



Progress and Prospects of Research on Climate Policy and Governance

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Abstract

Research on climate policy and governance has rapidly evolved since the early 1990s, yet there is a lack of a systematic review, especially in quantitative methods, that provides an overall account of this interdisciplinary field. This article provides a bibliometric analysis of 2487 SSCI journal articles published from 1990 to 2018 to characterize the intellectual landscape of climate policy and governance literature by visualizing the changes in researchers' collaboration and publications' cocitation and identifying the emerging research agenda. The findings show that publications on this topic have surged since the Kyoto Protocol came into effect in 2005. Environmental studies, economics, and public administration are three major disciplines drawing high attention to this field. Scholars and research institutions from the United States, the United Kingdom, and Germany have maintained dominance over climate policy and governance design. Moreover, we identify three pressing topics for creating future research agendas, including adaptive capacity, technology and innovation, and urban governance. Green technology innovation, local climate governance and the increasing political awareness will become future research trends.

Keywords

climate policy and governance; bibliometric analysis; literature review; research trends

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1. Introduction

Climate change is having an observable effect on the environment, hitting the vulnerable hardest, and causing food insecurity, population displacement and water scarcity. In response to the growing threats of climate change and environmental degradation, the international and regional organizations, national and local governments and private sectors have stepped up their efforts in policy-making and governance since the early 1990s (Akinro *et al.*, 2008; Baker *et al.*, 2012; Reid and Toffel, 2009; UNFCCC, 2018; Ziervogel and Ericksen, 2010). The past three decades have witnessed the development of international institutions (*e.g.* the UNFCCC and *Kyoto Protocol*, see Fig. 1) and policy initiatives from different levels of governance in climate mitigation and adaptation (Jayawardena and van Roon, 2016; Loft *et al.*, 2015). Researchers have explored the impacts of climate change (*e.g.* economic, ecological and social impact) with multidisciplinary approaches (Stern and Taylor, 2007; Tompkins and Adger, 2005; Weitzman, 2007). For example, economists have focused on the development and evaluation of strategies and policy instruments for climate actions (*e.g.* resource pricing and integrated ecologic-economic modeling) (Binkley and Van Kooten, 1994); energy scientists have focused on energy and environmental regulation and the exploration of renewable energy supplies (Lund *et al.*, 2000; Popp *et al.*, 2011); and social and political scientists have studied the effect of climate change on the public, including their collaborative efforts and decision-making processes, sustainable urban development at the local government level, and the climate change knowledge and perceptions at the individual level (Bulkeley and Betsill, 2013; Feldman and Ingram, 2009).

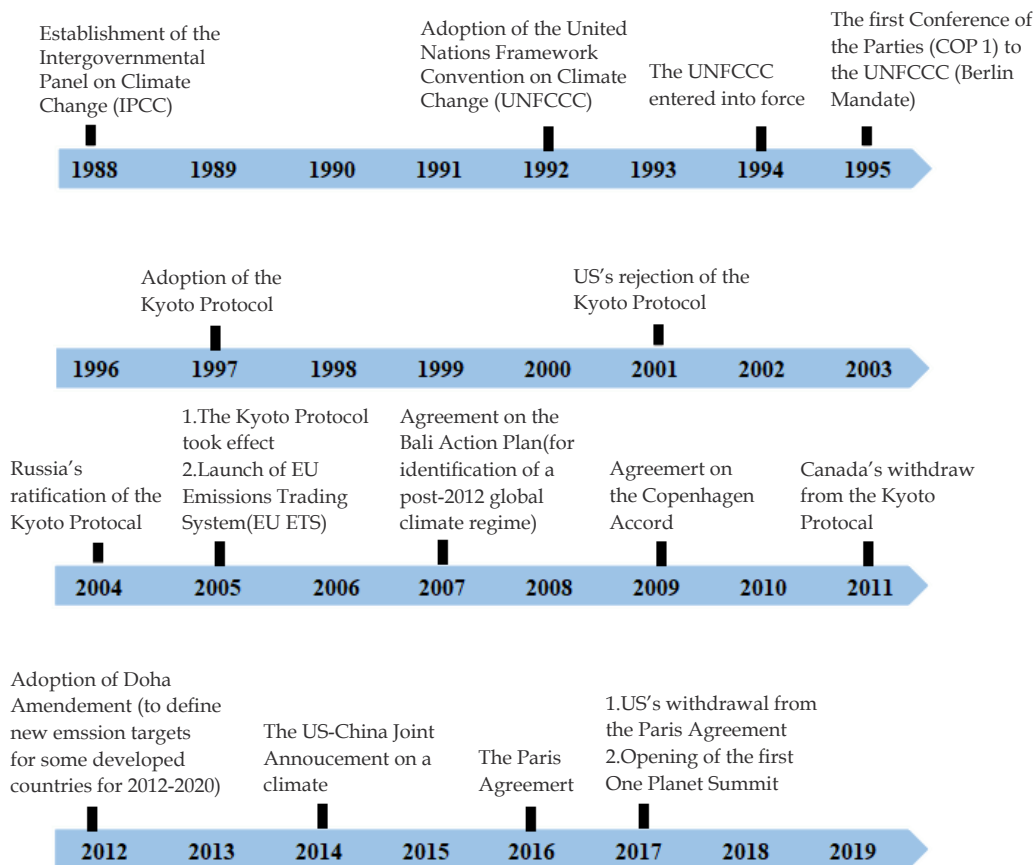


Fig. 1 Chronology of institutional development in climate policy and governance

Several studies have reviewed the literature on climate policy and governance. The first stream of study has reviewed barriers, drivers, and conditions shaping the design and implementation of climate policy (Bhardwaj *et al.*, 2019; Lwasa, 2015; Ryan, 2015). The second stream of study has summarized different patterns of international mechanisms and examined collected country specific data – mostly based on empirical cases (Bhardwaj *et al.*, 2019; Lwasa, 2015; Ryan, 2015). The third stream of study has discussed the impacts of climate policy (*e.g.* economics, public health or agricultural innovation), and takes the new approaches/strategies, policy actions to the emerging challenges (Fox *et al.*, 2019; Makate, 2019). However, existing reviews have two major limitations. Firstly, most studies have been regionally or locally focused, limiting the generalizability of discipline development. Secondly, most of the review articles have applied methods of coding or content analysis, which can be substantially influenced by the authors' subjective interpretation and their research background. Therefore, an impersonal bibliometric quantitative analysis (*e.g.* word frequency analysis, cluster analysis, and time-series analysis) is preferred.

