Available online at www.sciencedirect.com

ScienceDirect

Current Opinion in Environmental Sustainability

Climate catastrophe insurance for climate change: what do we know and what lies ahead?

Haitham Nobanee[1,2,3] and Xuan-Hoa Nghiem[4]

The complexities and seemingly uncontrollable nature of problems associated with climate change have intensified, giving rise to severe consequences, including rising sea levels, escalating temperatures, drought, deforestation, and heightened catastrophes such as typhoons. While long-term solutions such as energy transition and green finance are widely acknowledged, their implementation is time-consuming. Recognizing the urgency, there is a critical need to explore short-term, immediate measures to alleviate the adverse effects, particularly for ordinary and vulnerable groups. In this context, insurance emerges as a promising solution. This paper conducts a comprehensive review of the current state of research on climate catastrophe insurance for climate change, utilizing the Scopus database. Furthermore, the paper suggests directions for future research to address the pressing challenges posed by climate change.

Addresses
[1] College of Business, Abu Dhabi University, United Arab Emirates
[2] Oxford Centre for Islamic Studies, University of Oxford, United Kingdom
[3] Faculty of Humanities & Social Sciences, The University of Liverpool, United Kingdom
[4] International School, Vietnam National University, Hanoi, Viet Nam

Corresponding author: Nobanee, Haitham (nobanee@gmail.com, haitham.nobanee@adu.ac.ae, haitham.nobanee@oxcis.ac.uk, haitham.nobanee@liverpool.ac.uk)

Current Opinion in Environmental Sustainability 2024, **66**:101395

This review comes from a themed issue on **Climate Finance, Risks and Accounting**

Edited by **Rosella Carè, Othmar Lehner** and **Olaf Weber**

For complete overview of the section, please refer to the article collection, "Climate Finance, Risks and Accounting"

Available online 20 December 2023

Received: 13 September 2023; Revised: 20 November 2023; Accepted: 26 November 2023

https://doi.org/10.1016/j.cosust.2023.101395

Introduction

It is universally acknowledged that climate change constitutes a pressing global urgency, posing severe threats to nations worldwide [1]. The resultant climate catastrophes and extreme weather events have profound policy implications at macroeconomic, sectoral, and individual levels [2–14]. The devastating nature of these extreme climate events is already apparent, and the anticipated exacerbation of their severity and intensity due to global warming adds substantial threats to societies and the environment [15], jeopardizing the livelihoods of billions [17].

Recognizing the gravity of these adverse effects, scientists and researchers have explored a multitude of solutions. These encompass a broad spectrum, including advanced technologies such as information and communication technologies [18–23], energy transition [24,25], green finance [26–28], digital and data transformation [29,30], circular economy [31], and low-carbon materials [32]. However, the fruition of these solutions primarily occurs in the long run. Therefore, the necessity to devise immediate, temporary, and/or short-run solutions becomes imperative. Notably, climate catastrophe insurance emerges as a standout option, offering crucial funding for post-disaster recovery efforts.

The total burden inflicted by a climate disaster is contingent not only upon its initial damage but also on an economy's capacity to reconstruct its activities. Insufficient resources can impede reconstruction and recovery efforts, a challenge that insurance payouts can alleviate. The European Central Bank asserts that catastrophe insurance can mitigate uncertainty, stimulate investment, and facilitate recovery efforts [34].

