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Review

Financing sources for mitigation of adverse climate change: a systematic review

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Abstract
Accelerating climate change has harmed food and water security and affected both terrestrial and aquatic systems, hindering efforts to meet many Sustainable Development Goals [SDGs]. Climate finance can help mobilize financial resources and tackle the effects of climate change. This study analyzes existing literature on climate finance more broadly from its beginning to its current status. It reviewed 311 relevant articles from 2005 to 2023 using qualitative content analysis [QCA] and meta-analysis to identify common themes and their classification based on pre-determined article criteria. We also identify research gaps within each theme and suggest priority finance areas. Our result suggests that the periodic publications have drastically increased in the past few years, especially after the Paris Agreement in 2015. With content analysis of prior research, most of the research used quantitative and econometric approaches. With the review of papers, it can be concluded that climate finance is mostly constrained in vulnerable regions in which the risk of climate change and its adverse impacts are delicate, including low-lying coastal areas, SIDS, deserts, mountains, and Polar Regions. Innovative climate finance funding should focus on renewable energy, energy efficiency, and infrastructure that aids adaptation in vulnerable communities. Emphasis should be placed on initiatives that provide both mitigation and adaptation advantages, ensuring a resilient and sustainable future. While research primarily focuses on adaptation and mitigation, the interplay between these two areas requires further exploration. We highlight the knowledge gap in this research domain examining the financing sources for mitigation of adverse climate change from private and public sectors.

Keywords Climate financing · Systematic review · Climate change · Mitigation · Adaptation

Abbreviations

IPCC	Intergovernmental Panel for Climate Change
UNFCCC	United Nations Framework Convention on Climate Change
GCF	Green Climate Fund
SDG	Sustainable Development Goals

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1 Introduction

Irregular climate patterns have caused widespread damage to ecosystems, reducing their ability to adapt and recover. This adverse impact on nature has disrupted seasonal cycles and, consequently, severe socioeconomic impacts [1–3]. This adverse impact on nature and people globally is caused by human-induced climate change [4, 5]. IPCC report has confirmed that the human mortality from natural disasters in highly vulnerable regions was 15 times higher, as compared to low vulnerable areas as per the data from 2010 to 2020 [6]. The Sixth Biennial Assessment and Overview of Climate Finance Flows found that global climate finance flows reached an average of USD 1.3 trillion in 2021–2022, an increase of about 63 percent compared to 2019–2020 [7]. Although climate finance definition has not been defined in detail the UNFCCC Article 4.3 states "The developed country Parties and other developed Parties included in Annex II shall provide new and additional financial resources to meet the agreed full costs incurred by developing country Parties in complying with their obligations under Article 12, paragraph 1" [8]. Climate finance prioritizes principles on long-term investment that lead to safeguarding the environment and propels innovations in adaptation and mitigation strategies, causing not only the progress of renewable energy but also, a broader spectrum of emissions reduction and climate resilience outcomes [9–11]. This includes public financing and mobilising private finance that is provided under the climate agreements as a direct result of public funds [7, 12, 13]. There are several reasons for unfulfilled demand on climate finance depicted in various studies that result in environmental depletion [2, 14, 15], excessive use of non-renewable energy [16, 17], industrialization [18], unorganized economic growth [19, 20], the economy and the financial system [21, 22], unsustainable tourism [17, 23, 24] and sectoral output [25–27]. The literature on climate finance emphasizes that climate funds are indispensable in climate mitigation and adaptation [1, 28, 29]

Leaders demonstrated strong confidence in the establishment of various Climate funds like the Adaptation Fund, Green Climate Fund, and Climate Investment Fund. The Adaptation Fund, established under the Kyoto Protocol, is a crucial player in the global fight against climate change empowering vulnerable countries by allocating substantial funds to build resilience to climate change. It has committed US$ 1.2 billion in grant funding to over 180 adaptation projects, nearly half in least developed countries or small island developing states [30]. Developing countries represent less than 20% on supporting climate action averaging USD 1 265 billion during 2021–2022 [30]. This is primarily due to the challenges in securing both public and private financing, compounded by high capital costs [10]. Developing countries advocate for the exclusion of loans while most climate finance from developed countries is provided in the form of loans [30]. For example, in 2022, loans covered 69.4% of international public climate finance, with only 28% provided as grants [10]. Significant deficiencies in prevention and preparedness are observed even in developed countries due to extreme climatic events [12, 31].

The Kyoto Protocol 1992 established binding emission reduction targets for developed countries, marking the first global effort to combat climate change. However, the Protocol's limitations, including the absence of commitments from major developing nations, prompted the need for a more comprehensive agreement. The Paris Agreement 2015 superseded the Kyoto Protocol by engaging all countries in climate action. A key component of the Paris Agreement is the commitment of developed countries to provide climate finance to support developing nations' mitigation and adaptation efforts. This landmark agreement introduced Nationally Determined Contributions [NDCs] to foster a bottom-up approach to emissions reduction [32]. While building upon the Kyoto Protocol's financial mechanisms, the Paris Agreement aims to significantly scale up climate finance to meet the challenges posed by climate change to limit temperatures to rises of 2 degrees and pursue efforts for 1.5 degrees [32, 33].

Sustainable finance is a broad term encompassing financial activities that contribute to the Sustainable Development Goals [SDGs]. Green finance is a subset focused on environmental sustainability, such as reducing carbon emissions and protecting natural resources [34]. The absence of standardized definitions for many sustainability-related terms creates opportunities for greenwashing. The first article on green finance was observed in 2006 for green buildings [35]. Climate finance can be regarded as a subset of green finance [36] and more specifically concentrating on investments that tackle climate change. Unlike traditional finance, these approaches prioritize ethical considerations and address social and environmental issues [37]. In this regard, the study scans the volume of research on Sustainable Finance, Green Finance, besides climate finance, Adaptation Fund, Financing Climate change in the preliminary stage to depict the volume of in climate finance as compared to sustainable finance and green finance.

