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# CLIMATE CHANGE AND PARAMO ECOSYSTEM: A BIBLIOMETRIC ANALYSIS

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## ABSTRACT

***Climate change is one of the most urgent and complex challenges of our time. Several papers have examined the effects of climate change on the paramo ecosystem. However, a comprehensive bibliometric analysis of the topic is still lacking. The main objective of this study is to fill this gap by improving our understanding of previous research. To this end, we analyzed 201 articles, reviews, book chapters, conference papers and data papers indexed in Scopus between 1984 and 2024 using VOSviewer and Bibliometrix, two commonly used software tool for science mapping and bibliometric analysis. This study used bibliometric analysis to explore research trends, collaborative networks and thematic assessment of articles on climate change and paramo ecosystem. The results show three main research trends in the field, in these thematic tendencies, a predominance of life sciences and empirical approaches was identified. The results are a valuable resource for scientists, policy-makers and practitioners, providing a better understanding of the changing body of knowledge on climate change and paramo ecosystem research.***

**KEYWORDS:** Climate change; paramo; bibliometrics; ecosystem.

## INTRODUCTION

Climate change is one of the main challenges of our time, its complexity expands across multiple disciplines and its urgency points to the need to make quality knowledge available to decision makers. It is unequivocal that human influence has warmed the atmosphere, oceans and land, resulting in adverse impacts and associated losses and damages to nature and people, disproportionately affecting vulnerable communities around the world (IPCC, 2023). Since the Industrial Age, fossil fuel burning, deforestation and intensive agricultural practices have emitted unprecedented amounts of carbon dioxide ($CO_2$), methane ($CH_4$) and other greenhouse gases, increasing the natural greenhouse effect and raising global temperatures (Le Quéré *et al*., 2018). The damages and losses caused by climate change are increasingly irreversible, such as the retreat of glaciers and their impact on hydrological systems, the increase in mass mortality events such as floods, droughts and storms, the loss of hundreds of local species due to the increase in the magnitude of heat extremes, warming and acidification of the oceans, etc. (NOAA, 2021).

Although there is no consensus on the definition of paramo ecosystem, it can be generally said that paramos are continental biological archipelagos, high mountain ecosystems exclusive to the Neotropics, located between the lower limit of snow and the upper limit of the Andean forest in the crown of the mountain ranges (Sarmiento & León, 2015; Rangel-Ch, 2000; Llambí & Cuesta, 2014; Ospina, 2013; Hofstede, 2013; Luteyn, 1999.). It is argued that paramos are regulators of the water cycle and are often highlighted in public policy documents for the provision of ecosystem services related to water supply. Paramo ecosystems are particularly vulnerable to climate change, due to the rising of temperatures and shifting of precipitation patterns (Rosero-Erazo *et al*, 2024).

Bibliometric analysis is used to identify emerging trends in the performance of articles and journals, patterns of collaboration and research components, and to explore the intellectual structure of a particular field in the existing literature (Donthu *et al*., 2021). Developed in the second half of the 20th century, bibliometrics is an essential tool for decision-making in science policy and research resource management (Mongeon & Paul-Hus, 2016, De Bellis, 2009). Bibliometric methodology is quantitative and is based on the premise that the analysis of bibliometric data provides answers to questions about the research that these data represent (Jagadeesh, Balakumar & Senatore, 2024). Publications on bibliometrics have increased over the years and have been applied in various fields, including climate change. In fact, between 2005 and February 2025, 1914 papers on climate change have been published in the Scopus database using bibliometric analysis, of which 93% (1784) have been published since 2019, indicating a significant increase in the use of bibliometrics to inform climate change research and policy. Documents on the paramo ecosystem have been published in the Scopus database for a long time, with the first paper published in 1831. So far, 1600 documents have been published. Surprisingly, none of them uses a bibliometric methodology. This article uses a bibliometric approach to explore the main gaps in knowledge about climate change and the paramo ecosystem, with the aim of providing a quantitative and systematic overview of its evolution, impacts and future prospects. To the best of the authors' knowledge, no bibliometric study on climate change and the paramo ecosystem has been published in Scopus until February 2025.

In accordance with the main objectives of a bibliometric analysis, the research questions of this study are as follows: (1) Which publications, authors and countries have made the greatest contributions to climate change and the paramo ecosystem? (2) What are the underlying strands of research and how have key studies on the topic changed over time? (3) What are the research gaps in the field of climate change and paramo ecosystems during the study period? (4) What are the main concerns and trends that are emerging in the present day? This analysis is based on Scopus only. The Scopus database contains many articles on climate change and paramo ecosystems published in the last forty years.

## METHODOLOGY

Bibliometrics is a scientific discipline that focuses on the quantitative analysis of the production, dissemination and impact of academic literature, using statistical and mathematical methods to study patterns of publication, citation and research collaboration (Pritchard, 1969; Glänzel, 2003). While bibliometric analysis allows for the quantification of literature data, bibliometrics has often been criticized for its inability to engage with the actual content of published documents (Mufungizi, Musakwa & Chanza, 2023). However, the field of bibliometrics is intended to complement, not replace, qualitative research (Jagadeesh, Balakumar & Senatore, 2024).

There are two main techniques in bibliometric analysis: (1) Performance analysis and (2) Science mapping. The first examines the contributions of research constituents, meanwhile the second examine the relationship between research constituents to a given field (Donthu *et al.*, 2021). Following this classification there is a wide variety of indexes and measures in performance analysis, most of them are publication-related, citation-related metrics or a combination of both. Science mapping focuses in different kind of analyses: citation, co-citation, bibliographic coupling, co-word and co-authorship. Additionally, there is a third kind of techniques, called enrichment techniques, focused on network analysis, through network metrics, clustering and visualization.

Many researchers have used the Elsevier Science Scopus database for their research as it is recognized as a comprehensive scientific database suitable for scientometric studies (Abdelwahab, Taha & Mariod, 2025). Scopus is one of the largest databases, covering multiple disciplines and publication formats, and includes a citation monitoring system that is valuable for bibliometric analyses.