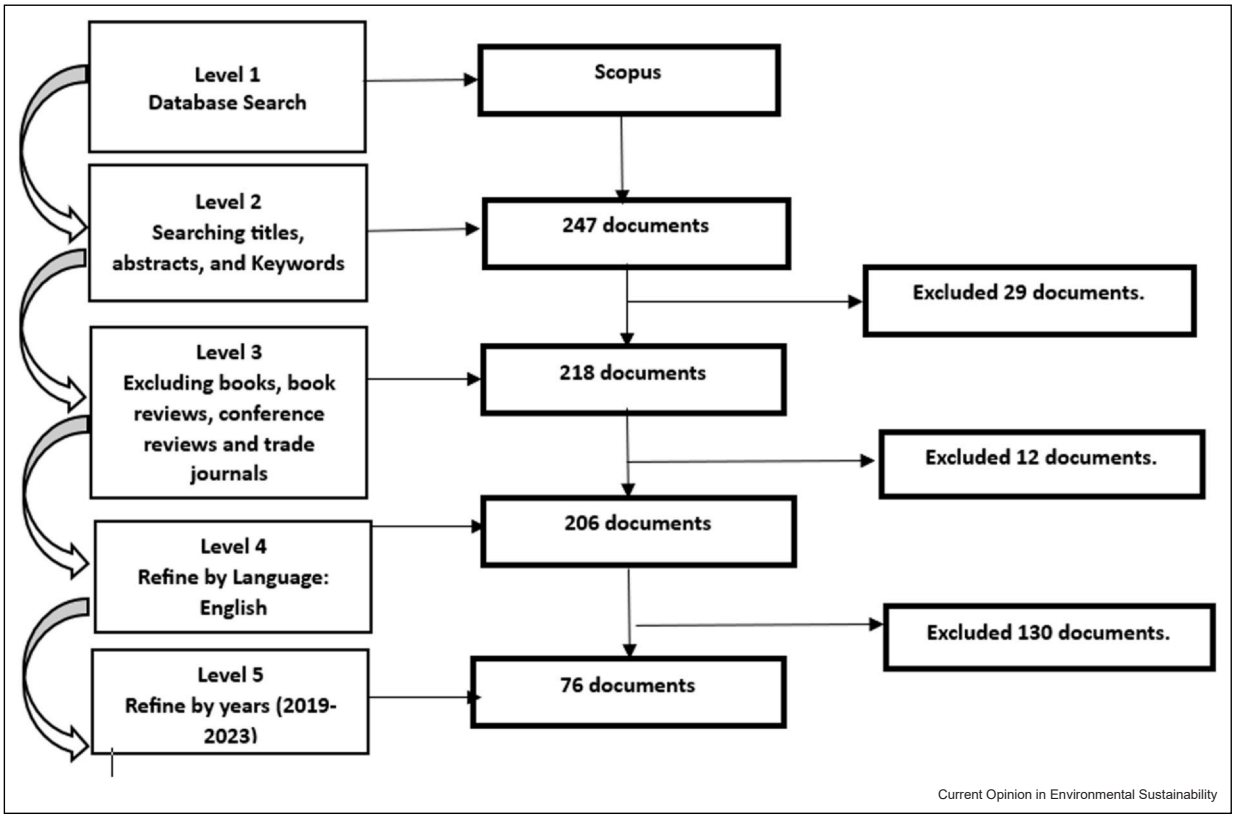
Climate change poses significant threats to human well-being with severe consequences, through rapid-onset events and slow-onset events. While the effects of slow-onset events are gradual, those of rapid-onset events (catastrophes: floods, hurricanes, and cyclones) are damaging. These catastrophes not only inflict serious immediate losses but also hinder post-disaster recovery efforts. To overcome these difficulties, it is of great importance to introduce temporary reliefs among which catastrophe insurance comes to prominence, thanks to its desirable properties. However, due to the nature and severity of climate catastrophes, insurance companies are also confronted with serious risks. This paper reviews the state of the recent literature on climate catastrophe insurance as well as how insurance companies can diversify the risks themselves.

Despite its substantial benefits, climate catastrophe insurance appears to be inadequately implemented. In 2022 alone, insured losses from natural catastrophes amounted to 132 billion US dollars, covering only 40% of the total losses. The remaining 181 billion US dollar protection gap is anticipated to escalate due to the heightened frequency, intensity, and severity of natural disasters, rendering existing insurance policies potentially unaffordable. The literature on climate catastrophe insurance for climate change thus appears underexplored and underestimated. In addition to examining and highlighting the most recent scholarship on climate catastrophe and insurance, this piece of analysis also outlines unaddressed knowledge gaps as well as suggests future research directions.

