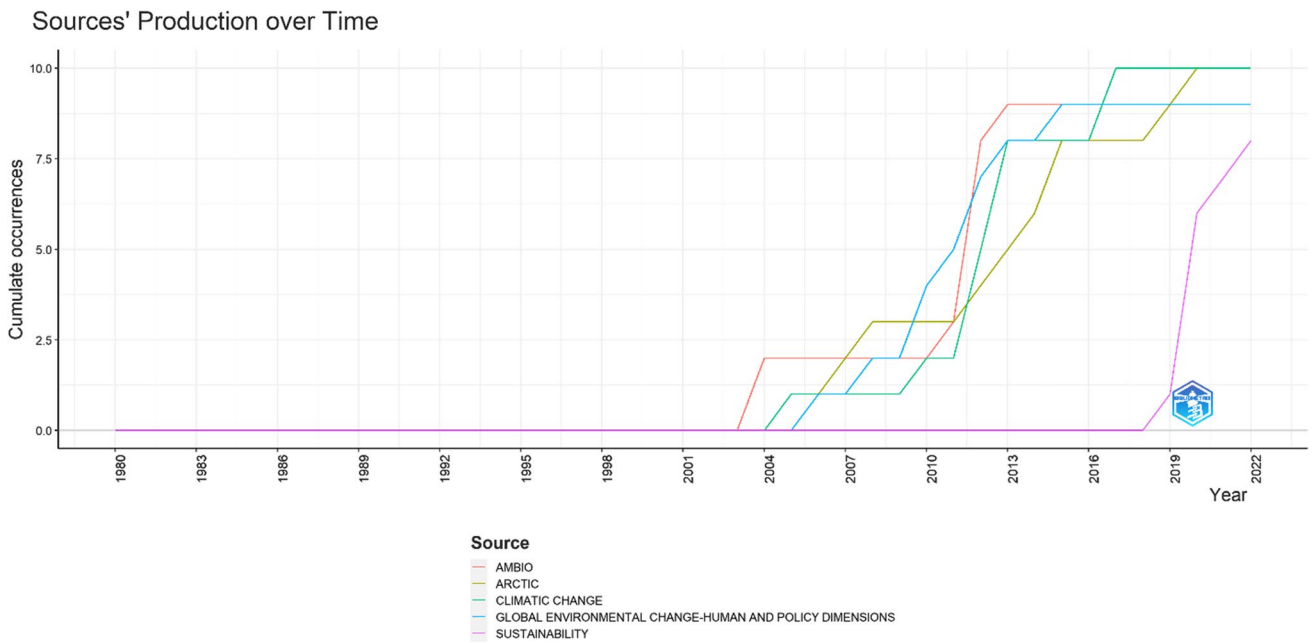


Fig. 8 Sources production on sustainability in the Arctic over time

Human and Policy Dimensions and Ambio, with 10, 10, 9 and 9 articles respectively. These journals also have high Journal Citation Report (JCR) impact factors, which are 1.36, 0.50, 1.66 and 3.15 respectively. Figure 8 also reveals that many journals cover environmental issues from various angles and scopes.

Figure 8 shows the yearly journal production of publications over time, from 1980 to 2022. It calculates yearly cumulative occurrences of top keywords/terms. The general trend is increasing over time, but especially for the Journal of Climatic Change and Global Environmental Change. Interestingly, Sustainability journal focus on sustainability in the Arctic topics started to increase and continued to surge from 2019 onward.

3.8 Countries contributions

Scientific collaboration is important because it helps scientists improve their work, make new discoveries, and share their findings with the world [10]. When one scientist works alone, they can make mistakes or miss a key piece of information that could change their entire approach to a problem. By working with others, they can benefit from different perspectives, expertise, and resources.

Scientific collaboration also enables scientists to tackle complex and global challenges that require cross-disciplinary and cross-sector approaches, such as COVID-19, climate change, biodiversity loss, food security, and future health crises [58]. Scientific collaboration can also foster peace and progress by bringing together warring nations, rebuilding cooperation, and reaching scientific excellence.

Figure 9 shows a world map with the countries that have published papers on sustainability in the Arctic. The countries are colored according to their frequency of publications, with darker colors indicating higher frequencies and lighter colors indicating lower frequencies. The graph also shows the exact frequency for each country as a number next to the country name. The graph shows that Canada has the highest frequency of publications, with 415 papers, followed by the USA with 241 papers. Figure 10 shows that the UK is the third most frequent country, with 51 papers. Norway and Finland are the next two countries, with 46 and 40 papers respectively. Russia, Sweden, Denmark, Australia and Germany are the last five countries in the graph, with frequencies ranging from 34 to 10 papers (Fig. 10).

Table 3 shows the total citations (TC) and the average article citations per year for the top 7 countries that have published papers on sustainability in the Arctic. The table is sorted in descending order of total citations. The table shows that Canada has the highest total citations, with 5142 citations, followed by the USA with 4634 citations. Norway is the third country with the highest total citations, with 1123 citations. The United Kingdom and Finland are the next two countries, with 832 and 418 citations respectively. Sweden, and Switzerland are the last two countries in the table, with total citations 313 and 301 respectivly. The table also shows that Switzerland has the highest average article citations per year, with 150.5 citations per year, followed by Norway with 112 citations per year.