To characterize the intellectual landscape of climate policy and governance, this study applies bibliometric analysis of studies on climate policy and governance to identify the most cited and influential scholars and articles and to explore the relationships between articles, authors, and references. Bibliometrics is useful to evaluate and describe previous articles by mapping the related knowledge, so as to illustrate the major knowledge areas and their evolution. This approach can also explore the internal relationship among articles, authors, references, etc. More importantly, this approach can help reveal emerging topics, identify opportunities to extend the existing literature and provide insights and guidance for future research agendas.

The remainder of this article is organized as follows. We first provide an overall account of research on climate policy and governance by presenting its publication statistics and descriptions. The Method and Data Collection section describes the data collection procedure and the bibliometric analysis tool, CiteSpace, adopted in this study. The Findings section presents three major findings as follows: a) the research collaboration networks (between countries, institutions, and authors), b) the cocitation networks (between articles and journals), and c) the emerging trends. The Conclusion section summarizes the key findings and proposes a future research agenda for climate policy and governance.

2. Knowledge Mapping of the Research on Climate Policy and Governance

Existing literature on climate policy and governance covers a broad range of topics (*e.g.* economic, social, and political responses to climate change) (Jordan and Lenschow, 2010; Jordan *et al.*, 2015; Tol, 2009). A quick literature search using the keywords “climate policy” and “climate governance” returned 2487 articles from the Web of Science, SSCI database. Fig. 2 presents a growing trend of increasing publications on climate policy and governance from 1990-2018. The study of climate policy and governance has been burgeoning since 2005, and most of the researches got published from 2009 to 2018. We offer three main explanations for this phenomenon. Firstly, compelling evidence shows rapid changes in the global climate; thus, climate change remains the toughest, most intractable political issue we, as a society, have ever faced. Scholars have shifted their concerns from “whether climate change exists” to “how to deal with the climate change” (Broto, 2017; Hölscher *et al.*, 2019). Secondly, the global impact of international conferences (*e.g.* the UNFCCC Conference of the Parties) and conventions (*e.g.* the *Kyoto Protocol* and the *Paris Agreement*) have substantially raised the public awareness of climate change issues, especially when the *Kyoto Protocol* coming into force in 2005 (Boykoff *et al.*, 2017; Hoffman *et al.*, 2005; Lee

et al., 2015). Thirdly, the past several decades have witnessed more climate actions at the local levels. For example, Nationally Determined Contributions (NDCs), which are at the heart of the Paris Agreement, highlight the bottom-up contributions of local actors (Forino et al., 2017; Rayner, 2010).

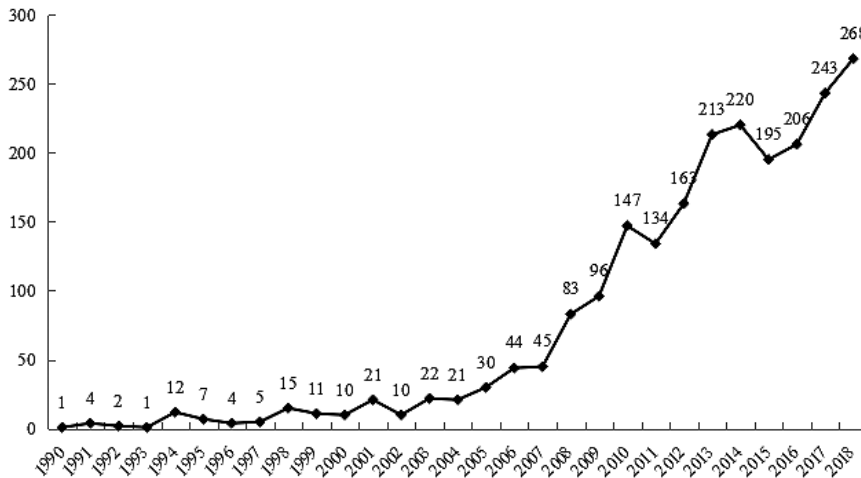


Fig. 2 The number of publications on climate policy and governance (1990–2018)

With the surge of climate policy and governance issues, the evolving and interdisciplinary nature of climate policy and governance research has also resulted in the need to map the current knowledge development. Fig. 3 presents the top ten research fields concerning climate policy and governance. In recent years, more studies are on economics and environment studies. From the early 1990s to the end of the 2010s, climate policy and governance had become a research topic ranging from science and engineering (e.g. environmental science, energy fuels, meteorology and atmospheric science) to social sciences (e.g. economics, public administration, international relations, and political science). Efforts to review and analyze the existing literature may contribute to an understanding of what knowledge has been generated thus far and the directions for future research.

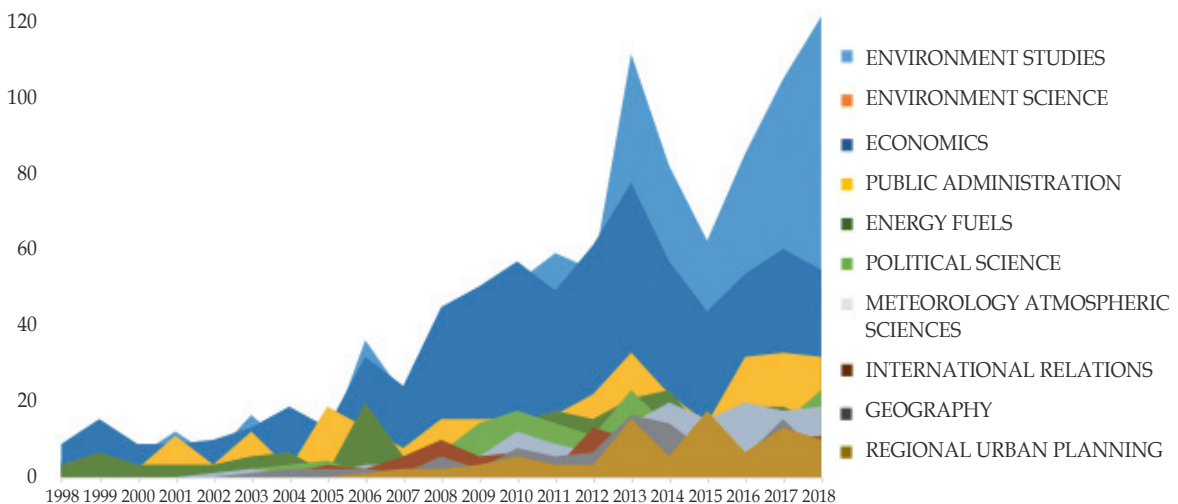


Fig. 3 Annual article output in the top ten research fields

3. Method and Data Collection

A bibliometric analysis involves applying statistical methods to trace the knowledge anatomy of a research field and is used to analyze research topics (De Bakker *et al.*, 2005). Previous studies have applied this method to analyze the number of journals (Martínez-López *et al.*, 2018; Valenzuela *et al.*, 2017; Valenzuela-Fernandez *et al.*, 2019), institutional units (Merigó *et al.*, 2019), countries and their relations (Cancino *et al.*, 2017; Mas-Tur *et al.*, 2019), and topics (Albort-Morant and Ribeiro-Soriano, 2016; Gurzki and Woisetschlager, 2017). We use bibliometric analysis to study a field in terms of its past and current situation, and the possible future development trend. Tools such as publication trends and citation network analysis are applied in climate policy and governance study. Additionally, co-citation for clustering, keyword analysis, page rank analysis and content analysis are also used.