The search strategy was based on literature review and search strategies from previous bibliometric studies in climate change. The following keywords were used for the search "páramo" OR "paramo" AND "climate change" OR "global warming" OR "greenhouse gases" OR "carbon dioxide emissions" OR "climate resilience" OR "climate action" OR "carbon footprint" OR "climate negotiations" OR "environmental change", considering their occurrence in titles, abstracts, and keywords in Scopus. Data for this study were obtained and exported in Research Information System (RIS) and Comma Separated Values (CVS) format in February 10, 2025 from Scopus database. The inclusion criteria for this systematic literature review were articles, reviews, book chapters, conference papers and data papers indexed in Scopus, published between 1981 and 2024, written in three languages: English, Spanish and Portuguese. Prior to 1981, documents were not taken into consideration because there were not records available. The search returned 201 documents.

The extracted data were analyzed using VOSviewer (version 1.6.20) for visualizing co-occurrence and co-authorship networks, and the Bibliometrix package of R Studio for visualizing author, source, country and document performance and co-citation networks. Open Office Calc was used for table management. DeepL.com AI services were used to correct grammar and spelling.

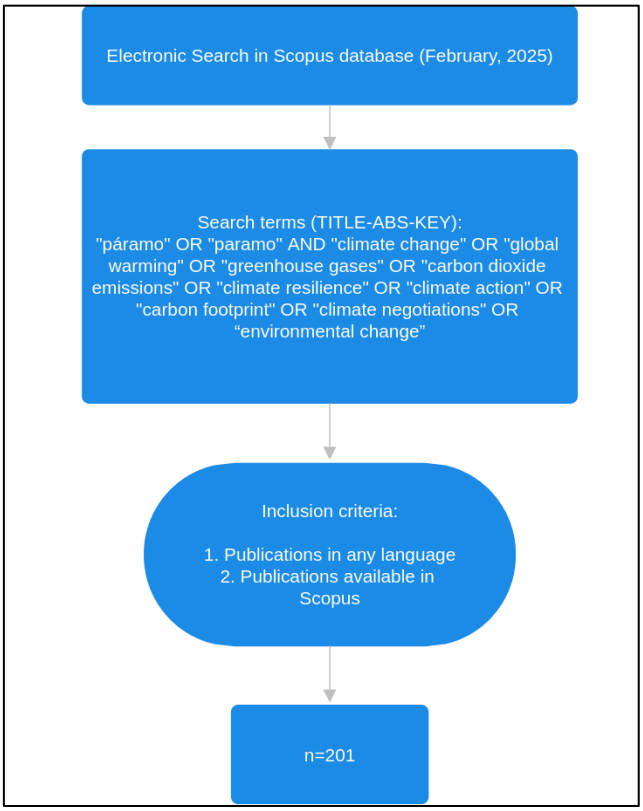


Fig. 1. Flowchart of systematic bibliometric analysis.

## RESULTS AND DISCUSSION

The results revealed 201 documents in English (165), Spanish (11) and Portuguese (1) from 1981 to 2024, including articles, reviews, book chapters, conference papers and data papers. 87,06% of the documents were data-driven articles. Of the 201 documents, 173 have citations reported by Scopus. According to the bibliographic database there are 4,194 citations with an h-index of 32.

### A. Performance Analysis

#### 1. Distribution of publications by countries and institutions

Of the 37 countries, the three most productive were Colombia (33,83%), Ecuador (29,35%) and the United States (28,86%). Of the 160 reported institutions, the Universiteit van Amsterdam (Netherlands) and Universidad de los Andes (Mérida, Venezuela) maintained their positions as the two most productive institutions with 20 and 19 contributions respectively, and the Institute for Biodiversity and Ecosystem Dynamics (Amsterdam, Netherlands), the Universidad de los Andes (Bogotá, Colombia) and the Universidad de Cuenca (Ecuador) shared the third most productive position with 13 contributions each. Of the 144 reported funding sponsors, the Departamento Administrativo de Ciencia, Tecnología e Innovación (Colciencias, recently MinCiencias, Colombia) and the National Science Foundation (United States) were the top sources of founding with 13 contributions each, followed by the Universidad de Cuenca and the Deutsche Forschungsgemeinschaft (Germany), both with 8 contributions.

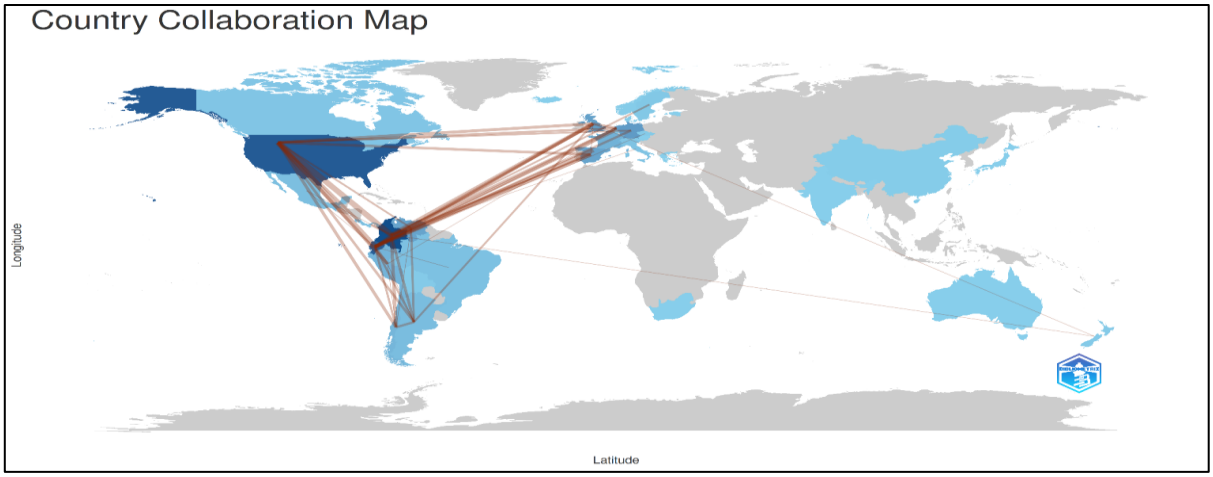


Fig. 2. Country Collaboration Map

#### 2.Annual number of publications and subject areas

An analysis of published documents by year from 1981 to 2024 reveals that there has been an increased in climate change and paramo ecosystem literature, particularly, since 2018. As Fig. 3 shows the longest interval with no publications in the area were between 1985-1990, meanwhile the number of publications peaked in 2020. Over the past four decades, the production rate has increased, with a compound annual growth rate (CAGR) of 7,34%. Over the last ten years, the production rate has increased significantly, with a CAGR of 13,35%.