Moreover, graph (10) is a scientific collaboration map shows the frequency of scientific collaboration between researchers from different countries, based on the co-authorship of research papers. The map shows the connections between cities or countries where researchers work together on scientific projects. The thickness or color of the lines indicates the strength or frequency of the collaboration. For example, Canada and the USA have the highest frequency of collaboration (15), followed by Canada and the UK (8), and Finland and Russia (10). The most connected countries are Canada, Finland,

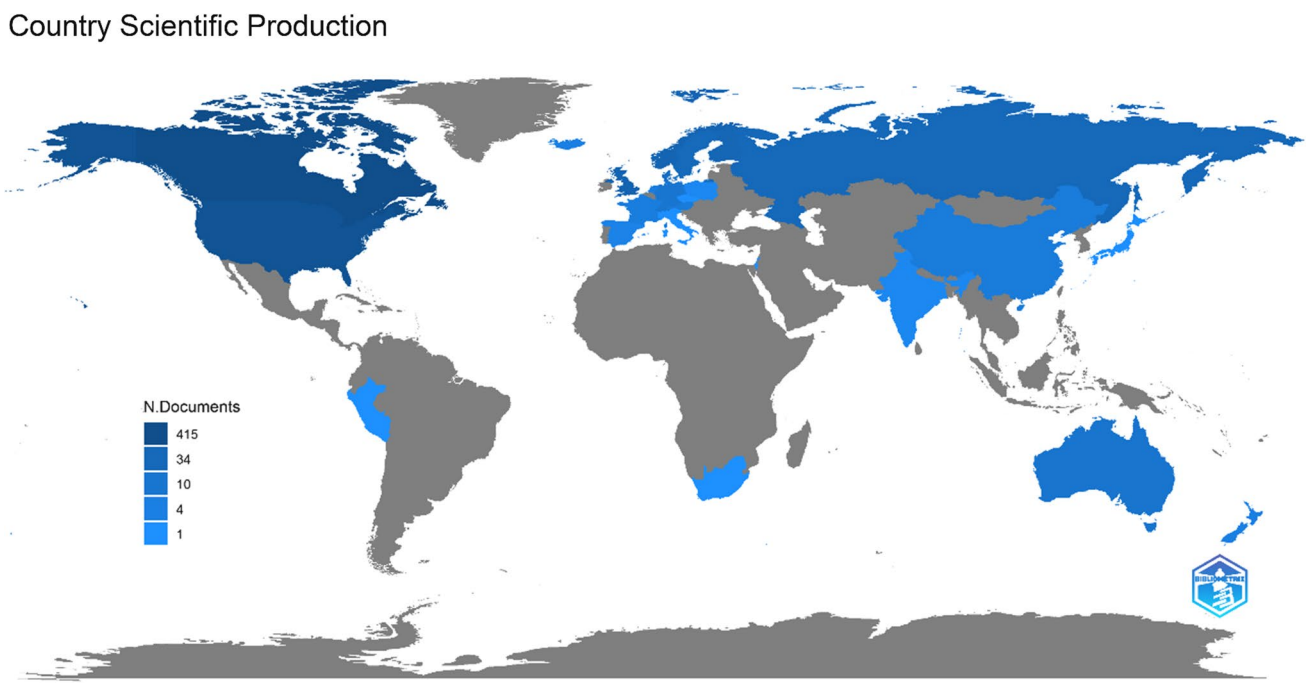


Fig. 9 Countries' Production on sustainability in the Arctic

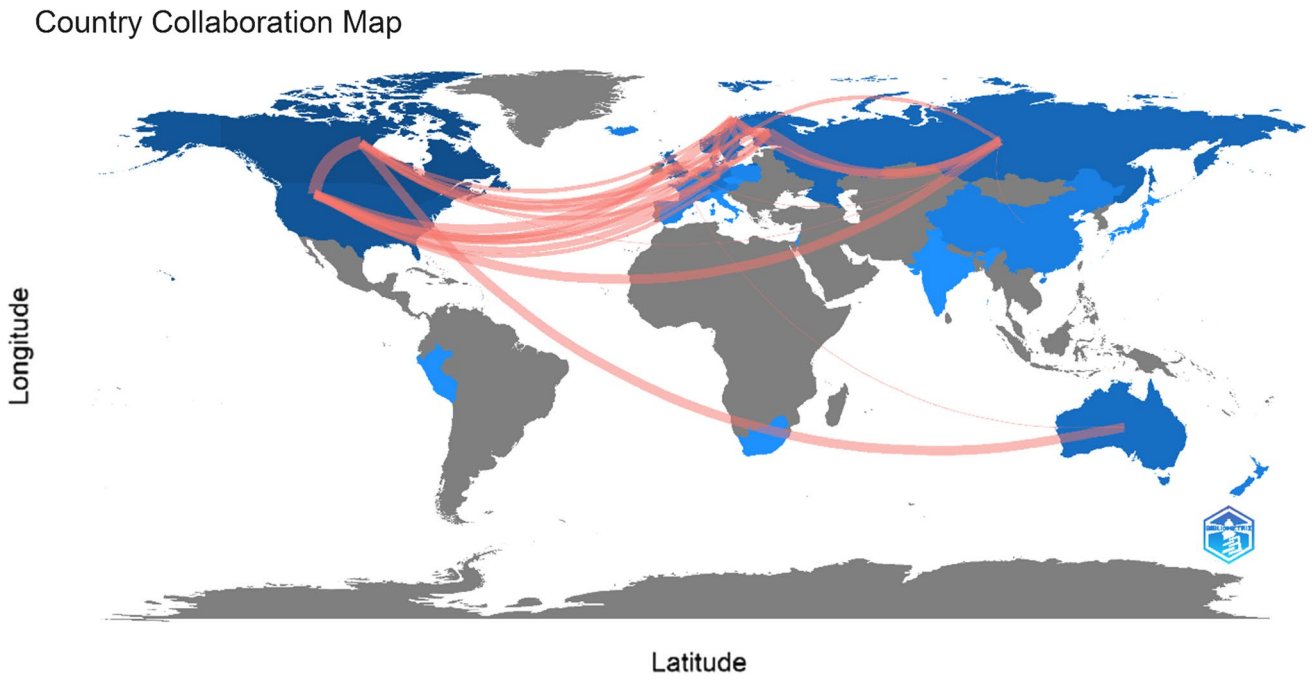


Fig. 10 Countries' Collaboration Map on sustainability in the Arctic

Norway, Russia, Sweden and the USA, as they have more than 40 collaborations each. The least connected countries are Austria, China, France, Iceland, Poland and Spain, as they have less than 10 collaborations each.

3.9 Institutions contributions