Bibliometric analysis

In this paper, we apply bibliometric review to a set of 76 published papers from the Scopus database from 2019 to 2023. By searching key terms relevant to the topic (catastrophe, climate change, and insurance), we also conducted keyword analysis and PRISMA flow diagram to investigate the scope, findings, and gaps of the 76 published articles. Following Khudzari et al. [35] and Nobanee and Ellili [36•], we focus only on the Scopus database as this database is wide-ranging, offering a comprehensive list of subjects and has been utilized by different scholars [36]. In the first step, we search the Scopus database using the keywords "climate catastrophe insurance", which returns a total of 247 documents. In the second step, we refine the search to the titles, abstracts, and keywords, which results in an exclusion of 29 documents to get the remaining 218 documents. Next, we exclude books, book reviews, conference reviews, and trade journals, thus leading to 12 documents being removed and only 208 documents remaining. In the fourth step, we limit the documents

Figure 1



Process applied for delimiting literature (PRISMA chart).

Table 1

Citation, content, and cluster analysis.

Cluster	Authors	Aims	Findings	Importance, contribution, and significance	Citations
Hazards, risk management, and assessment	Kron et al. [37]	1. Investigate weather disaster risks and damages. 2. Perform risk assessment, management, and mitigation focusing on insurance.	1. Weather catastrophes are disastrous and worsen. 2. Insurance is important in maintaining financial resources.	1. Global warming worsens more frequently, severe catastrophes. 2. Need to mitigate risks in terms of hazard, exposure, and vulnerability. 3. Insurance is important in risk reduction and post recovery.	68
	Christophers et al. [38••]	1. Examine climate finance instruments: green bonds and sovereign catastrophe insurance pools. 2. Examine risk constitution.	1. These instruments are effective. 2. Obstacles: political, economic, and logistical.	1. Highlights of the advantages and disadvantages of these instruments. 2. Need to examine how other climate finance instruments examine and configure risks.	39
Floods and disasters	Mendes-Da-Silva et al. [39]	1. Evaluate the probability of acquiring natural catastrophe insurance.	1. People experiencing flood and living in risk zones tend to acquire insurance policies. 2. People with disabilities likely to acquire insurance.	1. Importance of insurance against natural catastrophes. 2. Importance of insurance for people with disabilities against natural catastrophes.	6
	Pagano et al. [40]	1. Develop an insurance model for flood risk.	1. Importance of insurance in guarding against flood risk.	1. Augment traditional insurance models with Bayesian adaptation and blockchain technology.	2
Catastrophic events and modeling	Zanardo et al. [41]	1. Quantify economic losses inflicted by floods.	1. The NAO index is useful in predicting long-term flood-related losses of the EU.	1. Relevant stakeholders (insurers) may utilize NAO.	37
	Wasko et al. [42]	1. Measure economic losses caused by meteorological and hydrologic-related catastrophes.	1. More severe storms: insignificant. 2. Higher temperature: significant.	1. Stress impact of higher temperatures on greater economic losses. 2. Need to contain rising global temperatures.	11
	Rudik [43]	1. Develop recursive integrated assessment models (IAMs) addressing learning, uncertainty, and misspecification.		1. New framework for damage assessment. 2. Useful in designing an optimal carbon tax.	8
	Valverde-Arias et al. [44]	1. Develop an innovative index-based agricultural insurance.		1. Innovated index-based insurance effective in computing insurance premiums.	8
	Gray [45]	1. Develop innovative catastrophe models addressing frequent extreme weather events.	1. First-generation cat models are outdated. 2. Revised model effective.	1. New model to calculate potential economic losses by hurricane.	8
	Change et al. [46•]	1. Compute the frequency of catastrophe arrival using catastrophe (cat) bond spread.	1. Cat bond spread: significant in predicting catastrophe frequency.	1. Cat bond spread: significant in predicting catastrophe. 2. Insurers utilize the cat bond spread for (re)pricing of their contracts and risk-transferring.	5
	Jewson et al. [47]	1. Develop an innovative catastrophe model with revised year loss tables (YLTs)	1. YLTs: rigid, time-consuming.	1. YLTs adjusted more easily. 2. Assign weights to years in the YLTs, easier for adjustments.	4