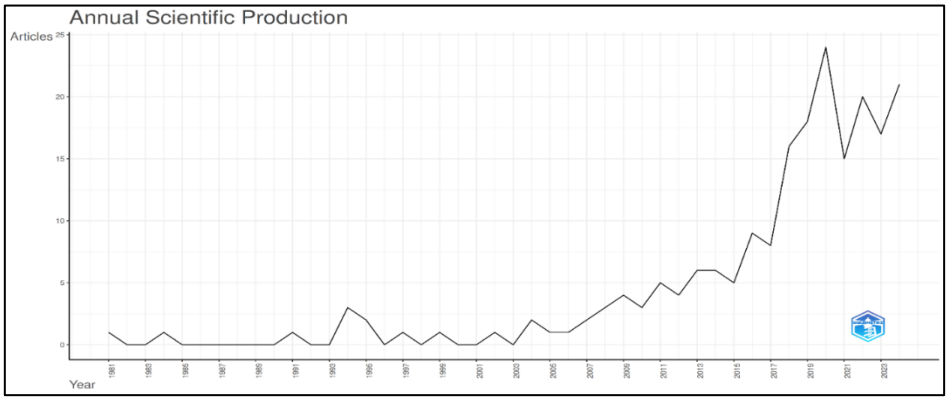


Fig. 3. Number of documents per year

Based on the categorization of subject area, the literature on climate change and paramo ecosystem has been distributed in 20 subject areas. The three most productive subject areas were Agricultural and Biological Sciences (30,53%), Environmental Science (27,37%) and Earth and Planetary Science (16,32%).

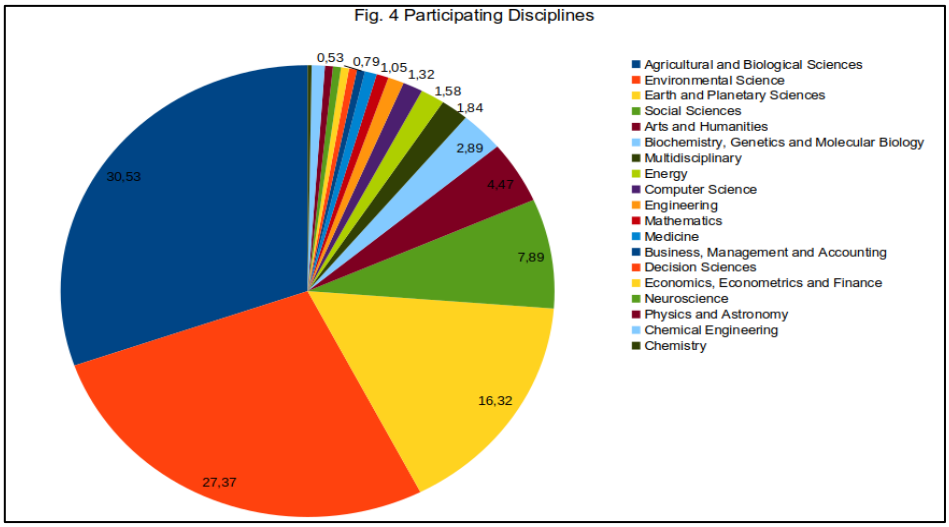


Fig. 4. Participating disciplines

## 3. Distribution by journals

Of the 136 journals on climate change and paramo ecosystem, the most significant and active were Plant Ecology and Diversity (3,48%), Plos One (2,99%), Frontiers in Ecology and Evolution (2,49%), Holocene (2,49%) Quaternary Science Review (2,49%), Science of the Total Environment (2,49%). Plant Ecology and Diversity is a Q2 journal (2023) with an h-index of 44 and PloS One is a Q1 journal (2023) with an h-index of 435. According to the number of contributions, Plant Ecology and Diversity published 7 documents, with 128 citations and an h-index of 6, meanwhile, PLoS One published 6 documents with 416 citations and an h-index of 6. But according to the general ranking and h-index of the journals, PloS One is the most influential journal, given that is a Q1 (2023) journal with a 435 h-index.

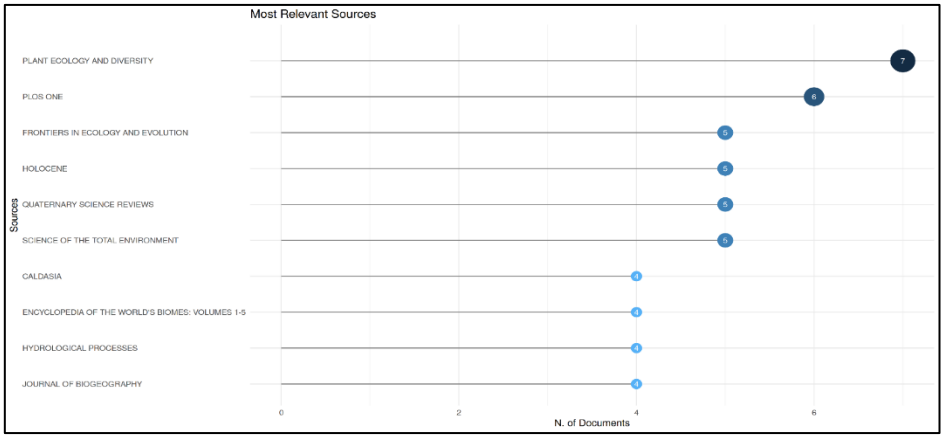


Fig. 5. Most relevant sources

According to the Bradford's Law (Ravichadra Rao, 1998) there are top 16 journal as the core sources, or zone 1, of climate change and paramo ecosystem, with 67 documents. The zone 2 corresponds to 53 journals with the next 67 documents and the zone 3 corresponds to 67 journals, with the next 67 documents.

## 4. Highly productive authors

Of the 160 authors that contributed, the top three authors were Llambí L. D., Hooghiemtra H. and Behling, H. corresponding to 5,47%, 4,98% and 3,98%, respectively (Fig. 6). Llambí L. D. works for the Universidad de los Andes (Mérida, Venezuela) and contributed 11 documents, with 286 citations and

an h-index of 7. According to Fig. 7 Hooghiemstra is the author with higher local impact by h-index, this author works for the Institute for Biodiversity and Ecosystem Dynamics (Amsterdam, Netherlands) and contributed 10 documents, with 612 citations and an h-index of 10. Finally, Behling, H. works for the Georg-August-Universität (Göttingen, Germany) and contributed 8 documents with 196 citations and an h-index of 6.