Additionally, fig. 11 shows the number of articles published by four universities about sustainability in the Arctic from 1980 to 2022. The graph reveals the trends and patterns of research output over time for each university. The graph

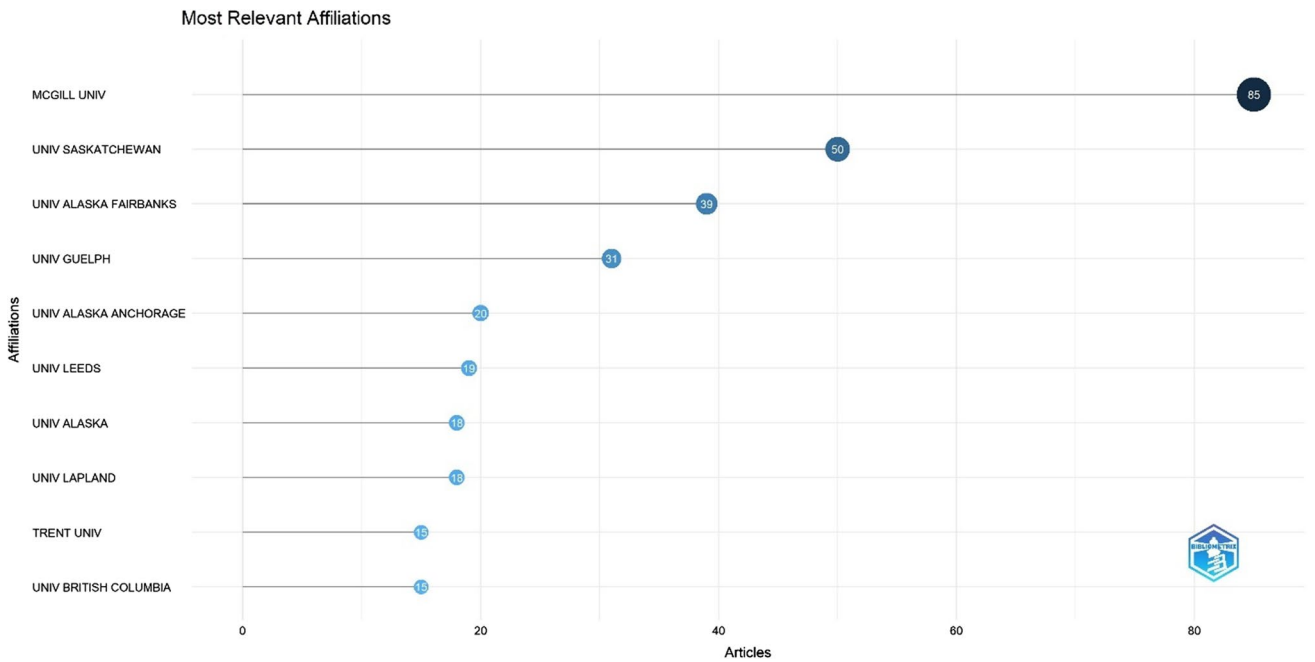


Fig. 11 Institution-Based Co-Authorship Analysis on Sustainability in the Arctic

Table 3 Total and Average Citation Per Country

Country	TC	Average article citations per year
Canada	5142	51.40
USA	4634	92.70
Norway	1123	112.30
United Kingdom	832	52.00
Finland	418	46.40
Sweden	313	44.70
Switzerland	301	150.50

indicates that Mcgill University had the most consistent and rapid growth in the number of articles, reaching 85 in 2020 and maintaining that level until 2022. University of Alaska Fairbanks also showed a steady increase in the number of articles, reaching 36 in 2022. University of Saskatchewan had a slower but steady growth, reaching 48 in 2022. University of Guelph had a more fluctuating pattern, with a peak of 31 in 2018 and no change since then. The results suggests that there are different factors and strategies influencing the research productivity and focus of each university in Arctic studies.