A recent bibliometric analysis by Shang and Jin examined 2311 articles on climate finance from the Web of Science, employing descriptive and cluster analysis [38]. While this study provides a valuable overview, it lacks in-depth

exploration given the substantial sample size. In contrast, a broader review by Kouwenberg, Roy, and Zheng encompassed renewable energy, green finance, investment, and climate risk [39]. A comprehensive review of existing literature on climate finance reveals a significant gap in in-depth analyses of research methodologies, scope, and findings [40, 41]. While numerous studies have explored various aspects of climate finance, there is a dearth of research that systematically evaluates the strengths, weaknesses, and methodological rigor of previous studies. Despite increasing academic interest, research on climate finance is still fragmented, with limited studies comprehensively assessing its mobilization, distribution, and impact. This study aims to investigate the existing academic literature on climate finance systematically by:

- Assess the current state of knowledge and identify key research gaps in climate finance.
- understanding the trends in climate finance research and evaluating the effectiveness of climate finance initiatives in achieving their intended goals

This section of the study is followed by the research methodology which elucidates the detailed and systematic approach of the literature review steps starting from searching for articles via keywords to retrieving the articles and scanning them to finally analyzing relevant literature as per the research objectives. Next, the results and discussion section presents the comprehensive detailed outcomes of the analysis of articles along with empirical evidence to achieve the aim of this review article. Finally, the closing section of the study summarizes and concludes the study with the contribution of each author in the study followed by Future Pathways.

2 Methodology

A systematic literature review approach is used to assess the extent of the study of climate finance. The systematic literature review is an effective technique to extract and synthesize the data which can assist and propose future directions [42–44]. It involves reviewing the documents after the clear formulation of research questions and selecting explicit and systematic methods to appraise relevant research critically [44]. This approach is extensively used in the health sciences, but it has not been commonly used in studies related to environment and climate change studies and offers considerable promise in the field [26]. Three-stage Systematic Literature Review [SLR] approach is used to surf, identify, download, and analyze relevant literature (Fig. 1) to meet the research objectives. This approach includes the following steps depicted in Fig. 1, with detail explained further.

2.1 Summary of document selection

2.1.1 Phase 1: stage 1: document selection

Scopus covers a wide range of journals with the keyword search which is currently limited to articles published after 1995 [45]. Around 99.11% of the journals indexed in Web of Science are also indexed in Scopus [46]. This literature research relates to the latest updates on the subject, it focuses on Scopus-indexed journals and further explores the Web of Science to ensure all documents are scanned.

This section discusses the keywords used to identify how these relate to the trend in climate finance studies.

In the search engine Scopus and Web of Science, in the first phase, several keywords search was performed using the terms "climate finance", "Adaptation fund", "Financing climate change", "Green finance", and "sustainable finance" for keywords, titles, and abstracts. "Financing climate change", "Green finance", and "sustainable finance" signify broader aspects including all types of financial flows with environmental objectives, Sustainable Development Goals.

The Kyoto Protocol introduced the concept of climate finance through the Adaptation Fund. For this reason, "Adaptation Fund" is also used as a Keyword for the initial search so that no research is overlooked in the next step for review. The Boolean "OR" was used to facilitate the search query for the keywords. Hence, other funds like the Green Climate Fund, and Climate Investment Fund are also not excluded in this search. Three different dates were taken to determine the extent of the search. Firstly, data was undefined, secondly, 2005 was taken considering the Kyoto Protocol, and lastly, 2019 aligned with the Paris Agreement. The period was considered from 1995 to 2023 for the initial phase. A total of 15,944 articles were found in the first step from Web of Science and 21,022 in Scopus. Details of the result are presented in the Annexure Table.