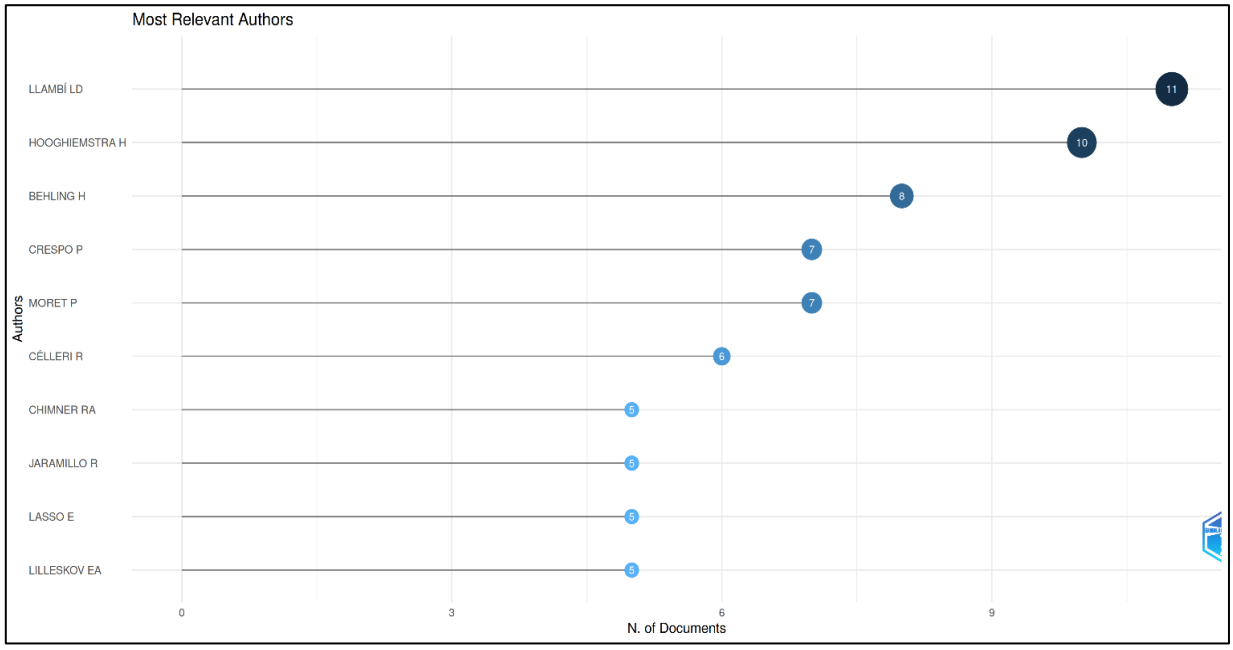


Fig. 6. Most relevant authors

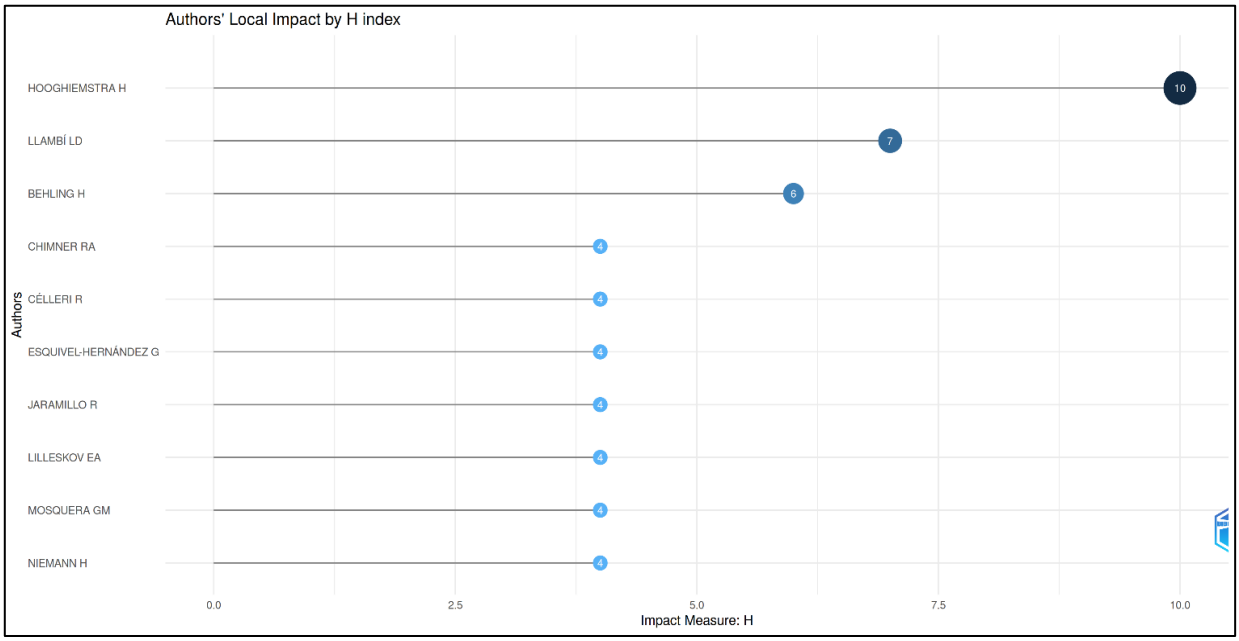


Fig. 7. Author Impact

**B. Science mapping and network analysis**

**5. Co-authorship**

The co-author network in Fig. 8 illustrates which author has contributed the most in climate change and paramo ecosystem literature, based on co-authorship. Each node represent an author. The size of the node represents the number of publications by an author, and the intensity of collaboration is assessed by the line thickness and nodes spacing. Authors are grouped into clusters based in their collaboration patterns, different colors represent the evolutions of collaboration patterns over time. From 160 distinct authors, and with the limit

of an author's minimum number of documents being 4, 21 authors met the threshold point. Three main networks emerged: the first is lead by Crespo, P.; the second is lead by Llambí, I. D.; and third is lead by Chimner, R. A. The network map indicates that Llambí and Crespo are a higly influential authors, given that they are connected with the main research communities in the field. Hooghiemtra and Behling are highly productive authors, but they are isolated of the collaboration networks. Chimner and Suárez plays the role of a bridge node, connecting the two main collaboration clusters.