3.10 Co-word analysis

One of the methods to analyze complex networks is to measure the centrality of nodes, which reflects how important or influential they are in the network structure. There are different types of centrality metrics, such as betweenness, closeness, and PageRank, that capture different aspects of node importance.

Previous research has employed co-word analysis to define the content of a particular field. Co-word analysis helps map the knowledge structure and dynamics of a research topic by illustrating the frequency and strength of association between keywords [59]. It also identifies research gaps, emerging issues, and future directions within a field [9], visualizing the knowledge structure and underlying forces of a research field through graphs, maps, or diagrams [60]. Keywords with high betweenness values connect many other keywords and clusters, while those with high PageRank values frequently co-occur with other keywords and clusters. Additionally, keywords with high closeness values are closely linked to many other keywords and clusters.

Table 4 shows the values of these metrics for some nodes in a network related to sustainability research. The nodes represent keywords or topics, and the edges represent co-occurrences or citations between them. The table also shows the cluster that each node belongs to, which indicates a group of nodes that are more densely connected to each other than to the rest of the network. By comparing the values of the centrality metrics, we can identify some patterns and insights about the network. For example, we can see that sea-ice has the highest betweenness centrality, which means that it lies on many shortest paths between other nodes and can act as a bridge or a bottleneck in the network. We can also see that vulnerability has the highest closeness centrality, which means that it has the shortest average distance to all other nodes and can reach them quickly. Moreover, we can see that PageRank centrality is correlated with cluster membership, as nodes in cluster 3 have much higher values than nodes in clusters 1 and 2. This suggests that cluster 3 is more influential and authoritative in the network, as it receives more links from other nodes. These centrality metrics can help us understand the roles and relationships of nodes in complex networks and reveal some key features of the network topology.

Figure 12 shows in deatails the Co-occurrences of the words, the blue cluster consists of 14 nodes that are related to various aspects of the physical environment and its changes, such as sea-ice, ocean, variability, change impacts, etc. These nodes have moderate values of betweenness and closeness centrality, which means that they are somewhat important or influential in the network. They also have some edges to cluster 3, which indicates that they have some connections or interactions with the social and human dimensions of climate change research. However, these nodes have low values of PageRank centrality, which means that they are not very authoritative or influential in the network. They receive fewer links from other nodes than cluster 3, which suggests that they are less cited or referenced in the literature. The green cluster consists of 19 nodes that are related to various aspects of the social and human dimensions of climate change research, such as vulnerability, adaptation, communities, health, knowledge, etc. These nodes have high values of betweenness, closeness, and centrality, which means that they are very important or influential in the

Table 4 Metrics for Some Nodes in a Network Related to Sustainability Research

Node	Cluster	Betweenness	Closeness	PageRank
Science	1	8.182078439	0.010869565	0.009759923
Policy	1	0.2	0.008264463	0.005830011
Sea-Ice	2	221.6083581	0.015873016	0.061555808
Nunavut	2	11.17593695	0.013333333	0.030439683
Alaska	2	0.535418376	0.011904762	0.016393439
Ocean	2	0.562000007	0.00952381	0.006821297
Capacity	2	0.52636614	0.011764706	0.014380344
Security	2	0.125088842	0.011363636	0.010779525
Systems	2	0.075967597	0.011363636	0.009422828
Beaufort Sea	2	2.497684084	0.011627907	0.012980174
Sustainability	2	0.034188034	0.010204082	0.007199526
Traditional Ecological Knowledge	2	0.992662454	0.011235955	0.011144199
Variability	2	0	0.01010101	0.006645308
Change Impacts	2	0	0.010526316	0.007244977
Igloolik	2	0	0.011363636	0.011579607
Polar Bears	2	0	0.009259259	0.005111579
Vulnerability	3	197.619859	0.016949153	0.088882246
Climate-Change	3	91.71555083	0.015384615	0.053575407
Adaptation	3	58.65377666	0.015151515	0.066550372
Communities	3	85.37801877	0.015151515	0.058218377
Impacts	3	43.04634373	0.014492754	0.045887398
Inuit	3	26.79749908	0.013888889	0.043950535
Resilience	3	18.83230853	0.01369863	0.042935366
Health	3	18.68684207	0.01369863	0.032512076
Knowledge	3	39.41448483	0.013157895	0.032496712
Management	3	14.23989004	0.0125	0.021928913
Adaptive Capacity	3	15.27200131	0.013333333	0.029776458
Canada	3	2.300884289	0.010989011	0.014314003
Framework	3	3.076860261	0.012048193	0.026405365
Community	3	0.343149756	0.012048193	0.016454964
Governance	3	39.12773785	0.012658228	0.021891008
Ice	3	0.095400305	0.011235955	0.014955316
Future	3	2.7396199	0.010989011	0.010126903
Human Dimensions	3	3.258386735	0.012195122	0.022883233
Fresh-Water	3	0.105600412	0.011111111	0.010086068
Risks	3	0.654080389	0.010989011	0.012939109
Determinants	3	0.304588887	0.010526316	0.010136559
Energy	3	0	0.01	0.007434442
Indigenous Health	3	0.068965517	0.01010101	0.007319605
Challenges	4	24.17040036	0.011235955	0.016636628
Perceptions	4	0.153846154	0.00877193	0.005920946
Perspectives	5	2.499780503	0.011627907	0.012661761
Dimensions	5	2.043701691	0.010752688	0.011134131
Human	5	0.42166624	0.011363636	0.010922506
Indigenous Peoples	5	0.177216298	0.01	0.006589631
Climate	6	45.28579064	0.00990099	0.010904606