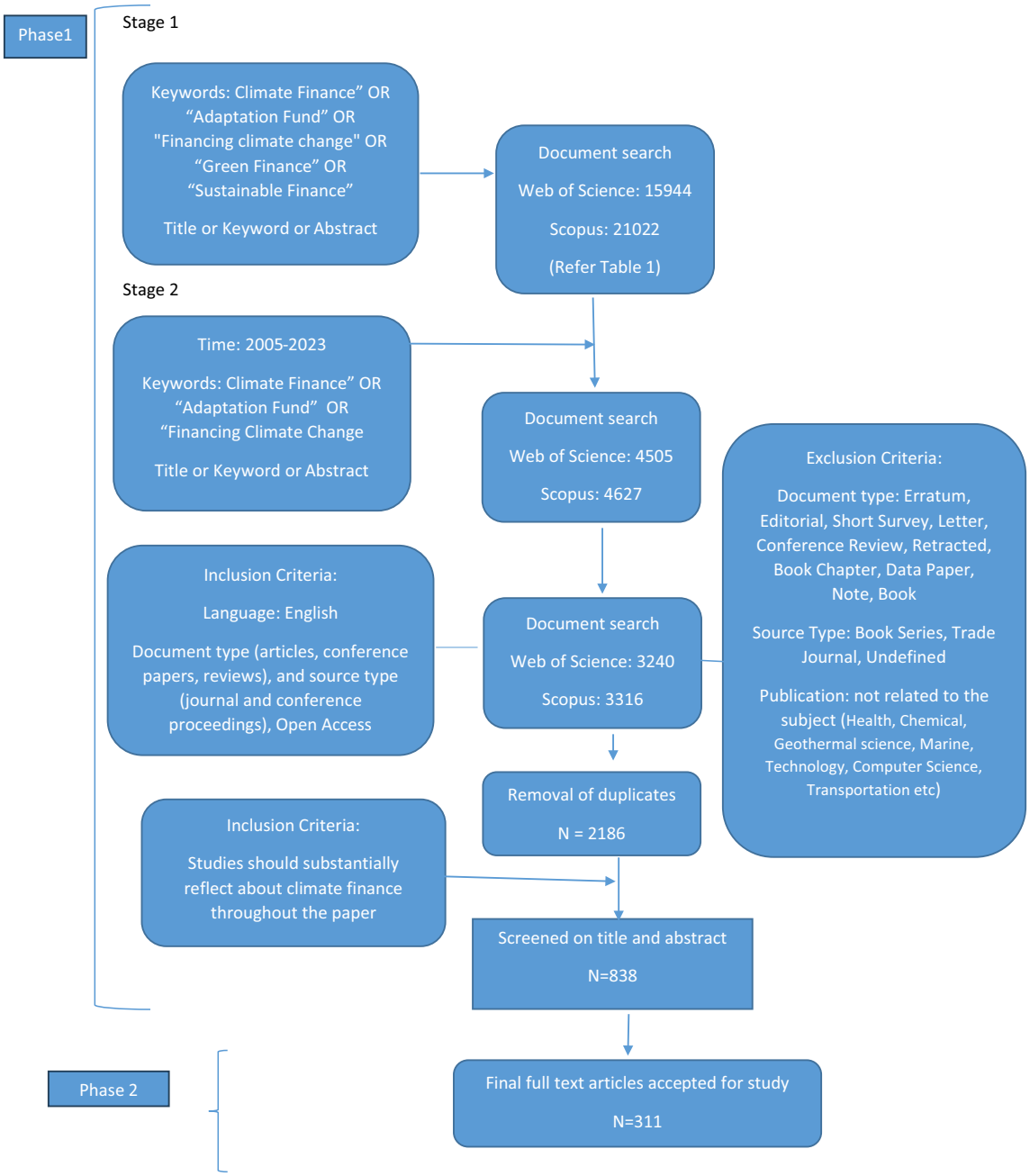

Fig. 1 Flowchart diagram depicting the documents allocated on a search string and assessed based on inclusion or exclusion criteria

This preliminary step involves mapping existing research in the field of climate finance. This process is significant because it helps establish a comprehensive understanding of the scope and comparative analysis of the volume of research already conducted on the topic. Phase 1 stage 1 delves into objective 1 to identify the scope of climate finance research by understanding the volume of transactions as compared to other broader research topics such as sustainable finance. Then, stage 2 deep dives into scanning the papers specific to three keywords as mentioned in Fig. 1. It is a part of the research methodology process to understand the influence and relationship with other terminologies but further filtering it to the next step of meta-analysis.

2.1.2 Phase 1: stage 2: selection of relevant articles

The data was further filtered as per the research objective. Green finance covers broader objectives on the environment where the climate is a part of it. On this note, in Stage 2, green finance was excluded to narrow the research. Similarly, "Sustainable finance" is not limited to climate, it covers a wide range including SDG where climate action is Goal 13. So, sustainable finance is also excluded in the next step of the keyword search. "Financing climate change" is covered by the keyword "climate finance". Concerning the scanning of papers and huge data, these keywords were excluded for further step 2. The research was limited to the keywords "Climate Finance" OR "Adaptation Fund" to cover the contribution to climate change. The data was limited from 2005 to 2023. This step showed 4505 articles from Web of Science and 4627 from Scopus respectively. In the next step, the outcome was restricted to the English language, document type [articles, conference papers, reviews], and source type [journal and conference proceedings], which resulted in 3240 articles from Web of Science and 3316 from Scopus. The removal of duplicates and data filtration of the entire search validated 838 documents for stage 2 and was accepted for this study.

Inclusion and exclusion criteria were applied to all the articles as outlined in (Fig. 1) to extract the relevant articles for the research. The article must be published in a top-tier journal or conference and should be an open-access journal. Articles that are published in reputable journals and conferences have a significant contribution to practicality and future research [47, 48]. A brief reading was conducted on the initial outcome of the search which passed 838 articles to the next step, based on title, keyword, and abstract. To address the study objectives of this research, the article must contain sufficient information on climate finance throughout the article in the introduction, methodology, and conclusions, not limited to policy recommendations. Articles that did not meet the criteria were excluded in a further step of research. An in-depth full-text review was also conducted in some cases, to determine the acceptance of the article on final review for the next process (Table 1).

2.1.3 Phase 2: content and meta-analysis

In the final stage, accepted articles [311 articles] were fully read and assessed with the aid of qualitative content analysis [QCA] and meta-analysis. QCA categorizes the text data to identify the common themes in research through classification [35].

This table provides a general overview of key themes and topics that emerged from the QCA process. Furthermore, a trend analysis was performed for the selected articles, the nations or target countries, the methods, and the analysis of areas of climate finance being studied in the articles.

2.2 Limitations of research

This research has focused on the open access academic articles in Web of Science and Scopus so there might be an unintentional exclusion of any research of any institutional research. Furthermore, the screening process has made the exclusion/inclusion of research consistent, however, there might be some degree of subjectivity [49].