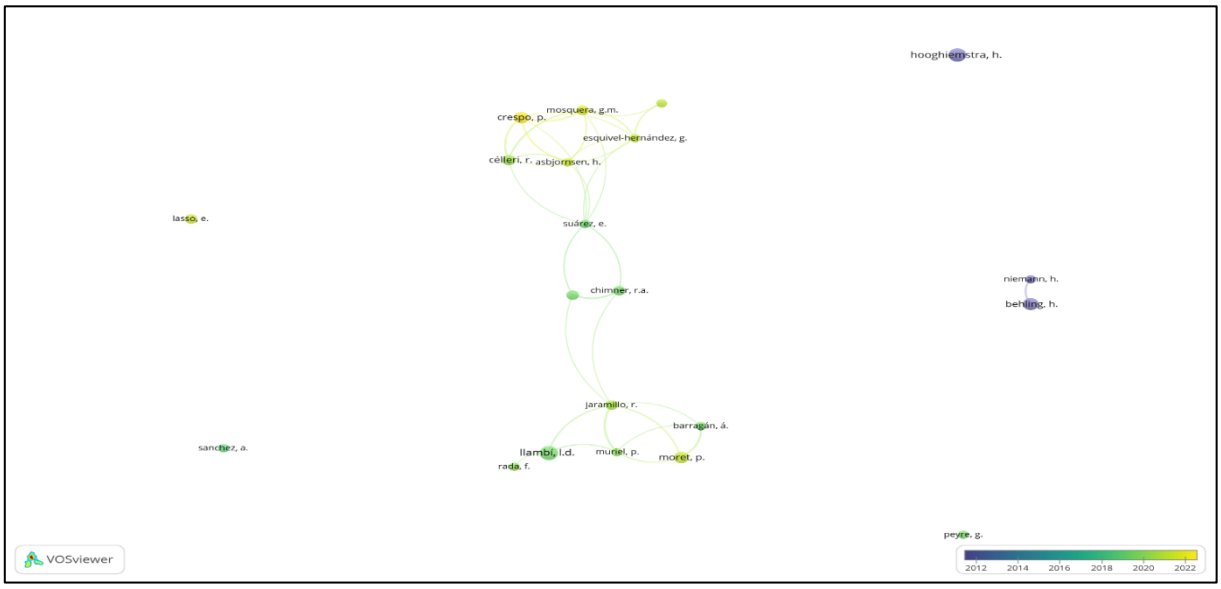


Fig. 8. Author co-authorship network (threshold 4 documents and 21 authors)

**6. Keyword co-ocurrence**

Keywords serve to summarize the contents of a research publication while also focusing and refining the research's essential concepts (Albugami *et al.*, 2024). Understanding the relationships between keywords helps to identifying research themes, trends and patterns. Fig. 9 depicts co-ocurrence analysis, each node represents a keyword. The size of the node represent the frequency of the keyword in the dataset, i. e., the number of publications where the keyword appears. The lines connecting nodes represent co-ocurrence relationships. Thicker lines indicate stronger associations, i. e., keywords appearing frequently in the same publications. Keywords are grouped into clusters based on their co-ocurrence patterns. Each cluster is represented by a different color, indicating the trends in the field over time.

The analysis of the authors' keywords revealed four meaningful clusters related to climate change and the paramo ecosystem (Fig. 9). The first cluster revolves around palynological and palaeoecological studies focusing on vegetation dynamics and history. These studies analyze evidence of climate and vegetation change in high mountain ecosystems in the tropics. In order to reconstruct the environmental history and/or to assess the response of these ecosystems to major mechanisms of natural and human disturbance regimes, these papers are mostly based on compound-specific carbon isotope compositions of lake sediments; high-resolution pollen records; pollen, spore, charcoal analyses and radiocarbon dating; meteorological and microclimatic data; temporal variation in diatom assemblage composition and structure; phytogeographic patterns of bryophyte flora; geodiversity assessment and mapping; literature reviews of ecological research; dated plant phylogenies.

The second cluster focuses on carbon cycle and sequestration, land cover and use, ecosystem services and water resources. These studies analyze carbon (C) accumulation and vegetation dynamics in tropical high mountain ecosystems to provide baseline assessments of carbon storage in the face of potential perturbations from land use and climate change. These studies generally focus on quantitative retrieval of soil organic carbon (SOC) storage for soils, above-ground carbon stocks distribution; spatial and temporal patterns of carbon accumulation; the effects of climate change and changes in land cover and use on these ecosystems carbon and water storage capacity and hydrology regulation. The carbon cycle is linked to the mitigation of climate change, and the Andean highland soil is likely to be a key component in the regional carbon cycle, and also exhibits one of the

highest ecosystem carbon stocks per unit area. Related to the carbon sequestration capacity, the Andean Paramo also has a huge water storage capacity due to the slow decomposition rate of organic matter and soil composition. Some of these studies focus on environmental monitoring of biodiversity, carbon stocks, hydrology, glaciers and land use dynamics in order to propose monitoring strategies and provide relevant information for environmental management. The Paramo ecosystem is highly valued for its water- and carbon-related ecosystem services, and its vulnerability to climate and land-use changes threatens its capacity to provide these ecosystem services. 13% of the documents in this cluster discusses social interactions and discourses about paramos and water resources from a sociological and socio-ecological perspective.

Biodiversity, adaptation, conservation and environmental protection form the third cluster. In tropical mountain ecosystems, habitat loss and fragmentation due to climate change and anthropogenic activities are major threats to biodiversity. The studies in this cluster assess the impact of climate change on paramo biodiversity. The main objectives of these documents are to address the relationship between patch characteristics over time on species diversity and composition, identify potential bioindicator species for montane habitats, assess the potential adaptation of endangered species to current and future climate change scenarios, address how biodiversity levels have fluctuated through time, discuss the effects of vegetation change on the availability of useful plants, update red list assessments and present new species, predict the future of paramo plant species and communities and model responses to climate change, understand fire ecology, monitor land change at different spatial scales, present the conservation status of specific paramos, identify nature-based solutions to improve the resilience of paramo socio-ecosystems, and understand the factors affecting paramo sustainability. 9% of the documents in this cluster introduce social science and humanities perspectives to demonstrate human-fauna assemblages as cultural paramo landscapes worthy of protection, to conduct ontological analyses of world-making and situated practices in the paramos to reflect on the environmental challenges of conservation, and to understand biocultural landscapes and socio-ecological systems.

The fourth cluster corresponds mainly to the geographical regions under study, countries as Ecuador, Colombia, Costa Rica, Perú and Venezuela. Within this cluster there are also the keywords related to the paramo ecosystem like alpine environment, tropical Andes, montane forest, grasslands, tundras, puna, peatlands and wetlands.