The chosen bibliometric tool, CiteSpace, is a robust quantitative tool (Makate, 2019). We use CiteSpace to detect and visualize important articles, influential authors, current hot research topics, as well as evolving trends in the climate policy and governance research. Given its high compatibility with CiteSpace (Chen, 2014) and its extension as a scholarly database with broad coverage of top-tier scholarly articles (Fetscherin and Heinrich, 2015), we select the Social Sciences Citation Index (SSCI) database of the “Web of Science Core Collection” for this analysis. To capture all relevant research on climate policy and governance, the search query is “TS=(climate policy OR climate governance)”. The results include 4200 articles related to climate policy published between 1990 and 2018. We set our study period from 1990 to 2018 to align with the publication of the first report of the IPCC assessments in 1990, which is a milestone of international climate governance. To search for more targeted and valid results from the database, we removed announcements, author indices, volume content pages, editorial material, proceedings papers, meeting notices, prefaces and publisher notes, and 2487 full-text papers were obtained.

4. Findings

4.1. Collaboration networks

Collaboration analysis is critical to understanding scholarly communication and knowledge diffusion (Chen *et al.*, 2012). Each bibliographic record analyzed by CiteSpace contains the title, the abstract, and the author information (Fang *et al.*, 2018). The co-authors and co-authorship indicate a collaborative relationship. For example, if a paper has two co-authors affiliated to the institutions in Germany and England respectively, the two countries then would be connected by lines in the country’s collaboration network. In this study, the collaboration analysis focuses on identifying the research community and key countries/institutions/authors in climate policy and governance. We present the dynamic development of the research community, which can serve as a useful guide for new researchers and those seeking potential cooperation and reviewers in the multidisciplinary research area of climate policy and governance.

4.1.1. Country collaboration network

Table 1 shows the countries where authors published the most on climate policy and governance. This study analyzed the frequency of co-citations, shown as the betweenness centralities (BC) of countries in Table 1. The United States ranks first on the list with 713 publications in total. The United Kingdom and Germany, two European countries with 332 and 250 publications respectively, are also productive in this research field. Two prominent Asian countries include China (77) and Japan (32), ranks 10th and 17th respectively in numbers of publications.

Table 1 Top 10 countries based on publication frequency (1990-2018)

Country	BC	Publication frequency
the United States	0.58	713
the United Kingdom	0.78	332
Germany	0.31	250
Australia	0.27	180
the Netherlands	0.29	173
Canada	0.25	148
Sweden	0	126
Norway	0.51	96
Switzerland	0.6	93
P. R. China	0	77

Notes: BC (Betweenness centralities): a metric of a node that measures how likely an arbitrary shortest path in a network will go through the node, which shows the contribution of a node to make connections with other nodes in a network.

Fig. 4a is the evolution of collaboration among countries. In the early 1990s, the United States and some European countries (e.g. Switzerland and Austria) were pioneers in climate policy and governance research. British and Norwegian researchers have a long collaborated history since the early 1990s. After the UNFCCC came into effect in 1993, more European countries turned their attention to climate issues. Germany emerged as the main hub of research collaboration in Europe, while the United States and the United Kingdom maintained their leading position globally. From 2006 to 2015, a denser collaboration network formed between countries. In particular, Canada, Australia, and the Netherlands made breakthroughs in climate policy and governance research with high numbers of publications. China, South Korea, and Japan are three prominent Asian countries starting research on climate policy and governance from 2006.

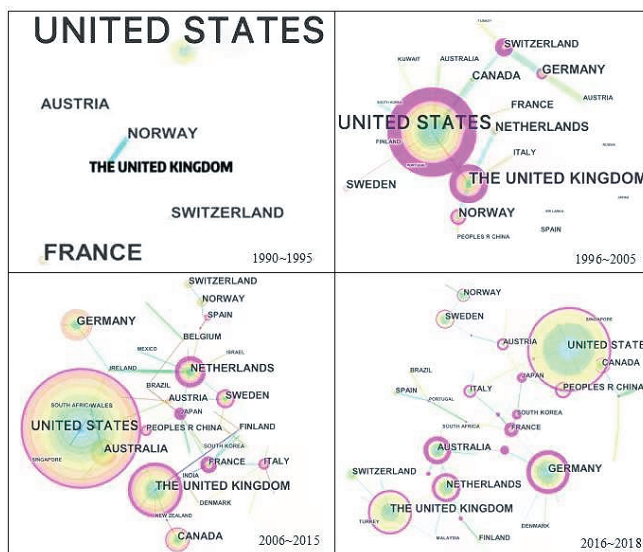


Fig. 4a Evolution map of country collaboration network (1990-2018)

Fig. 4b presents a visualization of the country's collaboration network of all publications during 1990-2018. The United States plays a central role in stable cooperation among various countries according to its highest BC (0.58), and the links between the United States and Germany, Switzerland, and Australia indicate that the cooperation has been gradually strengthened since the 1990s. Moreover, European countries (e.g. the United Kingdom and Germany) also play a crucial role in making connections with other countries according to their high BC (0.75 and 0.31 respectively). It also seems that geographically proximal countries are more likely to collaborate given their similar regional ecological vulnerabilities. Even though the United States maintains its dominance in climate policy and governance research, a trend of shared leadership with European countries has emerged.