Table 1 Key themes and the topics

Theme	Topics
Adaptation and Mitigation	Vulnerability assessments, adaptation planning, disaster risk reduction, climate-resilient financing for adaptation and mitigation
Donor Recipient Dynamics	Financial intermediaries, Public finance, private finance, blended finance, impact investing, climate funds, Debt Financing
Political and Socio-economic Dimension	Climate Justice, Economic analysis, Political economy, Climate policy, Governance, International cooperation, Power dynamics,
Monitoring and Risk assessment	Monitoring, Risk assessment

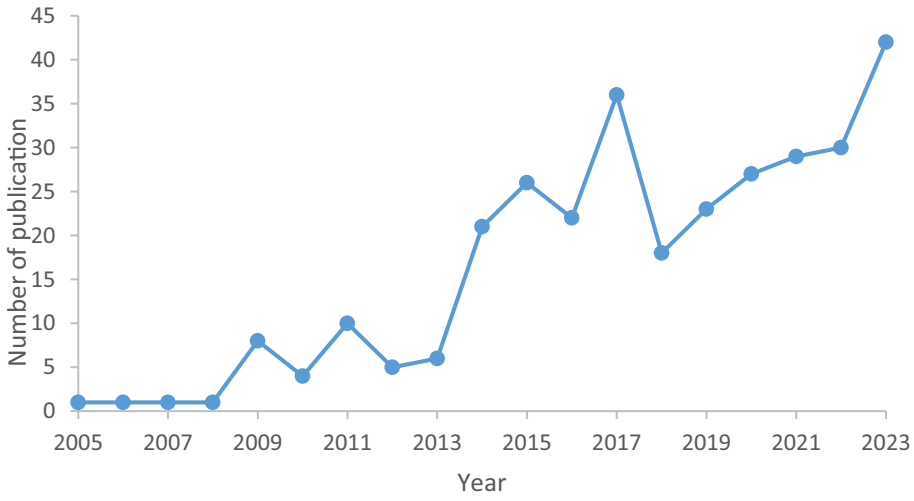

Fig. 2 Growth in climate finance research [N = 311]

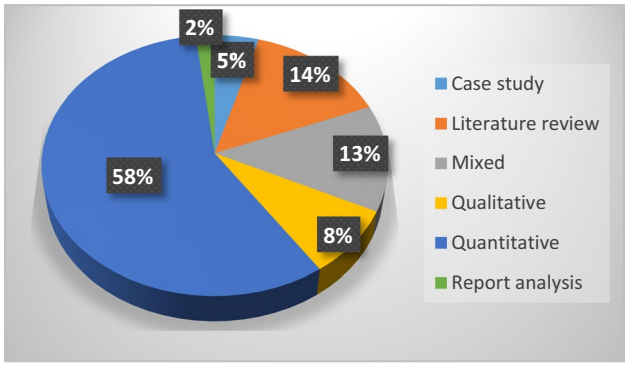

Fig. 3 Segregation of articles by research method [N = 311]

3 Result

3.1 Analysis of the trend of publications

The emerging necessity of climate finance is realized amidst increasing pollution and global warming driving momentum globally for reform. Climate change poses profound development challenges. Investment in climate change and research in this sector is a necessity in the current era.

Figure 2 shows the upward trend of research in the area of financing climate change which shows that researchers are becoming conscious of the impact of climate change. One of the research on climate change linked with economic vulnerability under bibliometric analysis also showed similar results of uprising trends in the research in the academic arena [40]. The growing trend of research on climate change is evidence that climate is a global concern.

Only one article was published in the initial years as shown in the figure in 2005–2008, which gradually increased. The perceived necessity of funding for climate change was realized and in 2005, the Kyoto Protocol was introduced. Massive growth in the research of climate finance was observed in 2014 with 21 papers as compared to 6 papers in 2013. However, with the formulation of the Paris Agreement in 2015, the highest number of articles in the sample were observed in 2023 followed by 2017 respectively. The number of articles seems to drop after 2017, but it is rising after 2018.

3.2 Analysis of methods of research

As shown in Fig. 3, much research was broadly done using global databases using statistical and econometric models with quantitative methods used with 58% of articles as per the nature of the subject, followed by a literature review

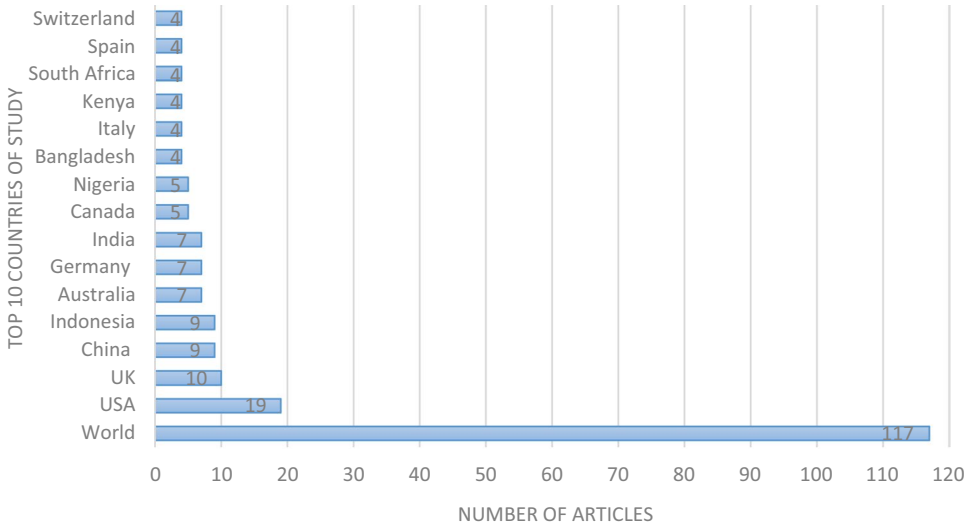

Fig. 4 Top 10 countries of research in the reviewed articles N = [311]

with 14%. Most of the qualitative research papers focused on field surveys and interviews, covering 8% of the articles. There were few research papers on report analysis [2%], mixed method [13%], and case studies [5%]. One paper on literature review and case study was regarded as a mixed approach, and one expansion of the previous article was ignored for this analysis. Two papers were based on a theory.