Four main periods of research can be identified from the variation of keywords over time. The first period is between 2010-2014. The main interest in this period coincides to cluster one, with emphasis on palynology and vegetation dynamics and history. The second period is between 2014-2018, the main interest in this period corresponds to the cluster three emphasis in biodiversity and conservation. The third period is between 2018-2024, the main interest in this period is consistent with the cluster two emphasis in land cover, ecosystem services and water resources.

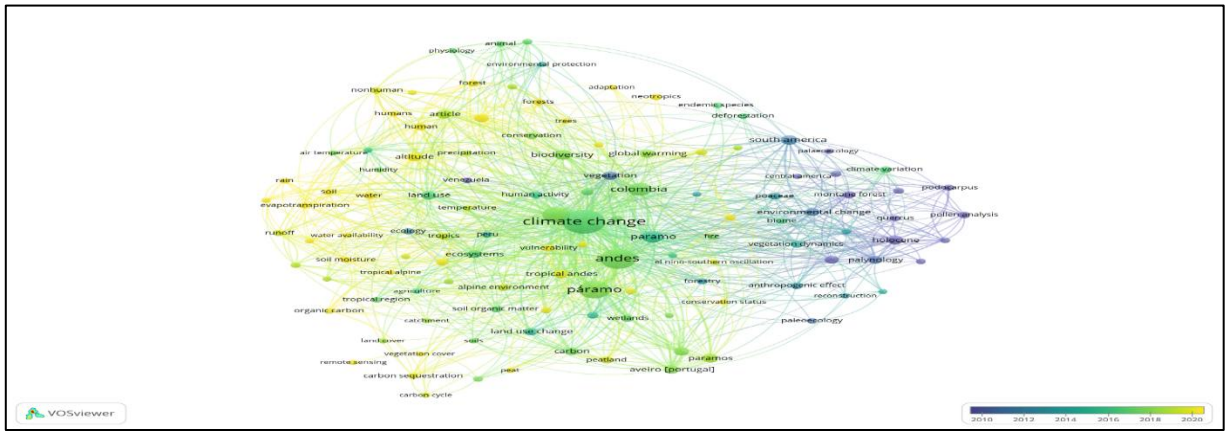


Fig. 9. Author's keywords co-ocurrence network

## 7. Citation analysis

Figure 10 shows keywords and authors in relation to cited sources. This identifies influential authors and documents that are frequently cited in the literature. The authors Buytaert, W., Sklenar, P. and Vuille M. are the top three most frequently cited sources on climate change and the paramo ecosystem. None of these authors were in the list of the top ten most influential authors previously identified by productivity and collaboration patterns.

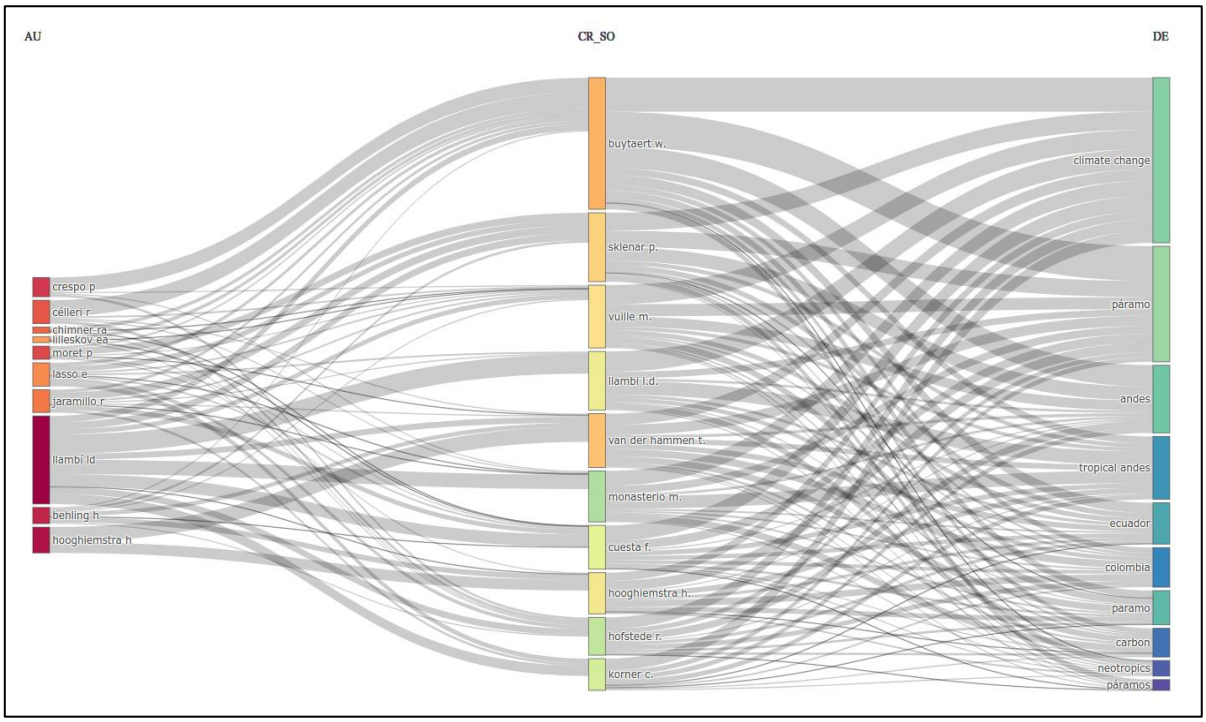


Fig. 10. Three field plot (authors, cited sources, keywords)

The most cited papers in the literature are Buytaert *et al.* (2006), Safford (1999) and Sánchez-Cuervo (2012). These documents were published in the journals Earth Science Review, Biogeography and Plos One respectively. None of these authors appeared in the list of the top ten influential authors previously identified according to productivity and collaboration patterns.