Table 1 (*continued*)

Cluster	Authors	Aims	Findings	Importance, contribution, and significance	Citations
Insurance systems	Taylor [48]	1. Investigate insurance-linked securitization (ILS)		1. ILS benefits: protecting real-estate markets, circulating money, and providing benefits for investors.	34
	Craig [49••]	1. Examine the role of insurance and financing mechanisms in adapting and mitigating climate catastrophe.	1. US National Flood Insurance Program (NFIP): effective.	1. Local and federal governments need to provide funds for adaptation to climate catastrophe.	29
	Morana and Sbrana [50]	1. Examine the impact of global warming on catastrophe (cat) bond pricing.	1. Global warming on cat bond risk: significant 2. Others: monetary policy and portfolio shift underestimated catastrophe risks.	1. Catastrophe risks need to be incorporated into cat bond pricing.	23

written in English only. The result of this fourth step is 130 documents being excluded and a total of 76 documents qualified for the final analysis. The process is summarized in the PRISMA chart in Figure 1.

Distribution and citation analysis

Among the 76 papers included in the analysis, only 15 (19.74%) of them are conducted in environment-related journals, followed by economics, business and finance journals (12 papers, 15.79%), climate journals (7 papers or 9.21%, 2 papers are both environment- and climate-related), geography-related journals (5 papers or 7.6%), health-related journals (5 papers, 6.58%), risk or hazard-related journals (4 papers, 5.26%), and agriculture journals (2 papers, 2.63%).

In terms of citations, as insurance for climate change is at its early stage of development, and therefore, remains underexplored and underestimated, it is not surprising that the number of citations is relatively low. Among these 76 papers, 52 of them have been cited at least one time and 14 papers receive more than 10 citations with Kron et al. [37] getting the highest number of citations (68 citations). The topics are diverse, ranging from hazards, risk management, and assessment; floods and disasters; catastrophic events and modeling; and insurance systems. Essential information is summarized in Table 1 below.