3.3 Nations of a research area

Figure 4 shows the top 10 countries which were used as the area of research in the selected 311 articles. As most of the research used quantitative data, more than 100 research were conducted comparing datasets of developed, developing, and least developed countries. Most research analyzed the fund flow mechanism to provide policy recommendations. The highest number of research was conducted in the United States with 19 research followed by the United Kingdom with 10 research. There were 9 research in China and Indonesia followed by 7 research in Australia, Germany, and India, with 4 in Bangladesh, Italy, Kenya, Spain, South Africa, and Switzerland respectively. These articles completely focused on a particular country. However, there was little research that focused on a group of countries and continents (Fig. 5).

The result depicts that a majority of articles have centered on **developing countries**. However, some papers had particular emphasis on **Africa**, **Europe**, and **Australia**. Here's a more structured breakdown:

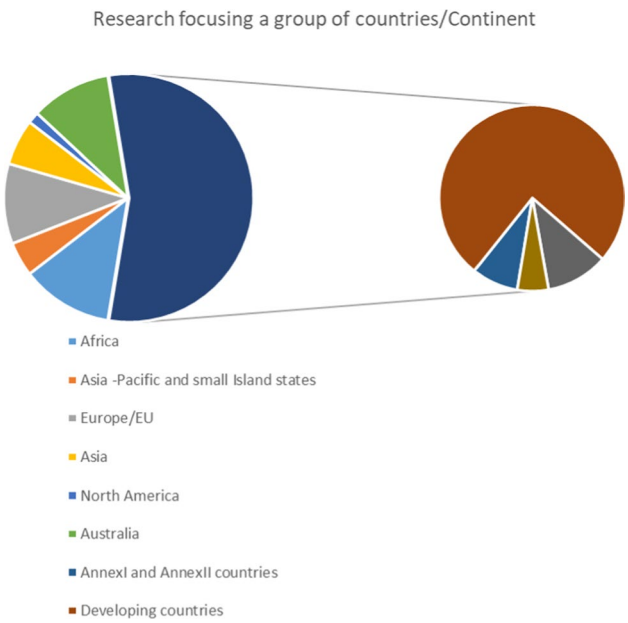

Fig. 5 Research that focused on Continents/Area Specific [N = 311]

1. **Africa (8 articles)**: A significant portion of research is focused on Africa, possibly due to its high vulnerability to climate change and the need for tailored financial mechanisms to address its challenges.
2. **Europe (7 articles)**: Europe may be studied for its role in climate finance, both as a region of significant climate policies and as a donor of financial resources to developing countries.
3. **Australia (7 articles)**: This continent appears to be another major focus, likely due to its position in the Asia–Pacific region and its involvement in regional climate finance discussions.
4. **Asia (4 articles)**: Research on Asia is somewhat less than in the previous regions but still significant. Within Asia:
    - **Greater Mekong region (3 articles)**: This sub-region may be studied due to its unique challenges and climate risks, necessitating financial solutions.
    - **ASEAN countries (1 article)**: ASEAN's collective climate finance efforts or policies might be a subject of interest, particularly in terms of regional collaboration.

This pattern suggests that climate finance research has a geographic bias toward regions with substantial vulnerability to climate change, as well as regions actively engaged in climate finance mechanisms, both as recipients and providers of funds. The focus on developing countries, particularly in Africa and parts of Asia, highlights the pressing need for climate finance solutions in these regions. The remaining papers moreover focused on country-specific research.

Most of the research used quantitative analysis with a total of 179, as shown in Table 2. For quantitative analysis, the papers used secondary data sources from the global databases extracted from various international organizations. There are 41 articles on literature review, with 26 using qualitative techniques, 41 with mixed methods, and 2 comprehensive reviews. Case studies include four studies in African countries that were country-specific [Kenya 2, Ethiopia, and South Africa], with one in China, India, and Australia with the rest being comparative case studies. Similarly, Report analysis includes the analysis of various reports published by international organizations such as UNFCCC, GCF, World Bank's Pilot Auction Facility, and the Caribbean Ocean Assets Sustainability Facility.

The table 3 above shows the breakdown of the papers based on research. The highest number of papers were observed on adaptation followed by Fund analysis. Fund analysis includes papers related to the Green Climate Fund [15 papers], 9 in Adaptation Fund and Paris Agreement, 3 in IPCC, 8 in REDD, and the rest for UNFCC, EU fund, trust fund, Global Green New Deal-GGND. 38 of climate policy research emphasizes the critical role of good governance in mobilizing climate change adaptation funds. Monitoring and risk assessment papers highlight the need for robust accountability frameworks delving into public and private financing, international climate finance, climate rent curse, and public instruments to support private financing. Hence, the themes depicted are interrelated in the sample research papers.