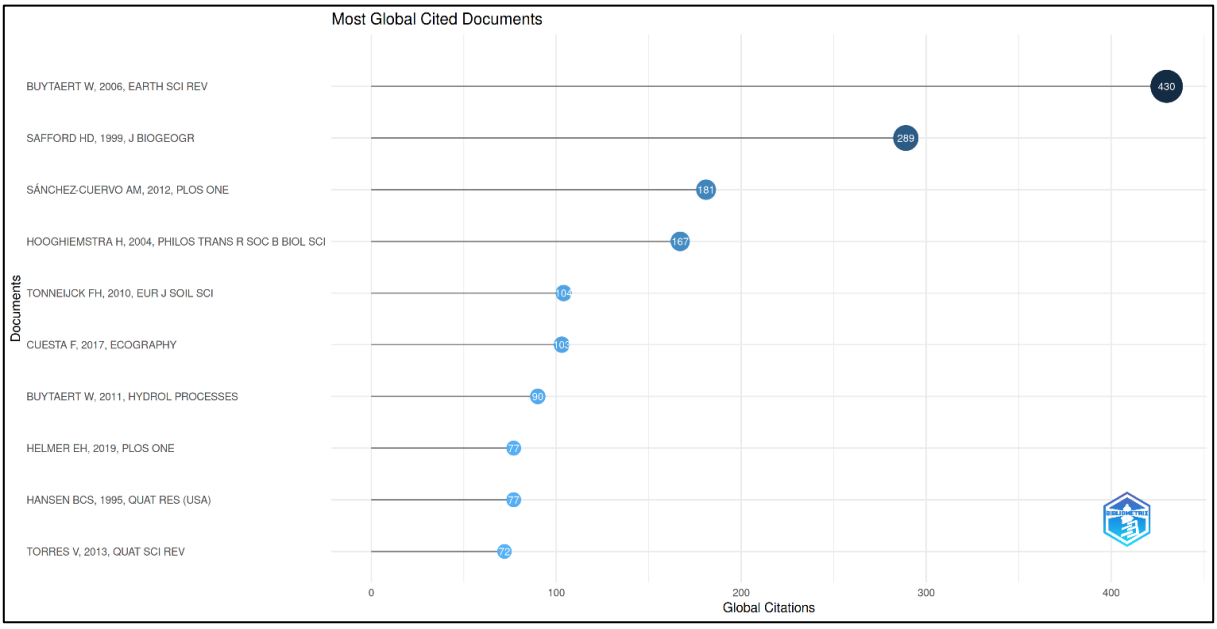


Fig. 11. Most cited documents

The most cited countries (Fig. 12) are the United States, Belgium and the Netherlands. This is noteworthy as that Colombia and Ecuador were identified as the two top countries in terms of productivity, ranking fourth and seventh position respectively in terms of citation, with the United States ranking third. The Netherlands ranked fifth, while Belgium did not appear in the top ten most productive countries in the literature.

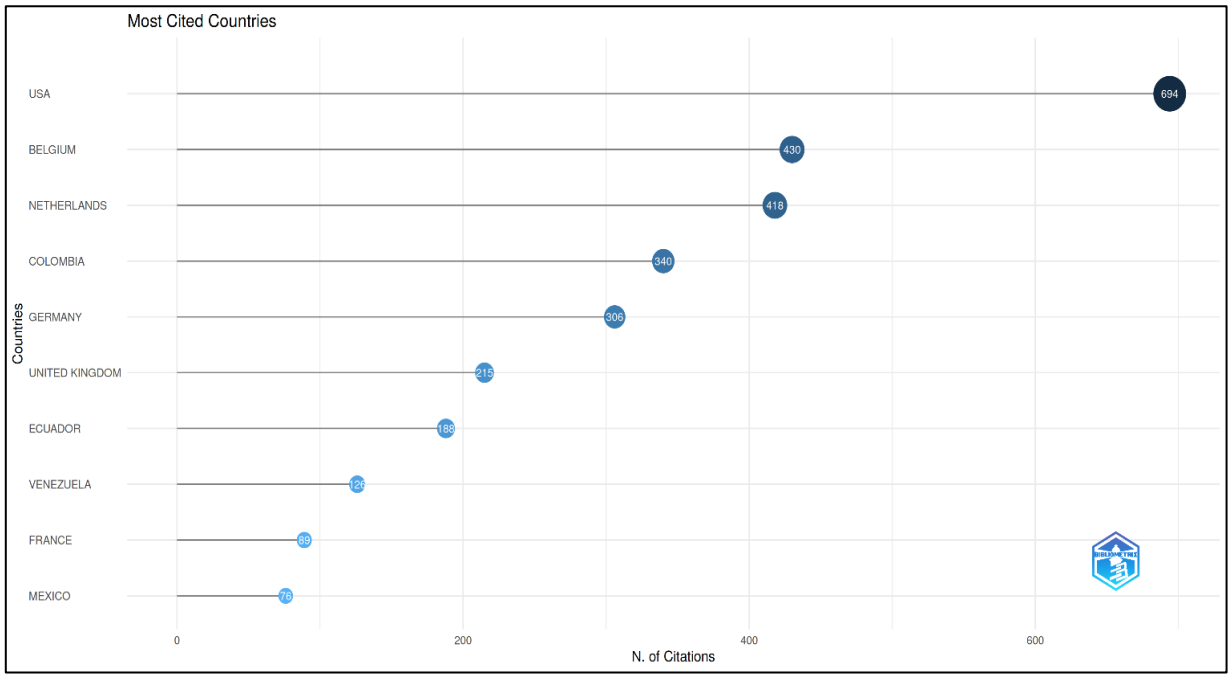


Fig. 12. Most cited countries

The co-cited papers, authors, or journals that show up as clusters on co-citation maps tend to share a common theme and can reveal different theoretical and conceptual domains (Smith, Vallury & Covelli, 2023). The size of nodes in the co-citation network reflects the number of times papers are cited in the reference list of articles in the sample (n=201), the proximity and linkages between the nodes reflect when the same pairs of papers are co-cited by many authors, thus forming the clusters of research that shared common themes. Four clusters are depicted in the co-citation network.

As Figure 13 shows, four clusters were identified according to the most cited documents in the references, led by Hedberg (1979), Luteyn (1999), Myers *et al*. (2000) and Faegri & Iversen (1989). According to the degree centrality, these are highly connected nodes, indicating their relevance in the literature, and according to the closeness centrality, these nodes share thematic trends with the nodes close to them in the network.