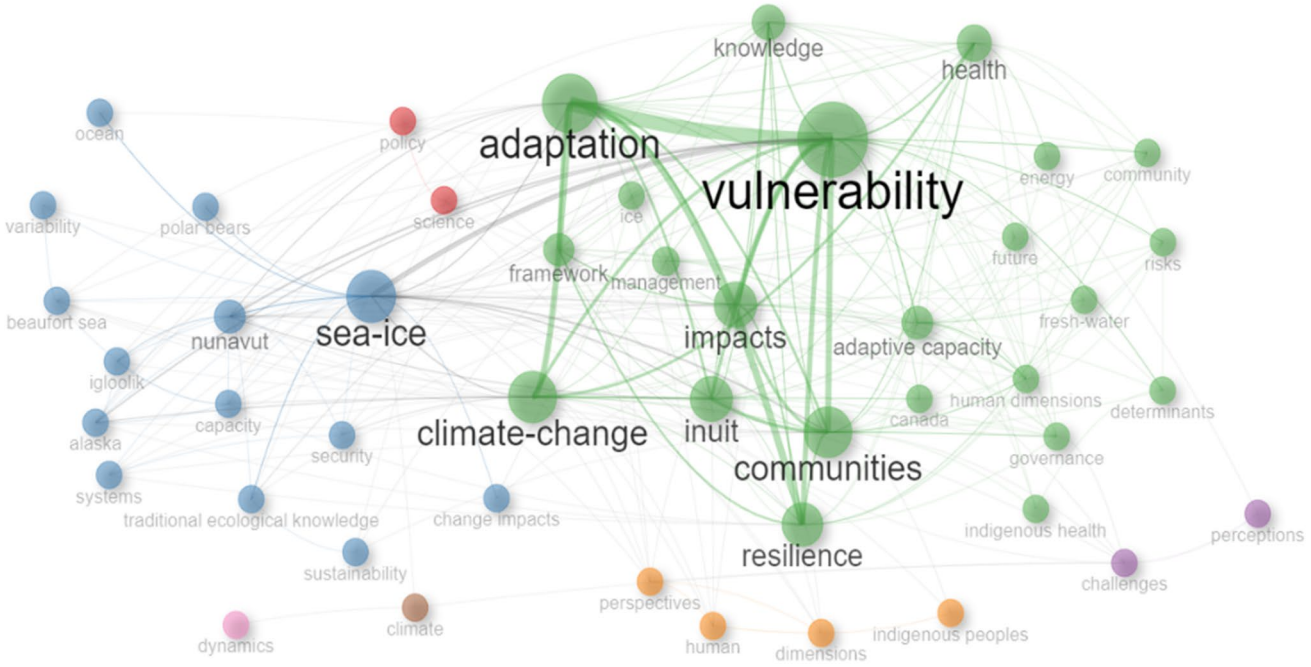


Fig. 12 Co-occurrence analysis

network as showen in Table 4. They also have many edges to each other and to the blue cluster, which indicates that they have many connections or interactions with the physical environment and its changes. These nodes have high values of PageRank centrality, which means that they are very authoritative or influential in the network. They receive many links from other nodes, which suggests that they are highly cited or referenced in the literature.

The analysis shows the frequency of some key words in the literature on sustainability in the Arctic. The most frequent word is vulnerability, which appears 45 times and reflects the main theme of the literature: how the Arctic and its people are vulnerable to various environmental and social challenges. The second most frequent word is climate-change, which appears 34 times and indicates the major driver of change in the Arctic region. The third and fourth most frequent words are sea-ice and adaptation, which appear 32 and 31 times respectively and suggest the importance of sea-ice as a critical resource and a source of risk for the Arctic inhabitants, as well as their adaptive strategies to cope with its changes. It reveals that the frequency of these words has increased over time, suggesting a growing interest and concern for sustainability issues in the Arctic. The next four words are communities, impacts, inuit and resilience, which appear 25, 25, 24 and 21 times respectively and imply the focus of the literature on the human dimension of sustainability in the Arctic, especially the indigenous Inuit communities who face multiple impacts from climate change and other factors and who demonstrate resilience in their responses. The last two words are health and knowledge, which appear 19 and 17 times respectively and indicate the relevance of health issues and local knowledge systems for understanding and enhancing sustainability in the Arctic. The graph also reveals that some topics are more stable than others, such as food security and Inuit culture, while others are more dynamic, such as climate change and resilience.

4 Conclusion and future directions

Although bibliometric analyses have been extended to other regions and substantive policy areas, there are none that have been undertaken for sustainability in the Arctic region. This paper represents this first bibliometric analysis of sustainability in the Arctic region using 213 English-language articles published between 1980 and 2022 from the Web of Science database, revealing key research trends of research. The results have shown that the research on Arctic sustainability has been growing at a moderate rate, with a significant increase in the last decade. Overwhelmingly, and not surprisingly, Canada, the United States, Norway, and Russia, have led research on Arctic sustainability. The bibliometric analysis has demonstrated that they collaborated extensively with each other, but also with other countries. The most productive and influential institution was McGill University, followed by the University of Saskatchewan and University of

Alaska Fairbanks. The most published journals were the journal of Climatic Change, Arctic Journal, Global Environmental Change: Human and Policy Dimensions and Ambio.