Table 2 Type of article based on the year [N = 311]

Year/Type of article	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	Grand Total
Case study			1					2		1	2	1	2	1	1	2		1		14
Expansion of previous article												1								1
Literature review		1			3	2	3			2	4	6	2	1	2	3	8	2	2	41
Mixed									1	4	3	2	4	5	5	4	5	3	5	41
Qualitative										1	3	1	1	1	5	2	4	4	4	26
Quantitative				1	5	2	7	3	5	13	14	8	25	10	10	16	12	21	27	179
Report analysis	1											3	2							6
Econometric model																		1		1
Comprehensive Review																			2	2
Grand Total	**1**	**1**	**1**	**1**	**8**	**4**	**10**	**5**	**6**	**21**	**26**	**22**	**36**	**18**	**23**	**27**	**29**	**32**	**40**	**311**

Table 3 Research themes and their count [N = 311]

Research themes	Number of papers
Adaptation and Mitigation	84
Adaptation	77
Mitigation	7
Donor Recipient Dynamics	26
Debt and equity financing	8
Private finance	5
Public finance	13
Monitoring and Risk assessment	31
Monitoring	26
Risk assessment	5
Political and Socio-economic Dimension	170
Climate justice	6
Economic analysis	10
Financial intermediaries	18
Fund analysis	58
International Finance	36
Policy and governance	38
Political economy	4
Grand Total	311

4 Discussions

Research papers underscore the critical need for increased scientific understanding of climate impacts to inform effective adaptation strategies [35]. The research conducted in the first stage to analyze the volume of articles published in different sectors. This shows that green finance had a significant number of research papers followed by Sustainable finance and Climate finance. Green finance is the broad aspect that comprises financing in sustainability, renewable resources, circular economy, biodiversity, and pollution [34, 50] and climate is a core element (Annexure). Further, a detailed analysis of the study of climate finance shows research on climate finance has expanded significantly in response to growing concerns about global warming.

4.1 Research trends on adaptation and mitigation

Early studies, primarily published between 2005 and 2008, focused on adaptation financing and the role of climate policies in sustainable development. The landmark study by Bowman has highlighted the banking sector's crucial role in climate resilience, with the shift of emphasis towards mitigation and equitable fund distribution [24, 51]. Climate change poses significant challenges, demanding substantial financial resources for mitigation and adaptation [52]. The allocation of climate finance has historically favored mitigation over adaptation. However, the growing recognition of the urgent need to build resilience has led to a shift in focus. While the ratio of mitigation to adaptation funding has improved, there is still a significant gap. To effectively address climate change, it is essential to allocate resources strategically, considering the specific needs and vulnerabilities of different regions. Global climate finance has steadily increased, with both public and private sources contributing to the overall flow of funds.

Collaborative efforts across diverse management landscapes are essential to identify factors influencing adaptation success and optimize limited resources. Leveraging public–private partnerships and exploring alternative financing mechanisms [53], such as remittances, can help overcome barriers and capitalize on opportunities. Strategic investments in renewable energy, energy efficiency, reforestation [68], and climate-resilient infrastructure are essential for building resilience and mitigating climate risks [6].

4.2 Geographic disparity on climate change impacts and vulnerabilities

Climate finance research has expanded significantly in recent years, with a growing emphasis on adaptation and mitigation strategies. While the majority of studies focus on developing countries, particularly in Africa and Asia, there is a growing body of research on developed economies and emerging markets. Geographic disparities in research are evident, with regions such as Sub-Saharan Africa and Small Island Developing States receiving relatively more attention [54].

Climate change disproportionately affects vulnerable populations in Africa, small island states, and other developing regions [55]. These communities face a confluence of challenges, including food and water insecurity, poverty, and limited access to basic services. While climate finance is essential for addressing these issues, a balanced approach to mitigation and adaptation is crucial for long-term resilience.

4.3 Donor-recipient dynamics and institutional capacity

The effectiveness of climate finance is influenced by the capacity of recipient countries to absorb and utilize funds. Studies have highlighted the importance of strong institutions, good governance, and effective project implementation [56, 57]. Donor countries play a crucial role in shaping the climate finance landscape, with their policies and priorities influencing the allocation of resources.

Climate finance research primarily focuses on donor-driven initiatives, with a strong emphasis on international funds, aid, and grants. The overarching goal is to facilitate the transition to low-carbon societies, where international organizations are flexible for implementing adaptation initiatives however, at the same time, it is difficult to measure and track levels of multilateral adaptation finance as emphasized by Pickering et al. [27]. Studies have identified various modes of climate financing, including public grants, loans, and equity, as well as private investments through channels such as green bonds and impact investing [29, 33]. While research often concentrates on adaptation and mitigation, understanding the role of financial intermediaries, such as banks and insurance companies, is crucial for effective climate finance mobilization [58, 59].

4.4 Public and private financing for climate action

While both public and private financing are essential for addressing climate change, the predominance of public funding in adaptation projects is evident. However, the growing recognition of the private sector's potential has led to increased efforts to mobilize private investment through public–private partnerships and supportive regulatory frameworks. While research primarily focuses on adaptation and mitigation, the interplay between these two areas requires further exploration. Governments have increasingly recognized the need to mainstream climate considerations into development planning, leading to efforts to allocate climate budgets across various sectors [50]. Building strong institutional capacity is crucial for effectively managing climate finance and ensuring accountability [9].

To maximize the impact of climate finance, close coordination between climate change policies and public expenditure is essential [13]. This approach enables a comprehensive assessment of vulnerabilities and the development of targeted interventions. By leveraging public funds to catalyze private investment, governments can create an enabling environment for climate-friendly projects and stimulate innovation [13].

Twelve articles were on public finance, while only 4 articles were on private finance. Two articles discussed both, so a number was added to each of public and private finance with a total of 13 in public finance and 5 in private finance. There is a growing trend in the participation of private and public actors in total climate finance investment [6]. Public financing is the main source of financing for climate in developing countries [40]. The demand for early public intervention has become essential, due to the high initial costs and investment required to adopt a low-carbon development path. Private financing in developing countries is only possible with an appropriate risk-adjusted return, with public support to overcome operational expenses and other obstacles, including climate-related research and development [58]. Large up-front costs to invest in projects can be undermined through incentives like transparent financial intermediation, stable political and regulatory bodies, a liberal trading regime, and administrative simplicity [38, 56, 60]. Impairment of private-sector financial intermediation creates doubts about counterparty solvency and

increased uncertainty about asset valuations [47, 61]. Due to the low-income level of people in developing countries, financial intermediation is rudimentary or non-existent [62]. Hence, development goals such as education, food security, poverty alleviation, and climate justice, when aligned to social safety nets targeting supporting climate change adaptation help to enhance the adaptive capacities of highly vulnerable rural and urban communities [52].