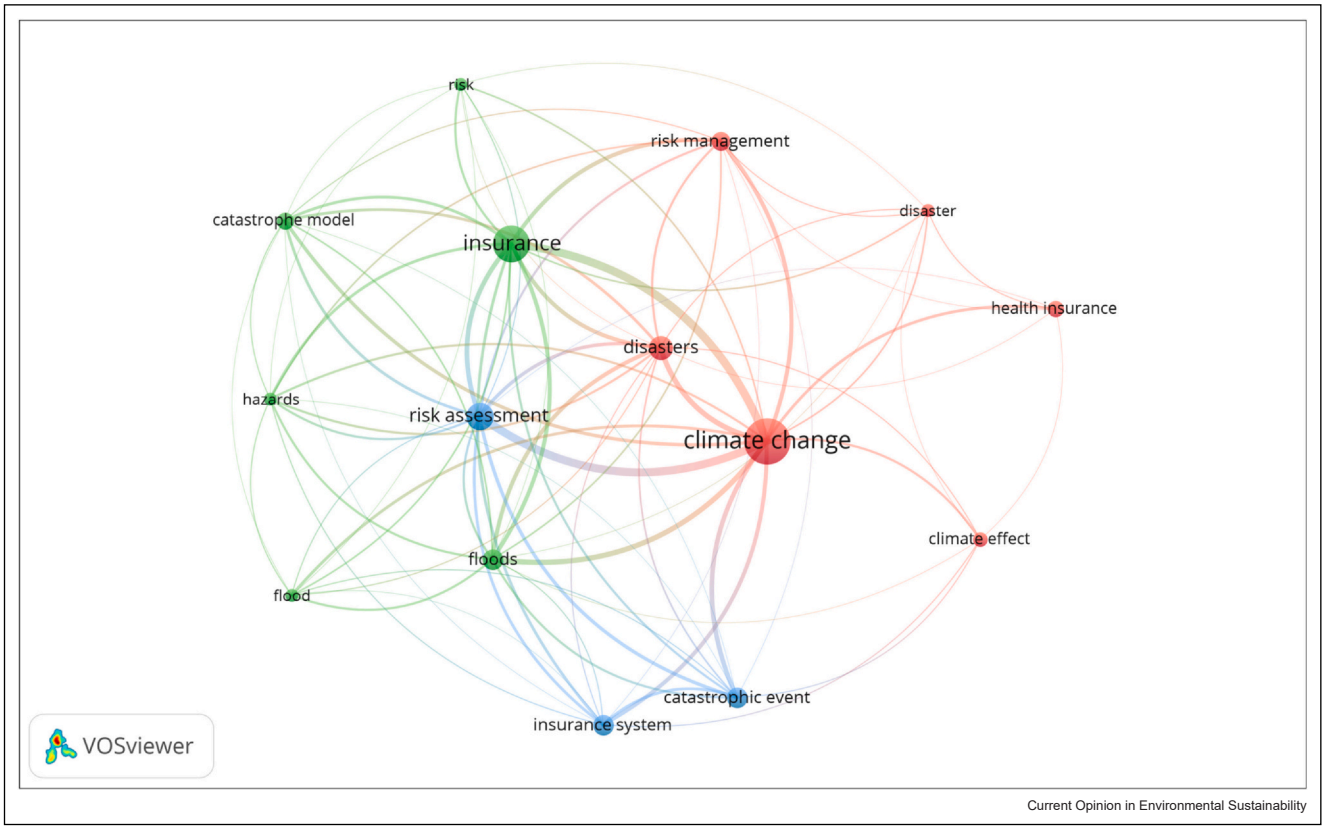
Keyword analysis

Figure 2 provides the occurrences of keywords of this paper. As the theme focuses on "climate catastrophe insurance for climate change", it does not come as a surprise that the two keywords "climate change" and "insurance" show the highest level of occurrences. Other frequently searched keywords include "risk assessment"; "risk management"; "catastrophe model"; "catastrophic events"; "insurance system"; "climate effect".

Overall discussion

The first notable issue here is in spite of growing attention to climate catastrophe, there still exists a dearth of research on climate catastrophe insurance, especially in the fields of economics, finance, and business. The majority of documents over the past four years (2019–2023) tend to focus on risk assessment and modeling of catastrophe arrivals. In terms of insurance, most papers focus on either revising current models used for computing losses of climate catastrophic events. Some papers pay attention to how insurers can transfer and diversify their risks by using catastrophe (cat) bonds. As the topic of catastrophe insurance remains relatively underexplored, the number of citations of each paper is not high compared with other studies.

Figure 2



A map of the most frequent keywords.

Conclusion, limitations, and future research directions

This paper extensively reviews recent literature on climate catastrophe insurance in the context of climate change, emphasizing risk assessment and modeling of catastrophe arrivals from 2019 to 2023. The focus within insurance literature centers on modifying models for calculating losses from climate catastrophic events, with some exploring strategies such as the use of catastrophe (cat) bonds to transfer and diversify risks. Despite the topic's potential significance, the relative underexploration is evident in modest citations compared with other studies. Acknowledging limitations, the exclusive use of the Scopus database may exclude relevant contributions from other databases, and the study may be susceptible to the "Matthew effect." Future research should delve deeper into insurers' diverse methods for modeling catastrophes and estimating economic losses. Additionally, the disproportionately high attention on the cat bond market requires further investigation to understand its implications in the broader effort to combat climate change.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this

Declaration of Generative AI and AI-assisted technologies in the writing process

In the course of preparing this work, the authors employed ChatGPT to both proofread the paper and refine various sections of the writing. Subsequently, they diligently reviewed and edited the content to ensure its accuracy and take full responsibility for the publication's content.