What researchers focus on matters. In terms of research trends, the bibliometric analysis, identified beyond Arctic and sustainability, of course, that vulnerability, adaptation, climate-change, sea-ice were the key words associated with scholarly inquiry. And, among these, the most cited articles were those that addressed the impacts of climate change on the Arctic environment and society, the adaptation and resilience strategies of the Arctic communities, and the governance and policy issues related to Arctic sustainability.

Our study offers important findings, yet it is subject to certain limitations. The research is based solely on English articles from the Web of Science, which might miss important work in other languages or databases. It also only includes papers published until 2022, leaving out any newer research. The search terms used could overlook relevant studies that use different words for the same concepts. The focus of the research might lean towards certain sustainability issues, like climate change, and not give enough attention to others. Lastly, the study might not capture the full interdisciplinary nature of sustainability if the literature is too specialized.

This bibliometric analysis suggests that further research is warranted to understand why the imbalances among areas of inquiry, given the various topics from health to food security to energy, among others, are often at the top of the agenda of national government, bodies such as Arctic Council, and Indigenous organizations. This suggests further research should be undertaken to understand whether policy drives the research agenda or vice versa, or whether there is any connection at all. And, why?

Author contributions Each of the three coauthors contributed to the text and editing the text. Fatma Ahmed led writing the introduction, methods, analysis and literature review. Greg Poelzer led writing the sections on the introduction, conclusion, and methods. Oscar Zapata led the writing of the sections discussion and conclusion. All authors edited the text.

Funding This research was supported by the United States National Science Foundation through grant number 2127364.

Data availability The data is available upon request.

Declarations

Competing interests The authors declare no competing interests.

References

1. Griggs D, Stafford-Smith M, Gaffney O, Rockström J, Öhman MC, Shyamsundar P, Noble I. Sustainable development goals for people and planet. Nature. 2013;495(7441):305–7.
2. Burkett V. Global climate change implications for coastal and offshore oil and gas development. Energy Policy. 2011;39(12):7719–25.
3. Porta L, Bankes N. Becoming arctic-ready: policy recommendations for reforming Canada's approach to licensing and regulating offshore oil and gas in the Arctic. Ottawa: Oceans North Canada; 2011.
4. Noble B, Hanna K. Environmental assessment in the arctic: a gap analysis and research agenda. Arctic. 2015. https://doi.org/10.1443/arctic4501.
5. Ahmed F, Hussainey K. A bibliometric analysis of political connections literature. Rev Acc Financ. 2023;22(2):206–26.
6. Ninkov A, Frank JR, Maggio LA. Bibliometrics: methods for studying academic publishing. Perspect Med Educ. 2022;11(3):173–6.
7. Ahmed, F., Poelzer, G. & Noble., (2024) "Meaningful Participation and Energy Transitions in the North. In Canadian Environmental Policy and Politics: Moving the Green Transition Forward, Oxford University Press
8. Ahmed MM, Ahmed F, Hussainey K. Co-word and bibliometric analysis of the sustainability reporting in Islamic banks. In: Hunjra AI, Hussainey KH, editors. Ethical finance and corporate social responsibility: a framework for sustainable development. Queensland: Emerald; 2023.
9. Leung XY, Sun J, Bai B. Bibliometrics of social media research: a co-citation and co-word analysis. Int J Hosp Manag. 2017;66:35–45.
10. Cheng F, Ma Y, Uzzi B, Loscalzo J. Importance of scientific collaboration in contemporary drug discovery and development: a detailed network analysis. BMC Biol. 2020;18(1):1–9.