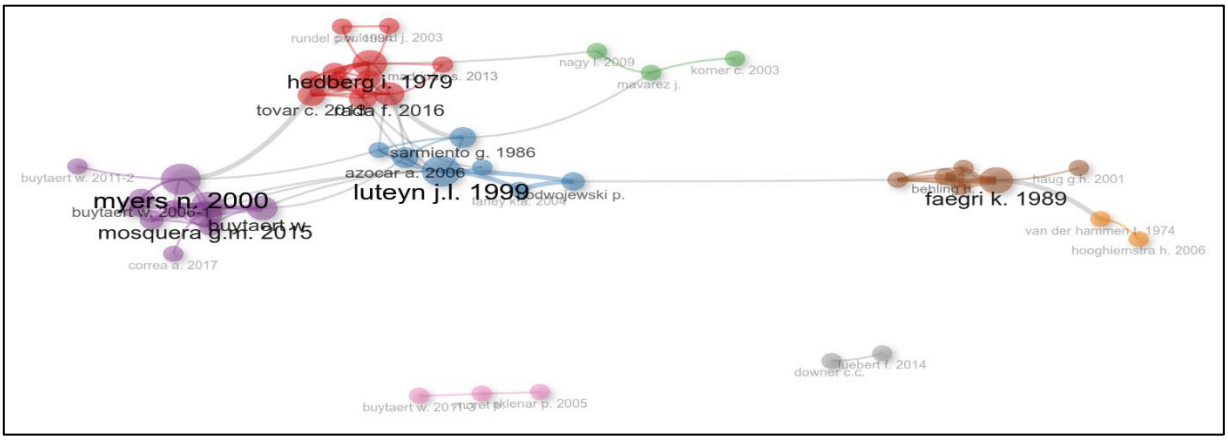


Fig. 13. Co-citation network

## DISCUSSION

The first set of findings in this study relates to performance analysis, i. e., the analysis of the contributions of research constituents to a given field (Donthu *et al*, 2021). These findings allow us to answer the first research question of this study regarding which publications, authors and countries have made the greatest contributions to climate change and the paramo ecosystem.

The research published in the Scopus database, which highlights the relationship between climate change and the paramo ecosystem, started to increase in 2018, with a CAGR of 13.35% since then. At that time, NASA reported 2018 was the fourth warmest year since 1880 (National Aerospace Agency, 2019). Reports such as this may be linked to increased research on climate change, such as in the case of paramo ecosystems. This suggests that there is a positive impact of these reports on the scientific community.

It is noteworthy that Colombia, Ecuador and the United States were the most productive countries in this field. Based on the affiliation of the authors, the Universiteit van Amsterdam (Netherlands) and the Universidad de los Andes (Mérida, Venezuela) are the leading institutions in the region. In terms of funding sources, MinCiencias (Colombia) and the National Science Foundation (United States) were the most important. This means that Colombia, Ecuador and Venezuela are hotspots in South America for research on climate change and paramo ecosystems; these countries concentrate about 84% of the area corresponding to paramo ecosystems in the world (Hofstede, Segarra & Mena, 2003). Outside the tropical Andean region, the United States and the Netherlands are additional hotspots for research in this area. In terms of influential journals, Plant Ecology and Diversity and Plos One are the most active and significant in the field, the latter having the higher h-index. The top three authors regarding productivity are Llambí L. D., Hooghiemtra H. and Behling, H., with the second having the higher h-index. These results could be of use to researchers and institutions in the search for collaborators, journals or sources of funding in this area of study.

The second set of findings of this study relates to science mapping and network analysis, i. e., the analysis of the relationship between research constituents (Donthu *et al*, 2021). These findings allow us to answer the second and the fourth research question: What are the underlying strands of research and how have key studies on the topic changed over time? What are the main concerns and trends that are emerging in the present day?

The analysis of the authors' keywords revealed four meaningful clusters related to climate change and the paramo ecosystem, three of them can be understood as the underlying strands of research in the field. These are, first, palynological and palaeoecological studies focusing on vegetation dynamics and history; second, carbon cycle and sequestration, land cover and use, ecosystem services and water resources; and third, biodiversity, adaptation, conservation and environmental protection. Four main periods of research were identified from the variation of keywords over time and reflect the change of these topics over time. Between 2010-2014 the main focus of the literature corresponds to the first cluster; between 2014-2018, the main focus of the literature corresponds to the third cluster; between 2018-2024, the main focus of the literature corresponds to the second cluster. This last period indicates the major concerns and trends that are emerging now in the field: carbon cycle and sequestration, land cover and use, ecosystem services and water resources. Within this cluster, the most recent publications between 2022 and 2024 are focused on geographical patterns and potential drivers on carbon dynamics in the high-andean peatlands cushion and the improvement of remote estimation on soil organic carbon in complex ecosystems, using Sentinel-2 and GIS with Gaussian processes regression.

With regard to the research gaps in the field of climate change and paramo ecosystems during the period under consideration, the third research question of this study, the major research trends mentioned above provide an insight. A small proportion of the literature introduces social science and humanities perspectives, including biocultural, sociological and socio-ecological approaches. This suggests that the analysis of the paramo cultural landscape and its world-making practices has been a neglected topic in the literature about climate change. Additionally, it is remarkable that of the 201 papers on paramo and climate change published in Scopus between 1981 and 2024, 87,06% are data-driven articles. This indicates a preeminence of empirical and quantitative analysis in the field. This suggests that for other types of scholarly works such as theoretical papers, literature reviews and case studies, there is a gap in the literature.

## CONCLUSION

Through bibliometric analysis, we explored research trends, collaborative networks and thematic assessment of documents on climate change and paramo ecosystems published in Scopus in the last forty years. As shown, these analyses revealed three main research trends in the field and their evolution over time. In these thematic tendencies, a predominance of life sciences and empirical approaches was identified. This suggests a gap in the literature and points to the need to increase scientific production in the field from the perspective of the social and human sciences and their publication in this type of academic databases.

It is important to note the limitations of this study. First, although Scopus is a widely used database for bibliometric analysis, there are many journals that are not indexed in Scopus. Second, 82,08% of the documents analyzed were written in english, this leaves out of the study publications in other languages. This is noteworthy because most of the paramo ecosystems are located in Spanish-speaking countries in the tropical Andes. As shown, countries like Colombia, Ecuador and Venezuela are hotspots in South America for research on climate change and paramo ecosystems. It is likely that a study that includes databases with publications mostly in Spanish (such as Scielo, Redalyc, among others) would yield an even higher incidence of these countries and their institutions in the field. The conclusions of this study may not be the case in those databases. Third, bibliometric analyses does not offer detail insight regarding thematic assessments, this would require an in-depth literature review. Despite the limitations mentioned, bibliometric analysis offer useful information for researchers and policy makers and help synthesize the literature.

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