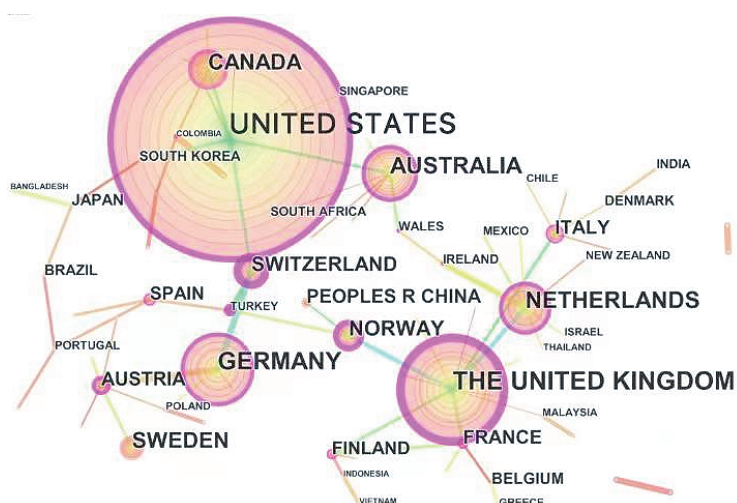


Fig. 4b A visualization of the country collaboration network (1990-2018)

4.1.2. Institution collaboration network

The institution collaboration network consists of 561 nodes and 316 collaboration links from 1990 to 2018 (see Fig. 5). The institution cooperation network indicates a relatively high maturity within the research community given its dense structure and highly close relationships. Table 2 presents the top 10 institutions by their publication frequency, where Vrije University Amsterdam leads with 51 publications and plays a crucial role in collaborating with other institutions as indicated by its high BC (0.09). Other institutions with high publication frequency include the Massachusetts Institute of Technology (39), the Australian National University (37), and the University of Oxford (31). European institutions take the lead in climate policy and governance research. Institutions in the United Kingdom are outstanding, with 4 institutions included on the list (the University of Oxford, University of Leeds, University of East Anglia, and University of Cambridge rank 4th, 6th, 8th, and 10th respectively). Fig. 5 also shows close collaboration among Massachusetts Institute of Technology, University of California Berkeley and Harvard University, three top institutions in the United States.

4.1.3. Author collaboration network

The emergence, formation, and development of a research field are closely related to its experts and scholars. Fig. 6 presents an author collaboration network consisting of 846 authors and 1123 collaboration

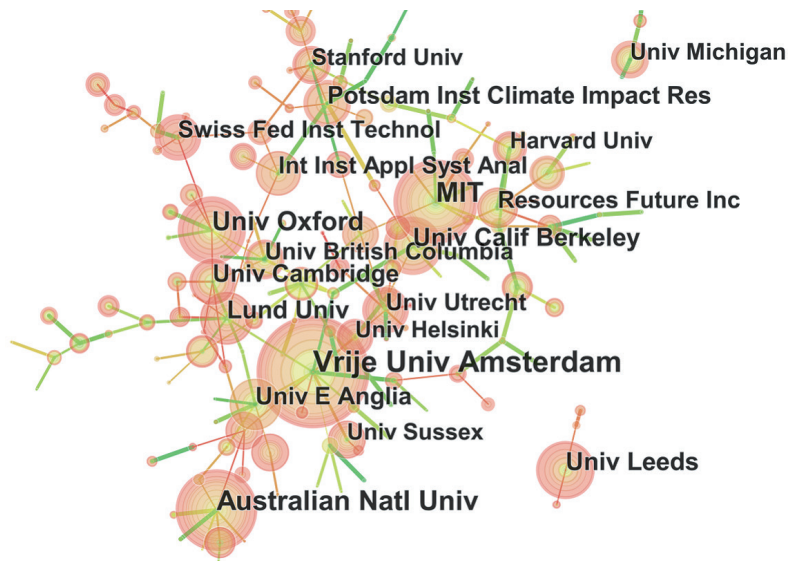


Fig. 5 A visualization of the institution collaboration network (1990-2018)

Table 2 Top 10 institutions based on publication frequency (1990-2018)

Institution	Country	BC	Publication frequency
Vrije University Amsterdam	the Netherlands	0.09	51
Massachusetts Institute of Technology	the United States	0.03	39
Australian National University	Australian	0.02	37
University of Oxford	the United Kingdom	0.03	31
University of California, Berkeley	United States	0.04	27
University of Leeds	the United Kingdom	0	27
Lund University	Norway	0.04	26
University of East Anglia	the United Kingdom	0.02	24
Potsdam Institute for Climate Impact Research	Germany	0.03	23
University of Cambridge	the United Kingdom	0.01	23

links. Tol, R.S.J. in Fig. 6, is one of the most influential scholars in climate policy and governance. He is affiliated with the Vrije Universiteit Amsterdam and specializes in the economics of energy, the environment, and integrated assessment modeling (Tavoni and Tol, 2010; Tol, 1999, 2013). In addition, the bold orange-colored links in Fig. 6 imply a broad collaboration over the past decade. In these clusters, Riahi, K. and van Vuuren, D.P. maintained close collaboration in research on shared socio-economic pathways (SSPs) (new climate models used to carry out integrated, multidisciplinary climate impact analysis and was used in the Intergovernmental Panel on Climate Change's (IPCC's) sixth assessment report) and on corresponding energy, land use, and greenhouse gas emissions implications (Riahi *et al.*, 2017).

Moreover, Table 3 presents basic information of other prolific researchers. Böhringer, C. published extensively on carbon trade and tariffs (Böhringer *et al.*, 2015), and Bulkeley, H. produced several influential works on the roles of cities and other non-state actors in responding to intensifying climate

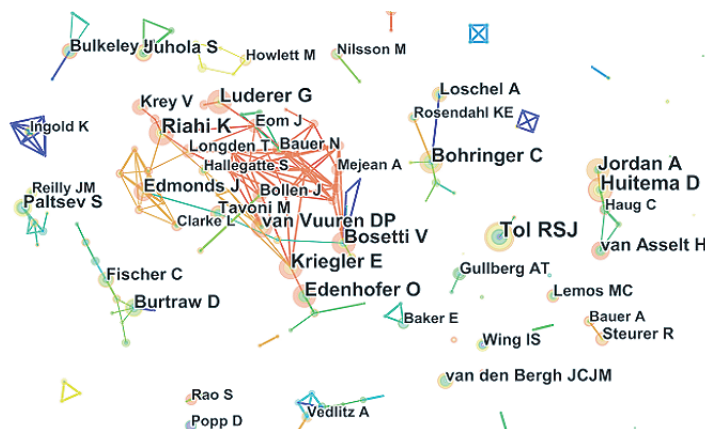


Fig. 6. A visualization of author cocitation network (1990-2018)

change (Bulkeley and Betsill, 2005). Most prolific scholars are affiliated with departments/faculty related to environmental studies (science), geography, and economics research. This is consistent with the top 10 research, as fields of climate policy and governance research shown in Fig. 3.