11. Li LL, Ding G, Feng N, Wang MH, Ho YS. Global stem cell research trend: bibliometric analysis as a tool for mapping of trends from 1991 To 2006. Scientometrics. 2009;80(1):39–58.
12. Yamaguchi NU, Bernardino EG, Ferreira MEC, de Lima BP, Pascotini MR, Yamaguchi MU. Sustainable development goals: a bibliometric analysis of literature reviews. Environ Sci Pollut Res. 2023;30(3):5502–15.
13. Di Vaio A, Zaffar A, Balsalobre-Lorente D. Carbon and decarbonization disclosure: role of responsible innovation in adoption of artificial intelligence of things towards SDGs. In: Misra S, editor. Artificial intelligence of things for achieving sustainable development goals. Cham: Springer Nature Switzerland; 2024. p. 99–121.
14. Adriaanse L, Rensleigh C. Web of science, scopus and google scholar: a content comprehensiveness comparison. Electron Libr. 2013;31(6):727–44.
15. Birkle C, Pendlebury DA, Schnell J, Adams J. Web of science as a data source for research on scientific and scholarly activity. Quantit Sci Stud. 2020;1(1):363–76.
16. Mengist W, Soromessa T, Legese G. Method for conducting systematic literature review and meta-analysis for environmental science research. MethodsX. 2020;7:100777.
17. Aria M, Cuccurullo C. bibliometrix: an R-tool for comprehensive science mapping analysis. J Informet. 2017;11(4):959–75.
18. Hinzman LD, Bettez ND, Bolton WR, Chapin FS, Dyurgerov MB, Fastie CL, Osterkamp TE. Evidence and implications of recent climate change in northern Alaska and other arctic regions. Clim Change. 2005;72(3):251–98.
19. McGuire AD, Anderson LG, Christensen TR, Dallimore S, Guo L, Hayes DJ, Romanovsky V. Sensitivity of the carbon cycle in the arctic to climate change. Ecol Monogr. 2009;79(4):523–55.
20. Wassmann P, Duarte CM, Agusti S, Sejr MK. Footprints of climate change in the arctic marine ecosystem. Glob Change Biol. 2011;17(2):1235–49.
21. Armitage D, Béné C, Charles AT, Johnson D, Allison EH. The interplay of well-being and resilience in applying a social–ecological perspective. Ecol Soc. 2012. https://doi.org/10.5751/ES-04940-170415.
22. Stroeve J, Markus T, Boisvert L, Miller J, Barrett A. Changes in arctic melt season and implications for sea ice loss. Geophys Res Lett. 2014;41(4):1216–25.
23. Ford JD, Smit B, Wandel J, Allurut M, Shappa K, Ittusarjuat H, Qrunnut K. Vulnerability to climate change in igloolik, nunavut: what we can learn from the past and present. Polar Rec. 2006;42:127–38.
24. Eugster W, Rouse WR, Pielke RA Sr, et al. Land–atmosphere energy exchange in arctic tundra and boreal forest: available data and feedbacks to climate. Glob Change Biol. 2000;6:84–115.
25. Moritz C, Patton JL, Conroy CJ, et al. Impact of a century of climate change on small-mammal communities in Yosemite National Park USA. Science. 2008;322:261–4.
26. Stohl A, Klimont Z, Eckhardt S, et al. Black carbon in the arctic: the underestimated role of gas flaring and residential combustion emissions. Atmos Chem Phys. 2013;13:8833–55.
27. Cameron ES. Securing indigenous politics: a critique of the vulnerability and adaptation approach to the human dimensions of climate change in the Canadian Arctic. Glob Environ Change-Human Policy Dimens. 2012;22:103–14.
28. Comiso JC, Hall DK. Climate trends in the arctic as observed from space. Wiley Interdiscip Rev-Clim Change. 2014;5:389–409.
29. Willox A, Cunsolo C, Landman K, Houle K, Ford JD. "From this place and of this place": climate change sense of place and health in Nunatsiavut Canada. Soc Sci Med. 2012;75:538–47.
30. Forbes BC, Freshwater D, Kumpula T. Catastrophic ice break-up on the Taimyr Peninsula Russia: impacts on migrating reindeer and their herders. Proc Natl Acad Sci USA. 2009;106:3882–6.
31. Mistry J, Berardi A. Bridging indigenous and scientific knowledge. Science. 2016;352:1274–5.
32. Bjerregaard P, Young TK, Dewailly E, Ebbesson SOE. Indigenous health in the arctic: an overview of the circumpolar Inuit population. Scand J Public Health. 2004;32:390–5.
33. Callaghan TV, Björn LO, Chapin FS III, et al. Response to ecosystem change and to their effects on human well-being. Ambio. 2004;33:198–203.
34. Pearce TD, Ford JD, Laidler GJ, Smit B, Duerden F, Allarut M, Andrachuk M, Baryluk S, Dialla A, Elee P, Lewko J, McDonald M, Moffat S, Moses J, Mulvad G, Nasogaluak B, Ohmagari K, Prno J, Sellwood B, Stevenson A, Wandel J, Wright M. Community collaboration and climate change research in the Canadian Arctic. Polar Res. 2009;28:10–27.
35. Huet C, Rosol R, Egeland GM. The prevalence of food insecurity is high and the diet quality poor in Inuit communities. J Nutr. 2012;142:541–7.
36. Farre AB, Stephenson SR, Chen L, Czub M, Dai Y, Demchev D, Efimov Y, Graczyk P, Grythe H, Keil K, Kivekas N, Kumar N, Liu N, Matelenok I, Myksvoll M, O'Leary D, Olsen J, Pavithran SAP, Petersen E, Raspotnik A, Ryzhov I. Commercial arctic shipping through the Northeast passage: routes, resources, governance, technology, and infrastructure. Polar Geogr. 2014;37(4):298–324.
37. Ford JD, Smit B, Wandel J, Allurut M, Shappa K, Ittusarjuat H, Qrunnut K. Climate change in the arctic: current and future vulnerability in two Inuit communities in Canada. Geogr J. 2008;174:45–62.
38. Bronen R, Chapin FS III. Adaptive governance and institutional strategies for climate-induced community relocations. Proc Natl Acad Sci USA. 2013;110:9320–5.
39. Loring P, Gerlach SC. Food security and conservation of Yukon River salmon: are we asking too much of the Yukon River? Environ Sci Policy. 2009;12:912–21.
40. Ford JD, Pearce T. What we know what we don't know and what we need to know about climate change vulnerability in the western Canadian Arctic: a systematic literature review. Environ Res Lett. 2010;5:014008.
41. Chan HM, Fediuk K, Hamilton S, Rostas L, Caumartin R, Egeland G, Loring E. Food security in Nunavut Canada: barriers and recommendations. Int J Circumpolar Health. 2006;65:416–31.
42. Ford JD, Gough W, Laidler G, MacDonald J, Irwin C, Qrunnut K. Climate change in the arctic: current and future vulnerability in two Inuit communities in Canada. Arctic. 2006;60:27–40.