Data Availability

Data will be made available on request.

References and recommended reading

Papers of particular interest, published within the period of review, have been highlighted as:

- • of special interest
- •• of outstanding interest

1. Wilson AJ, Orlove B: **Climate urgency: evidence of its effects on decision making in the laboratory and the field**. *Curr Opin Environ Sustain* 2021, **51**:65-76.

2. Bowen KJ, Ebi KL: **Governing the health risks of climate change: towards multi-sector responses**. *Curr Opin Environ Sustain* 2015, **12**:80-85.

3. Bowen K, Ebi K: **Governing the health risks of climate change: opportunities for regeneration in an age of planetary health**. *Curr Opin Environ Sustain* 2020, **46**:1-2.

4. Buckingham K, Brandt J, Anderson W, Do Amaral LF, Singh R: **The untapped potential of mining news media events for understanding environmental change**. *Curr Opin Environ Sustain* 2020, **45**:92-99.

5. Ogle SM, Butterbach-Bahl K, Cardenas L, Skiba U, Scheer C: **From research to policy: optimizing the design of a national monitoring system to mitigate soil nitrous oxide emissions**. *Curr Opin Environ Sustain* 2020, **47**:28-36.

6. Cao A, Esteban M, Valenzuela VPB, Onuki M, Takagi H, Thao ND, Tsuchiya N: **Future of Asian Deltaic Megacities under sea level rise and land subsidence: current adaptation pathways for Tokyo, Jakarta, Manila, and Ho Chi Minh City**. *Curr Opin Environ Sustain* 2021, **50**:87-97.

7. Chu EK, Cannon CE: **Equity, inclusion, and justice as criteria for decision-making on climate adaptation in cities**. *Curr Opin Environ Sustain* 2021, **51**:85-94.

8. •• Mcnamara KE, Westoby R, Chandra A: **Exploring climate-driven non-economic loss and damage in the Pacific Islands**. *Curr Opin Environ Sustain* 2021, **50**:1-11.

This paper reviews and points out the fact that climate change and catastrophes may also have non-economic losses which in turn, can inflict serious consequences on any country. By employing Pacific Islands nations as an example, the authors confirm that climate change and catastrophes may adversely affect non-economic issues including but not limited to: biodiversity loss, cultural loss, human dislocation, destruction, and deterioration of ecosystems.

9. Mechler R, Deubelli TM: **Finance for loss and damage: a comprehensive risk analytical approach**. *Curr Opin Environ Sustain* 2021, **50**:185-196.

10. Oppermann E, Kjellstrom T, Lemke B, Otto M, Lee JKW: **Establishing intensifying chronic exposure to extreme heat as a slow onset event with implications for health, wellbeing, productivity, society and economy**. *Curr Opin Environ Sustain* 2021, **50**:225-235.

11. Schlingmann A, Graham S, Benyei P, Corbera E, Sanesteban IM, Marelle A, Soleymani-Fard R, Reyes-García V: **Global patterns of adaptation to climate change by indigenous peoples and local communities. A systematic review**. *Curr Opin Environ Sustain* 2021, **51**:55-64.

12. Zickgraf C: **Climate change, slow onset events and human mobility: reviewing the evidence**. *Curr Opin Environ Sustain* 2021, **50**:21-30.

13. Blekking J, Giroux S, Waldman K, Battersby J, Tuholske C, Robeson SM, Siame G: **The impacts of climate change and urbanization on food retailers in urban sub-Saharan Africa**. *Curr Opin Environ Sustain* 2022, **55**:101169.

14. Lluch-Cota SE, Del Monte-Luna P, Gurney-Smith HJ: **Transformational adaptation in marine fisheries**. *Curr Opin Environ Sustain* 2023, **60**:101235.