Table 3 Top 10 Authors based on publication frequency (1990-2018)

Author	Publication frequency	Institution	Most cited work
Tol, R.S.J	20	Economics of Climate Change, Institute for Environmental Studies and Department of Spatial Economics, Vrije Universiteit Amsterdam	The economic effects of climate change
Riahi, K.	17	International Institute for Applied System Analysis, Luxemburg	A new scenario framework for climate change research: the concept of shared socioeconomic pathways
Huitema, S.	15	Institute for Environmental Studies, Vrije University Amsterdam	Emergence of polycentric climate governance and its future prospects
Böhringer, C.	14	Department of Business Administration, Economics and Law, University of Heidelberg	Measuring the immeasurable – A survey of sustainability indices
Jordan, A.	13	School of Environmental Sciences, University of East Anglia	Environmental policy integration: A state of the art review
Bulkeley, H.	13	Department of Geography, University of Durham	Rethinking sustainable cities: Multilevel governance and the ‘Urban’ politics of climate change
van Vuuren, D.P.	13	Faculty of Geosciences, Utrecht University	The representative concentration pathways: an overview
Luderer, G.	12	Sustainable Solutions, Potsdam Institute for Climate Impact Research	The economics of decarbonizing the energy system – results and insights from the RECIPE model intercomparison
Juhola, S.K.	12	Helsinki Institute of Sustainability Science, University of Helsinki	Challenges of adaptation to climate change across multiple scales: A case study of network governance in two European countries
Baue, A.	12	Department of Science and Technology Studies, Alpen-Adria University Klagenfurt	Multi-level governance of climate change adaptation through regional partnerships in Canada and England

4.2. Cocitation networks

Cocitation network analysis was first proposed by Small (1973). A cocitation relationship exists when two articles are cited by one or more articles at the same time. Thus, a higher citation frequency implies a higher cocitation level. Damschroder *et al.*, (2009) proposed that cocitation analysis helps explore new theories and reflects the scientific communication structures between researchers and the evolution of knowledge. The cocitation analysis uses the expectation-maximization algorithm based on a series of attributes, including citation frequency and BC values. To find the most influential points by exploring the underlying clusters with high article cocitation counts associated with the most cited works/authors/journals, the following section presents the Article Cocitation Network and Journal Cocitation Network.

4.2.1. Article Cocitation Network

The most cited articles can be regarded as landmarks due to their ground-breaking contributions (Chen *et al.*, 2012). Fig. 7 presents the most cited articles by cocitation frequency. Two clusters of climate policy and governance research can be identified. In the upper cluster, Stern's (2008) article entitled *The Economics of Climate Change* is the most cited article in our dataset with 73 cocitations. This article examines the economic impact of climate change and proposes implications for emissions targets, policy instruments, and global action for climate change governance. Research on the economic impact of climate change was further strengthened by Weitzman's work in 2009. His article takes climate change as a prototype example to analyze the implications of structural uncertainty for the economics of low probability, high-impact catastrophes, and suggests that catastrophe insurance might provide a useful means of framing the economic analysis of catastrophes. These two articles lay a foundation for researching the economic impact of climate change and its policy implications (Weitzman, 2009).

Two other highly cited articles in the upper cluster are Ostrom's (2010) and Keohane and Victor's (2011) articles. Ostrom (2010), the founder of public choice theory, takes climate change as a global collective-action problem and proposes polycentric efforts to reduce the risks associated with greenhouse gas emissions. The author argues that polycentric governance approaches on the one hand may facilitate achieving benefits at multiple scales, on the other hand, may create problems such as inconsistent policies, inadequate certification, gaming the system, and free riding. Keohane and Victor (2011) pointed out that a loosely coupled set of specific regimes might lead to distinct cooperation problems between governments and non-state actors. However, fragmented institutions may promote more effective management of climate change due to their flexibility across issues and adaptability over time. Discussions of regime complexes and collective action have followed and been enriched by many other scholars (Ayling and Gunningham, 2017; Henstra, 2017; Keohane and Victor, 2016), constructing a basis for climate policy and governance research in the political science field. Overall, the articles in the upper cluster discuss climate policy and governance issues on a global scale and focus more on the economic and political facets of climate issues.

Compared to the upper cluster, the lower cluster of cocitation works focuses more on the urban and city levels. Harriet Bulkeley is the most influential scholar in the field of urban governance of climate change. Bulkeley's work with Broto published in 2013, *A Survey of Urban Climate Change Experiments in 100 Cities*, is the most cited work in this field. This article analyzes a database of 627 technical and social innovations of urban climate governance and explores the heterogeneous roles of actors, settings, governance arrangements, and technologies involved (Broto and Bulkeley, 2013). Bulkeley's works *Revisiting the Urban Politics of Climate Change* (2013) and *Cities and the Governing of Climate Change* (2010) are also the two most cited works in this field, with both examining the history and development of urban climate

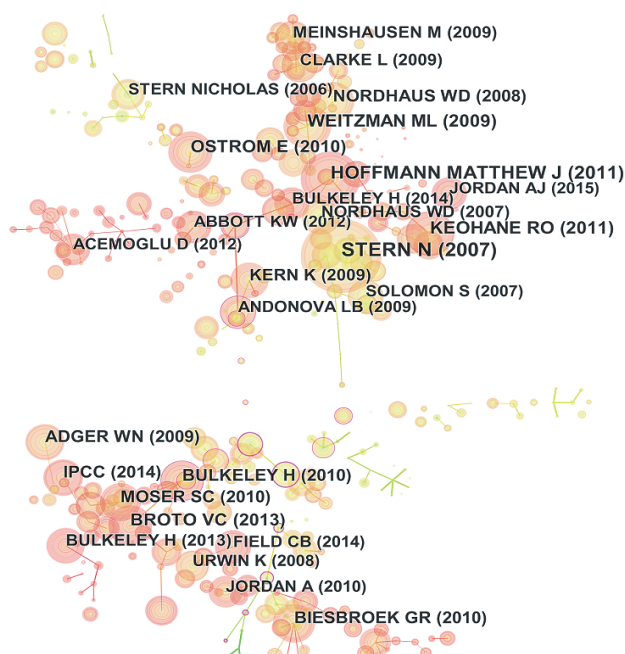


Fig. 7 The most cited articles with cocitation frequency (1990-2018)

governance, the policies and measures put into place and the multilevel governance context in which these measures are undertaken. Notably, some scholars have focused on urban climate change adaptation strategies. Biesbroek *et al.* (2010) summarize the National Adaptation Strategies of seven European countries and review the processes of strategy development and implementation. Adger *et al.* (2009) and Moser and Ekstrom (2010) discuss the limits of and the barriers to climate change adaptation. The first 10 years of the 21st century form the rudimentary stage of climate policy and governance research, and the most influential articles have proliferated since the 2010s. Table 5 lists the top ten most cited articles by cocitation frequency.