4.5 Political and socio-economic dimensions

The Paris Agreement in 2015 marked a turning point, with a surge in research on climate finance governance, policy, and law. The papers increasingly emphasized the need for visionary national-level policies and the potential of digital technologies to enhance climate finance effectiveness. National Climate Change Policies often articulate low-carbon development goals, but the effective implementation of adaptation and mitigation measures remains a challenge. Climate justice, economic analysis, and political economy have been central themes in the socio-economic aspect, with a focus on adaptation, risk assessment, and the interplay between climate finance and broader development goals. For instance, four papers investigated the link between climate justice and equitable distribution of climate change burdens and benefits, to reduce social vulnerability and preserve the rights for adaptation.

Climate finance is the most contentious issue in climate politics [25]. The effectiveness of climate finance is influenced by various factors, including institutional capacity, governance, power dynamics, and the alignment of financial flows with development priorities [63]. Addressing the gap in the international fund flow mechanism is crucial for scaling up climate action [19, 53]. Private finance should be a part of wider financial flows toward low-carbon and climate-resilient development. Moreover, the integration of climate finance with other development objectives, such as poverty reduction and sustainable growth, is essential for achieving long-term resilience.

4.6 Climate finance mechanism with financial instruments and intermediaries

A variety of climate finance mechanisms have been explored in the literature, including public grants, loans, and investments, as well as private sector financing. A diverse range of financial instruments, including grants, loans, equity, and insurance, are employed to fund climate change mitigation and adaptation efforts. While public finance remains a dominant source, the increasing role of private investment is essential for scaling up climate action [6]. Financial intermediaries, such as banks and insurance companies, play a crucial role in channeling funds to climate-related projects [63].

The period after 2010 witnessed a broadening of research scope, encompassing the effectiveness of international climate funds, community-based adaptation costs, and the role of financial instruments such as insurance and banking in supporting socioeconomic development and disaster recovery. Research also delved into the distribution of climate-related risks and responsibilities, the potential of climate derivatives, and the growing influence of the private sector. The first policy on climate finance was observed in 2010 by Buchner, B. "The State of International Climate Finance: Is It Adequate and Is It Productive?".

Numerous papers highlight the importance of insurance mechanisms in managing climate risks. Six papers discussed insurance under financial intermediaries. By offering financial protection against climate-related disasters, insurance can help build resilience and facilitate private-sector investment. However, the effectiveness of insurance depends on factors such as the depth and breadth of coverage, as well as the ability of governments to create enabling environments.

4.7 Comparative analysis of research conducted on developed and developing countries

The availability of financial resources is directly affected by adverse climate, resulting in losses and damages impeding national economic growth, particularly for developing, least developed countries and coastal residents [51]. Most of the research papers focused on developing countries, 50% of which had an association with developed countries to depict the find flow mechanism. While a handful of research focused on country-specific and region-specific as well, 36 articles discussed international climate finance. Developing countries require external aid and assistance, whilst developed countries are committed to providing financial support and resources to combat the severe climate change [59]. Even though the investment in climate change has considerably increased, huge gaps were observed in the articles for estimating the climate finance demands as compared to investments. Articles have shown that most of the investments in developing countries are focused on mitigation finance. While most research papers depict that adaptation finance can go long-term, resource allocation criteria are one of the important factors to consider, in any project for sustainable development.

Vulnerability represents the primary criterion in the case of adaptation funds, whilst the main criterion for mitigation funds is the potential of emission reduction in transition to a low-carbon economy by developing countries [35, 64]. This is due to extreme weather conditions, social vulnerabilities, or lack of strategy and planning. Powerful and developed countries have a crucial role in contributing to low carbon, especially energy transition and more climate finance support. So, many articles tried to depict the mechanism of fund flow to recipient countries for effective utilization of funds in developing countries. Besides, a proper mechanism of data monitoring and performance evaluation of the effectiveness of climate aid is essential to analyze the significance of aid and support provided to developing countries [64, 65]. Countries with higher climate vulnerability tend to receive more mitigation and adaptation funds, however, there was one research, suggesting that 'moderately vulnerable' countries are likely to receive more funding than the 'most vulnerable' countries [40]. Further, the research also showed that despite the higher climatic vulnerabilities, the Sub-Saharan Africa and South Asia regions were likely to receive significantly less adaptation and overlap funding. Investment readiness and past funding had significant effects on current funding. Although positive changes have occurred since the 2015 Paris Agreement, there are considerable challenges to distributive justice.

5 Future pathways of research

Climate finance research has grown significantly in recent years. As the field evolves, future research in this area can focus on the following pathways:

- **Predictive analytics for climate finance:** Leveraging advanced predictive modeling techniques and data-driven models that can enable policymakers to allocate resources more effectively and forecast the long-term financial requirements of climate adaptation and mitigation, helping to align funding with future needs.
- **Policy analysis:** A substantial body of research has examined appropriate climate finance policies, including governance, EU regulations, and public–private partnerships. Nineteen papers in this category explored how to effectively channel public funds to support private-sector investments. Future research can focus on detailed policy analysis by assessing the consistency of climate and development policies and identifying opportunities for greater alignment.
- **Synergies between climate finance and SDGs:** Quantifying the co-benefits of climate finance investments in terms of SDG achievement, such as poverty reduction, improved health, and enhanced food security would be one of the future pathways of research. Future research should prioritize the interrelationship between climate finance and multiple Sustainable Development Goals [SDGs], particularly in developing countries, emphasizing the need for a multi-lens approach to address complex social challenges effectively.
- **Socio-economic dimensions:** To address the complexities of climate change, future research should explore innovative financing mechanisms, the specific needs of developing countries, and the potential of technology to enhance the climate finance flows across different socioeconomic groups and regions, and identify potential equity implications.