15. Butler CD: **Pandemics: the limits to growth and environmental health research**. *Curr Opin Environ Sustain* 2020, **46**:3-5.

17. Siders A, Ajibade I, Casagrande D: **Transformative potential of managed retreat as climate adaptation**. *Curr Opin Environ Sustain* 2021, **50**:272-280.

18. Dube OP, Brondizio ES, Solecki W: **Introductory article: technology, innovations, and environmental sustainability in the Anthropocene**. *Curr Opin Environ Sustain* 2020, **45**:A1-A6.

19. Gras C, Caceres DM: **Technology, nature's appropriation and capital accumulation in modern agriculture**. *Curr Opin Environ Sustain* 2020, **45**:1-9.

20. Naser HA: **Technology for environmental management in Small Island Developing States: the case of Bahrain**. *Curr Opin Environ Sustain* 2022, **59**:101219.

21. Francisco M: **Artificial intelligence for environmental security: national, international, human and ecological perspectives**. *Curr Opin Environ Sustain* 2023, **61**:101250.

22. Nasreen S, Khan FI, Nghiem X-H: **The effects of financial development and technological progress on environmental sustainability: novel evidence from Asian countries**. *Environ Sci Pollut Res* 2023, **30**:53712-53724.

23. Nghiem X-H, Bakry W, Al-Malkawi H-AN, Farouk S: **Does technological progress make OECD countries greener? New evidence from panel CS-ARDL**. *Manag Environ Qual: Int J* 2023, **34**:1555-1579, https://doi.org/10.1108/MEQ-11-2022-0296

24. Guo B, Guo Q, Amri F, Abbas S, Nghiem XH: **Powering environmental sustainability through renewable energy and natural resources: a Dynamic ARDL simulation approach**. *Environ Sci Pollut Res* 2023, **30**:90906-90923.

25. Surroop D: **Energy transition to decarbonize the energy system in Mauritius**. *Curr Opin Environ Sustain* 2023, **61**:101268.

26. •• Chen Y, Zhao ZJ: **The rise of green bonds for sustainable finance: global standards and issues with the expanding Chinese market**. *Curr Opin Environ Sustain* 2021, **52**:54-57.

This paper emphasizes the importance of the green bond (a key instrument in green finance) and the development of the green bond market in China. It also examines and highlights the strengths and weaknesses as well as future developments of green bond market in China.

27. Huybrechs F, Bastiaensen J, Van Hecken G: **Exploring the potential contribution of green microfinance in transformations to sustainability**. *Curr Opin Environ Sustain* 2019, **41**:85-92.

28. Bakry W, Mallik G, Nghiem X-H, Sinha A, Vo XV: **Is green finance really "green"? Examining the long-run relationship between green finance, renewable energy and environmental performance in developing countries**. *Renew Energy* 2023, **208**:341-355.

29. De Albuquerque JP, Anderson L, Calvillo N, Coaffee J, Cunha MA, Degrossi LC, Dolif G, Horita F, Klonner C, Lima-Silva F: **The role of data in transformations to sustainability: a critical research agenda**. *Curr Opin Environ Sustain* 2021, **49**:153-163.

30. Wang J, Nghiem X-H, Jabeen F, Luqman A, Song M: **Integrated development of digital and energy industries: paving the way for carbon emission reduction**. *Technol Forecast Soc Change* 2023, **187**:122236.

31. Piscicelli L: **The sustainability impact of a digital circular economy**. *Curr Opin Environ Sustain* 2023, **61**:101251.

32. Grainger A, Smith G: **The role of low carbon and high carbon materials in carbon neutrality science and carbon economics**. *Curr Opin Environ Sustain* 2021, **49**:164-189.

34. European Central Bank (ECB): **Policy options to reduce the climate insurance protection gap**. *ECB Discussion Paper*; 2023.