Table 5 Top 10 most cited articles with cocitation frequency (1990-2018)

Author	Year	Cocitation frequency	Article
Stern, N.	2008	73	The economics of climate change
Keohane, R.O. and Victor, D.G.	2011	44	The regime complex for climate change
Weitzman, M.L.	2009	43	On modeling and interpreting the economics of catastrophic climate change
Ostrom, E.	2010	41	Polycentric systems for coping with collective action and global environmental change
Broto, V.C. and Bulkeley, H.	2013	40	A survey of urban climate change experiments in 100 cities
Bulkeley, H.	2010	39	Cities and the governing of climate change
Biesbroek, G.R. <i>et al.</i>	2010	39	Europe adapts to climate change: Comparing national adaptation strategies
Moser S.C. and Ekstrom J.A.	2010	38	A framework to diagnose barriers to climate change adaptation
Adger W.N. <i>et al.</i>	2009	36	Are there social limits to adaptation to climate change?
Bulkeley, H. and Betsill,	2013	35	Revisiting the urban politics of climate change

4.2.2. Journal Cocitation Network

Table 6 lists the 10 journals with the highest cocitation frequency in the climate policy and governance field. *Climate Policy* is the top-cited journal with a cocitation frequency of 656, followed by *Energy Policy* (482), and *Climatic Change* (308). *Science* and *Nature*, top academic journals publishing original research across a wide range of scientific fields are also on the list. Both of the two journals have the highest BC values (0.46 and 0.45 respectively) on the list. Other listed journals with high BC values are *Global Environmental Change* (0.43), *Climate Policy* (0.17), and *Climatic Change* (0.17). *Climatic Change*, *Nature*, *Science*, *Global Environment Change* and *Climate Policy* are thus the key nodes connecting to others in the journal cocitation network (see Fig. 8). The most prolific journals may not necessarily have the highest impact factors, though they tend to have higher cocitation frequencies, which implies their substantial influence on this field.

Table 6 Top 10 most cited journals with cocitation frequency (1990-2018)

Journal	Cocitation frequency	BC	Publication	Impact factor
Climate Policy	656	0.17	148	4.797
Energy Policy	482	0.09	160	4.880
Climatic Change	308	0.17	79	4.168
Global Environment Change	250	0.43	60	4.381
Ecological Economics	205	0.11	47	4.830
Nature	201	0.45	7	41.577
Science	199	0.46	10	41.058
Energy Economics	179	0.02	66	3.199
Nature Climate Change	171	0	37	17.184
Environmental Science and Policy	168	0.03	77	1.919

Fig. 8 presents the cocitation network for climate policy and governance journals. In total, 173 different journals are identified, illustrating a diverse body of knowledge in climate policy and governance research. Notably, three major subdomains of journals emerge from this research field, namely economics, energy and political science. With a focus on the economic impact of climate change, *Ecological Economics* and *Energy Economics* concern the interfaces and interplay between ecosystems and the economy. Specific research areas include the evaluation of natural resources, sustainable agriculture and development, ecologically integrated technology, and integrated ecologic-economic modeling. Another journal with an economic focus is *Environmental and Resource Economics*, which is concerned with economic theory and methods to address environmental issues and problems. Areas of particular interest include the evaluation and development of instruments of environmental policy, resource pricing and the valuation of environmental goods, and indicators of environmental quality. *Energy Policy* is one of the most influential journals concerning energy supply security, and the quality and efficiency of energy services. This journal addresses the policy implications of energy supply and utilization from their economic, social, planning, and environmental aspects. Areas of particular interest include energy and environmental regulation, energy supply security, the quality and efficiency of energy services. With a focus on the political and social impacts of climate change, *Climate Policy* and *Environmental Science and Policy* concentrate more on the environmental politics development and sustainable urban development,

which cover a broad range of topics including political science, sociology, geography, international studies, and urban studies.

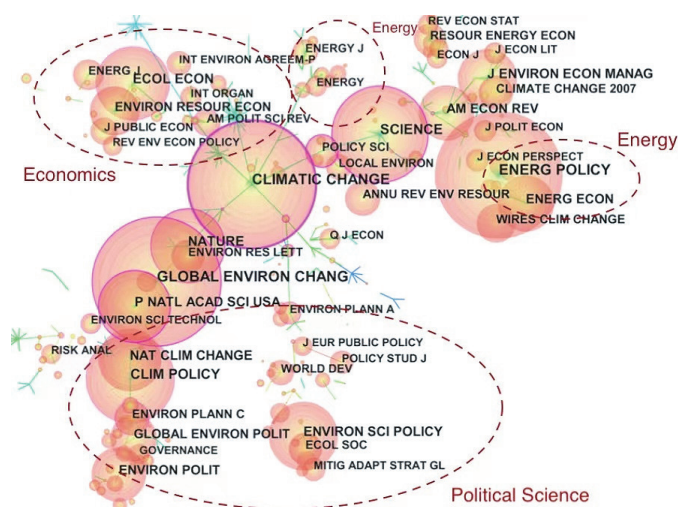


Fig. 8 A visualization of the journal cocitation network (1990-2018).

4.3. Emerging trends

Bibliometric analysis is frequently used to analyze keywords to identify the development of research topics (Adger *et al.*, 2009; Moser and Ekstrom, 2010). Keywords analysis can be used to visually reveal the development trend and current research focuses of climate change and governance research. The co-occurrence network of high-frequency keywords is shown in Fig. 9. Two streams of keywords were identified, namely, climate mitigation and climate adaptation. Climate mitigation refers to an anthropogenic intervention designed to reduce the sources or enhance the sinks of greenhouse gases (Hiraishi *et al.*, 2014), and mitigation policies are thus applied to slow global warming through low-carbon initiatives and energy-saving behaviors. The cluster of climate mitigation comprises of the keywords such as “emission”, “renewable energy” and “risk”. It is worth noting that China and the United States are the only two country names included as keywords in this cluster, with the former positioned more centrally among surrounding keywords. These two countries may appear as they are the major emitters of greenhouse gases (World Resources Institute, 2017). In addition, as the most influential economies worldwide, these two countries are both of great importance in international climate negotiations (Jordan and Lenschow, 2010). The United States was the pioneer of CO₂ emission trading mechanisms in the 1970s and 1980s, and the advanced experience was hailed for successfully achieving emissions reductions, saving costs, and inducing technological innovation (Ellerman, 2003; Brink and Wamsler, 2018). However, as the country drifted away from international mechanisms (its withdrawal from the *Kyoto Protocol* in 2001 and the *Paris Agreement* in 2017), the United States was accused of undermining the climate change governance integrity of the international institutions.