6 Conclusion

The trend of research in this arena has systematically grown over the past years, while new concepts and methods of finance are also constantly emerging with alternative investment strategies in line with the development of global policy frameworks and agreements. The emerging need for immediate action on climate change has drastically increased the papers with the highest number of articles observed in 2023 followed by the year 2017 with the formulation of the Paris Agreement in 2015. Substantial growth in the research of climate finance was observed in 2014 with 21 papers as compared to 6 papers in 2013.

Mitigation covers a larger fund coverage of fund utilization as compared to adaptation but most of the research papers in this review show a greater emphasis on the latter. With the review of papers, it can be concluded that climate finance is mostly constrained in vulnerable regions in which the risk of climate change and its adverse impacts are delicate, including low-lying coastal areas, SIDS, deserts, mountains, and Polar Regions. This includes both adaptation and mitigation strategies on climate finance which should be allocated considering multiple issues. Adaptation finance supports the most vulnerable countries while developing countries are assisted via mitigation finance. Public and private actors, international organizations, financing institutions, governments, and investors, should shift or expand their investments sustainably to minimize the capital availability gap and existing adaptation

gaps between developed and developing countries. These investments shall assist in new market opportunities and promote socio-economic benefits, seeking to enable the transition towards low-carbon and climate-resilient development. Proper access to finance is fundamental to removing the barriers to adaptation, especially for vulnerable regions.

Despite the increasing trend of research in climate finance, there is minimal progress in the reduction of carbon emissions and climate-resilient development [66]. The progress and achievement of the Paris Agreement are dependent on societal decisions and strategic actions implemented in the coming decade. This can be enabled by appropriate adaptation and mitigation strategies inclusive of proper governance and technological resources, monitoring mechanisms, building capacities, proper use of financial intermediaries, and fund flow mechanisms, and policy reforms involving both private and public financing. Replacement of outdated or pollution-intensive methods with green and clean production technologies, investment aligned with climate resilient development could become apparent with a developed and transparent financial system. Investment decisions for transforming the economy entail strategic choices between various development paths, given the magnitude of the risk [67]. Change management is another essential to restructure the production and consumption pattern to steer the economy toward more equitable strategies for both private and public investment.

Our study findings show that there are potential knowledge gaps in terms of the concept and scope of climate finance. Climate finance encompasses climate-specific fund disbursement, including funds created by international, bilateral, multilateral, and other financial aid in the form of international projects, national budgets, and private funds with debt and equity financing for mitigation and adaptation activities. Thus, the concept of climate finance is not limited to the transfer of public and private funds from developed to developing countries or national transfer to local levels. However, as depicted the assessment of financial instruments on climate funds flowing to developing countries needs to be monitored, with updated policies and regulations for accountability and transparency. Most of the articles focus on analyzing fund utilization, modes of financing, and policy-level recommendations. Few papers focused on climate finance data to drive the policymakers to make a sustainable vision of climate finance, while few articles also included interconnection with other sectors such as climate justice, economic analysis on climate finance, political economy on adaptation, political analysis, Risk assessment, governance, and public policy to support private finance via public instruments respectively.

The study has provided a pathway for an appropriate research stream to understand various financial instruments and the proportion of fund utilization. Innovative use of financial instruments and financial approaches can help reduce climate risk and mobilize resources effectively. In this regard, future studies can focus specifically on financial instruments to foster the objectives of the Paris Agreement.

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Declarations

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Consent for publication The author provides the full consent to participate and publish the article.

Competing interests The authors declare no competing interests.

Appendix

Individual comparison of word search

	Particulars	Title	Title or keyword	Title + keyword	Title or keyword or abstract	Title + keyword + abstract
Climate finance	Scopus					
	Date undefined	563	2124	303	4975	252
	2005–2023	549	2034	298	4694	247
	2019–2023	355	1306	202	2863	169
	Web of Science					
	Date undefined	541	604	–	3762	–
	2005–2023	534	597	–	3653	–
	2019–2023	369	428	–	2844	–
Adaptation fund	Scopus					
	Date undefined	55	123	17	1332	16
	2005–2023	51	114	17	1204	16
	2019–2023	21	47	11	559	11
	Web of Science					
	Date undefined	59	64	–	2307	–
	2005–2023	56	61	–	2123	–
	2019–2023	26	30	–	875	–
Financing climate change	Scopus					
	Date undefined	94	419	16	1869	14
	2005–2023	92	404	15	1801	13
	2019–2023	41	185	10	1027	10
	Web of Science					
	Date undefined	90	137	–	1833	–
	2005–2023	88	134	–	1774	–
	2019–2023	40	104	–	875	–
Sustainable finance	Scopus					
	Date undefined	695	4152	324	8764	269
	2005–2023	677	3779	318	8093	265
	2019–2023	541	2433	284	5020	240
	Web of Science					
	Date undefined	481	508	–	5287	–
	2005–2023	450	476	–	4978	–
	2019–2023	286	308	–	2424	–
Green finance	Scopus					
	Date undefined	1211	2416	847	4082	836
	2005–2023	1163	2316	847	3887	803
	2019–2023	1100	2049	828	3126	787
	Web of Science					
	Date undefined	1478	2504	–	3623	–
	2005–2023	1460	2486	–	3583	–
	2019–2023	1382	2204	–	3546	–

Data extracted on 20.01.2023

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