43. Chapin FS III, Peterson G, Berkes F, Callaghan TV, Angelstam P, Apps M, Beier C, Bergeron Y, Crepin AS, Danell K, Elmqvist T, Folke C, Forbes B, Fresco N, Judson W, Kofinas G, Krebs CJ, Landres PB, Manley P, McDowell PF, Moberg F, Ostfeld R, Schindler DW, Shvidenko A, Tonnessen K, Walker BH. Resilience and vulnerability of northern regions to social and environmental change. Ambio. 2004;33:344–9.
44. Descamps S, Jenkyns I, Gilchrist G, Currie D. Climate change impacts on wildlife in a high arctic archipelago—Svalbard Norway. Glob Change Biol. 2017;23:490–502.
45. Willox AC, Harper SL, Ford JD, Landman K, Houle K, Edge VL. "From this place and of this place:" climate change, sense of place, and health in Nunatsiavut, Canada. Soc Sci Med. 2013;93:38–47.
46. Stephenson SR, Smith LC, Agnew JA. Divergent long-term trajectories of human access to the Arctic. Nat Clim Chang. 2013;3:156–60.
47. Ford JD, Berrang-Ford L, King M, Furgal C. Vulnerability of aboriginal health systems in Canada to climate change. Glob Environ Chang. 2010;20(4):668–80.
48. Chapin FS III, Peterson G, Berkes F, Callaghan TV, Angelstam P, Apps M, Fresco N. Policy strategies to address sustainability of Alaskan boreal forests in response to a directionally changing climate. Proc Natl Acad Sci USA. 2006;103(45):16637–43.
49. Willox A, Cunsolo C, Landman K, Houle K, Ford JD, et al. The land enriches the soul: on climatic and environmental change affective geographies and the emotional embodiment of social and ecological transformation in the Canadian Arctic. Q Res. 2013;13(2):249–66.
50. Gearheard S, Matumeak W, Angutikjuaq I, Maslanik J, Huntington HP, Leavitt J, Barry RG. "It's not that simple": a collaborative comparison of sea ice environments, their uses, observed changes, and adaptations in Barrow, Alaska, USA, and Clyde River, Nunavut, Canada. Ambio: J Human Environ. 2006;35(4):203–11.
51. Wenzel GW. Canadian Inuit subsistence and ecological instability—if the climate changes must the Inuit? Polar Res. 2009;28(1):89–994.
52. Caine KJ, Krogman N. Powerful or just plain power-full? A power analysis of impact and benefit agreements in Canada's north. Organ Environ. 2010;23(1):76–98.
53. Durkalec A, Furgal C, Skinner MW, Sheldon T. Climate change influences on environment as a determinant of indigenous health: relationships to place, sea ice and health in an Inuit community. Soc Sci Med. 2015;136–137(17):17–26.
54. Marino E. The long history of environmental migration: assessing vulnerability construction and obstacles to successful relocation in Shishmaref *Alaska*. Glob Environ Change-Human Policy Dimens. 2012;22(2):374–81.
55. Moran EF. Human adaptation to Arctic zones. Annu Rev Anthropol. 1981;10(1):1–25.
56. So JK. Human biological adaptation to arctic and subarctic zones. Annu Rev Anthropol. 1980;9(1):63–82.
57. Lewis CE, Thomas WC. Expanding subarctic agriculture social, political and economic aspects in Alaska. Interdisc Sci Rev. 1982;7(3):178–87.
58. Lewis Y. Research collaborations bring big rewards: the world needs more. Nature. 2021;594(7863):301–2.
59. Khasseh A, Faramarz S, Hadi S, Afshin M. Intellectual structure of knowledge in imetrics: a co-word analysis. Inf Process Manage. 2017;53(3):705–20.
60. Bernatović I, SlavecGomezel A, Černe M. Mapping the knowledge-hiding field and its future prospects: a bibliometric co-citation, co-word, and coupling analysis. Knowl Manag Res Pract. 2022;20(3):394–409.
61. Zupic I, Čater T. Bibliometric methods in management and organization. Organ Res Methods. 2015;18(3):429–72.
62. Zhao X, Nan D, Chen C, Zhang S, Che S, Kim JH. Bibliometric study on environmental, social, and governance research using CiteSpace. Front Environ Sci. 2023;10:1087493.
63. Martinez-Garcia A, Coll-Ramis MÀ, Horrach-Rosselló P. Analysing leadership in tourism education research: a scientometric perspective. Eur J Geogr. 2024a;15(1):67–80.
64. Martinez-Garcia A, Ferrer-Rosell B, Horrach-Rosselló P, Mulet-Forteza C. An overview of the European research in tourism, leisure and hospitality since the first indexed publication. London: IntechOpen; 2024b.
65. Martinez-Garcia A, Horrach-Rosselló P, Mulet-Forteza C. Mapping the intellectual and conceptual structure of research on CoDa in the 'social sciences' scientific domain a bibliometric overview. J Geochem Explor. 2023;252:107273.
66. Martinez-Garcia A, Horrach-Rosselló P, Mulet-Forteza C. Evolution and current state of research into E-learning. Heliyon. 2023. https://doi.org/10.1016/j.heliyon.2023.e21016.