The upper stream is mainly connected to the keywords such as “vulnerability”, “policy”, “governance”, “politics” and “city”, implying a research focus on climate adaptation policies. The term “adaptation” refers to public policies, practices and projects that moderate the damage caused by climate change and exploit the opportunities associated with climate change (Ellerman, 2003). A wide range of policy sectors is likely to be affected, including water, agriculture, forestry, fishing, biodiversity, insurance, transport, energy, tourism, and health sectors. The keyword “European Union” emerges in

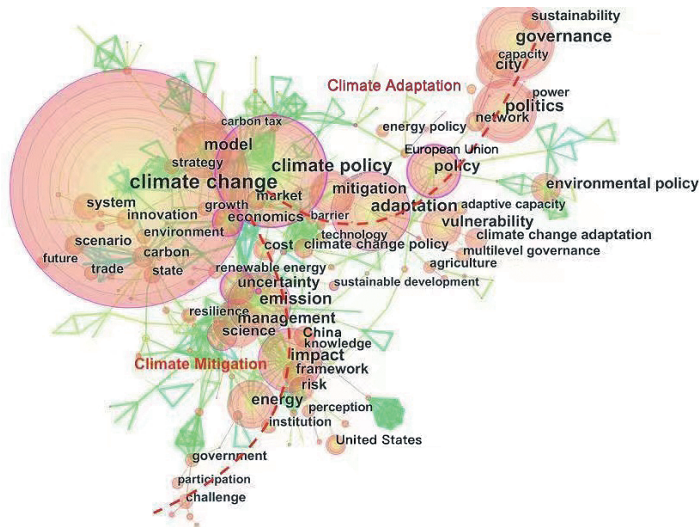


Fig. 9 The co-occurrence network of high-frequency keywords (1990-2018).

this stream. Due to their geographic positioning at high latitudes, European countries are extremely vulnerable to climate risks such as the sea level rise and extreme weather, leading to extensive studies on adaptive strategies (Adger *et al.*, 2009; Moser and Ekstrom, 2010). Unlike mitigation efforts often coordinated at national and international levels, adaptation strategies are mostly initiated at the local government level (e.g. cities and counties), where the effects of climate change are directly experienced (Bulkeley and Betsill, 2013; Klein *et al.*, 2007;).

A statistical analysis of the time zone view and the burst of keywords is provided in Table 7 and Fig.10. The time zone view refers to trends in the research field. Bursts include the keywords that appear the most in a short period or with a high frequency of usage. According to the major keywords found over 29 years, the main topics of climate policy and governance research are synthesized into three research trends: shifts from performance evaluation to green technology innovation, from international institution design to local climate governance and from eliminating scientific uncertainty to political awareness increase.

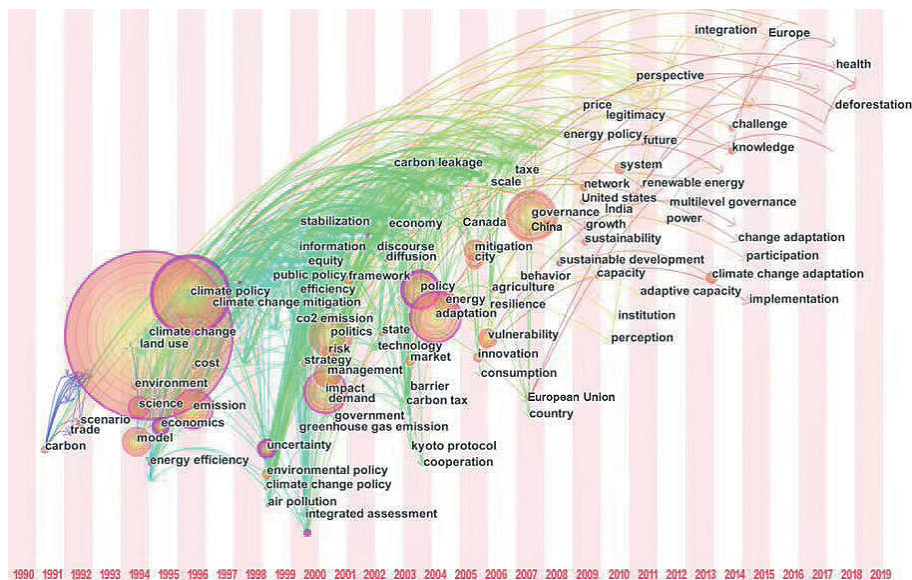


Fig. 10 Time zone view of keywords (1990-2018)

Table 7 Keywords with the strongest citation bursts (1990-2018)

Keywords	Strength	Begin	End	1990 - 2018
Greenhouse gas	4.0946	1994	2006	
Global warming	3.9519	1995	2010	
Irreversibility	3.5779	1998	2012	
Energy technology	3.179	2001	2011	
Technical change	3.3087	2003	2012	
CO ₂ abatement	7.4887	2004	2011	
Research and development	6.0366	2005	2012	
Emissions trading	3.5163	2007	2012	
Social ecological system	3.6931	2010	2012	
Institution	3.1937	2011	2012	
Adaptive capacity	3.4461	2011	2015	
Regime complex	4.7458	2015	2017	
Climate governance	5.3512	2017	2018	

4.3.1. From performance evaluation to green technology innovation

The economic impacts of climate change (*e.g.* temperature, precipitation, humidity, and sea levels) have attracted the attention of researchers since the early 1990s, while the approaches to address climate change have been continuously redefined and expanded by academics and policy-makers (Hornsey *et al.*, 2016; Schlosberg and Collins, 2014). Early studies have mostly focused on climate mitigation policies to alleviate the adverse impacts of climate change, as most of the keywords during 2000-2007 are climate policy performance-related words (*e.g.* “integrated assessment,” “impact,” “strategy” and “efficiency”). The design and implementation of the carbon market and emission trade are popular topics in climate policy and governance research given their potential for emission reductions and removal (Edenhofer, 2014; Peters and Hertwich, 2008).

However, a shift has occurred since the publication of the IPCC’s fourth assessment report on climate change in 2007. The report argues that the warming trend of the global climate system is unequivocal, as indicated by observed data on global average temperature rise, large-scale snow and ice melt, and global average sea-level rise (Pachauri and Reisinger, 2008). A large number of studies are concerned with efforts to reduce or prevent the emission of greenhouse gases by using new technologies and renewable energies, such as by rendering older equipment more energy efficient, changing management practices and consumer behavior (Borba *et al.*, 2012; Comodi *et al.*, 2012; Whitmarsh and Köhler, 2010). Discussions of green technologies cover a broad range of fundamentally different forms of innovation, including green innovation and technology and environmental policy integration (Popp *et al.*, 2010). Green technologies have been deployed at an unprecedented scale around the globe and have led to increasing academic discussion (Delina *et al.*, 2014; Tosun and Schoenefeld, 2017). Green innovation in technologies (*e.g.* the design of green products, energy-saving and recycling, and low-carbon technology) has been highlighted as a means to achieve a transformation of social, cultural, economic, environmental, and power relations in climate governance and to build a more just, sustainable, and resilient ecological system (Kalkanci *et al.*, 2019; Schroeder and Kaplan, 2019; Shahzad *et al.*, 2020).