35. Khudzari JM, Kurian J, Tartakovsky B, Raghavan GV: **Bibliometric analysis of global research trends on microbial fuel cells using Scopus database**. *Biochem Eng J* 2018, **136**:51-60.

36. • Nobanee H, Ellili NOD: **Non-fungible tokens (NFTs): a bibliometric and systematic review, current streams, developments, and directions for future research**. *Int Rev Econ Financ* 2023, **84**:460-473.

This paper provides a benchmark example of how to conduct a bibliometric review. By employing non-fungible tokens as an example, this paper demonstrates the necessary steps in a bibliometric review.

37. Kron W, Löw P, Kundzewicz ZW: **Changes in risk of extreme weather events in Europe**. *Environ Sci Policy* 2019, **100**:74-83.

38. •• Christophers B, Bigger P, Johnson L: **Stretching scales? Risk and sociality in climate finance**. *Environ Plan A: Econ Space* 2020, **52**:88-110.

This paper critically reviews the structure and risk configuration of two important climate finance mechanisms: green bonds and sovereign catastrophe insurance pools. By highlighting the advantages and

disadvantages of these instruments, this paper calls for greater attention paid to climate finance to better understand, manage and mitigate climate risks.

39. Mendes-Da-Silva W, Lucas EC, De Franca Carvalho JV: **Flood insurance: the propensity and attitudes of informed people with disabilities towards risk**. *J Environ Manag* 2021, **294**:113032.

40. Pagano AJ, Romagnoli F, Vannucci E: **Flood risk: financing for resilience using insurance adaptive schemes**. *Agrochimica* (322) 2019, **305**.

41. Zanardo S, Nicotina L, Hilberts AG, Jewson SP: **Modulation of economic losses from European floods by the North Atlantic Oscillation**. *Geophys Res Lett* 2019, **46**:2563-2572.

42. Wasko C, Sharma A, Pui A: **Linking temperature to catastrophe damages from hydrologic and meteorological extremes**. *J Hydrol* 2021, **602**:126731.

43. Rudik I: **Optimal climate policy when damages are unknown**. *Am Econ J: Econ Policy* 2020, **12**:340-373.

44. Valverde-Arias OR, Esteve P, Tarquis AM, Garrido A: **Remote sensing in an index-based insurance design for hedging economic impacts on rice cultivation**. *Nat Hazards Earth Syst Sci* 2020, **20**:345-362.

45. Gray I: **Hazardous simulations: pricing climate risk in US coastal insurance markets**. *Econ Soc* 2021, **50**:196-223.

46. • Chang CW, Wang Y-J, Yu M-T: **Catastrophe bond spread and hurricane arrival frequency**. *N Am J Econ Financ* 2020, **54**:100906.
This paper was the first-ever paper utilizing available information in the catastrophe (cat) bond market to forecast the frequency of hurricanes. In addition to the cat bond spread, other variables confirmed to be significant include ratings of the bond, trigger indemnity, and covered territory.

47. Jewson S, Barnes C, Cusack S, Bellone E: **Adjusting catastrophe model ensembles using importance sampling, with application to damage estimation for varying levels of hurricane activity**. *Meteorol Appl* 2020, **27**:e1839.

48. Taylor ZJ: **The real estate risk fix: residential insurance-linked securitization in the Florida metropolis**. *Environ Plan A: Econ Space* 2020, **52**:1131-1149.

49. •• Craig RK: **Coastal adaptation, government-subsidized insurance, and perverse incentives to stay**. *Clim Change* 2019, **152**:215-226.
This paper reviews the role of insurance and financing mechanisms in adapting and mitigating climate catastrophe focusing on the specific example of the US NFIP. This paper highlights the crucial role of state- and local-financed insurance programs in adapting to and mitigating climate change catastrophes as well as post-disaster recovery efforts.

50. Morana C, Sbrana G: **Climate change implications for the catastrophe bonds market: an empirical analysis**. *Econ Model* 2019, **81**:274-294.