4.3.2. From international institution design to local climate governance

The 1997 *Kyoto Protocol* established an international institutional framework for national governments in response to climate change and linked emission targets for developed countries to international carbon market mechanisms. The keyword timezone results show the leading countries and regions in climate governance (e.g. the United States, the European Union, China and India) immediately after the *Kyoto Protocol* came into effect in 2005. The development of international institutions has thus brought about an ongoing discussion of the coherence, accountability, fairness, and sustainability of evolving institutional arrangements for various stakeholders (both states and nonstate actors) (Hagen *et al.*, 2016; Schleich *et al.*, 2016). However, doubts surrounding efforts to build a comprehensive regime have emerged. As Keohane and Victor (2011) state in their influential study *The Regime Complex of Climate Change*, governments are widely varying in their interest in international institutions and capacity to take climate action, which makes adaptability and flexibility in institutional settings extremely important.

Thus, “multilevel governance,” highlighting the adaptability and flexibility of government levels, reemerged as a keyword in 2012. The focus of climate governance then been shifted from the international level to the local government level (Fünfgeld and McEvoy, 2014; Krause *et al.*, 2016). Urban climate governance highlights the various strategies and responses to climate change in different cities or regions. “Climate change adaptation” and “adaptive capacity” became heated-discussed keywords at this time (see Fig. 10). The local government level is taken as the most appropriate level for climate action, typified by a strong preference for loose, networked forms of governing such as through policy mainstreaming and information sharing (Keskitalo *et al.*, 2016). In addition, there are still intense debates on the extent to which deliberate interventions need to be made by governors at national or supranational levels (“planned adaptation”) and how affected actors and communities at local levels should take policy initiative and actions independently (“autonomous adaptation”) (Doherty *et al.*, 2017; Mastrandrea *et al.*, 2010; Thorn *et al.*, 2015). More empirical cases are needed to explore this issue.

4.3.3. From eliminating scientific uncertainty to political awareness increase

The question of “whether climate change exists” has concerned climate scientists for a long time based on doubts about “whether climate change is caused by human interference” (Hagen *et al.*, 2016; Jordan and Lenschow, 2010). Thus, scientific uncertainty surrounding climate change was the focus of early climate policy and governance research. “Integrated assessment model” and “policy scenario,” keywords of 1990 to 2001, are research methods applied to verify the existence of climate change and its impacts (e.g. Dell *et al.*, 2014; Maccini and Yang, 2009). As scientific uncertainty surrounding climate change has reduced, research on public perception and behavior in response to enhanced climate change has increased rapidly, as the keywords such as “perspective,” “perception” and “knowledge” have emerged as key topics of climate policy and governance research.

With an increase in research on public awareness and behavioral change in response to climate change, research focuses vary under different sociopolitical contexts. Increased public awareness in developing countries is urgently needed in the face of water and food shortages and greater risks to health and life as a result of climate change (Pondorfer, 2019; UNFCCC, 2019). As climate change affects individual’s well-being, the public has the right to obtain more adequate and accurate information on this issue (FitzRoy *et al.*, 2012; Fisher and Dodman, 2019; Tsang and Kolk, 2010). Moreover, public views and evaluation of climate change is based on to what extent climate change is a social fact and an urgent social problem to be solved. Public awareness and active responses are necessary for climate policy and

governance, not only contributing directly to addressing the problem but also providing a strong social foundation for the implementation of social-political systems and policies to solve the problem. Therefore, public awareness, perceptions and knowledge of climate change have been intensively studied in the past few years, such as in Lee's (2015) research investigating the predictors of public climate awareness and risk perception and in Ferdushi's (2019) research exploring farmers' awareness of climate change in developing countries, which may provide avenues for future research.

5. Conclusion

This article provides a bibliometric analysis of 2487 SSCI journals published from 1990 to 2018 to characterize the intellectual landscape of the climate policy and governance literature. Our findings illustrate the evolution of researchers' collaboration and publication cocitations, and identify the emerging research agenda. The following conclusions can be drawn from the results.

Firstly, works on climate policy and governance published during 1990-2018 show a significant increasing trend, especially from 2008 to 2018. Secondly, scholars with a professional background in environmental science, economics, and public administration have been most concerned with climate policy and governance issues. The research field has evolved into a multidisciplinary research field since 2005. Thirdly, research on climate policy and governance is dominated by the United States, the United Kingdom and Germany, among which, the United States plays a dominant role in stable cooperation with other countries. Connections between countries strengthened from 1990 to 2018. The institutional cooperation network indicates a high level of maturity, as networks have a dense structure and strong relationships. Fourthly, the findings indicate that authors receiving the most attention are experts in environmental studies (science), geography, and economics research. *Climate Policy*, *Energy Policy* and *Climatic Change* are the most influential journals in this field with the highest publication and citation numbers.

This study identifies three emerging trends in climate policy and governance research. Firstly, the research focus has shifted from the performance evaluation of climate policy to the highlights of green technology innovation. Green innovation in technologies (e.g. the design of green products, energy-saving and recycling, and low-carbon technology) is seen as a means to achieve a transformation of social, cultural, economic, environmental, and power relations in climate governance. Secondly, a focus on international institutional development has shifted to multilevel governance with more attention to local sustainable development. We call for future studies exploring how governance at national or supranational levels should intervene in actions at the local level. Finally, with more scientific evidence showing the existence of climate change, the means to strengthen public awareness and knowledge and participation in climate governance is a future research direction.

Here, we outline three potential research agendas based on our analysis and findings. Firstly, the bibliometric analysis identifies new keywords (e.g. "health," "knowledge" and "participation"), and most of them focus on individual behavior at the local level. We thus call for future research focused on the impact of climate change on individuals' well-being. Therefore, climate change issues should be skillfully framed into significant local agendas on air pollution, health, and congestion (Betsill and Corell, 2001). Secondly, we call for more studies on climate policy and governance in developing countries (e.g. China). The existing literature has discussed climate change issues in developed countries, as the dominant research institutions in climate policy and governance research are mostly based in the United States

and European countries. However, climate change is expected to jeopardize sustainable development in both developed and developing countries, and the effects will be more challenging for the latter, where adaptation planners may not have the skills required to perform vulnerability assessments (Chaudhury *et al.*, 2017). Climate research on developing countries is thus urgently needed. Thirdly, most existing studies have discussed the evolution of international mechanisms and the development of local climate policies with a detached approach while ignoring the interactions between the two levels of policy implementation. Given that the context matters due to different political and socioeconomic environments, especially between developed and developing countries, we call for future research on the impact of the international agenda on domestic climate policy development.

The present study has some limitations. Firstly, researchers tend to cite their own works and high-quality papers, which may impact the number of citations of top journals. Future research may consider excluding self-citations in calculations. Secondly, as all data collected in this study are from English-language sources, future research may obtain more comprehensive results by including articles written in other languages.

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