Global Environmental Change 23 (2013) 1684–1693

Contents lists available at ScienceDirect

Global Environmental Change

journal homepage: www.elsevier.com/locate/gloenvcha

A quantitative analysis of the causes of the global climate change research distribution

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ARTICLE INFO

Article history:
Received 30 July 2012
Received in revised form 8 August 2013
Accepted 18 August 2013

Keywords:
Bibliometric analysis
Knowledge production
Adaptation
Stability
Policy
Vulnerability

ABSTRACT

During the last decades of growing scientific, political and public attention to global climate change, it has become increasingly clear that the present and projected impacts from climate change, and the ability adapt to the these changes, are not evenly distributed across the globe. This paper investigates whether the need for knowledge on climate changes in the most vulnerable regions of the world is met by the supply of knowledge measured by scientific research publications from the last decade. A quantitative analysis of more than 15,000 scientific publications from 197 countries investigates the distribution of climate change research and the potential causes of this distribution. More than 13 explanatory variables representing vulnerability, geographical, demographical, economical and institutional indicators are included in the analysis. The results show that the supply of climate change knowledge is biased toward richer countries, which are more stable and less corrupt, have higher school enrolment and expenditures on research and development, emit more carbon and are less vulnerable to climate change. Similarly, the production of knowledge, analyzed by author affiliations, is skewed *away* from the poorer, fragile and more vulnerable regions of the world. A quantitative keywords analysis of all publications shows that different knowledge domains and research themes dominate across regions, reflecting the divergent global concerns in relation to climate change. In general, research on climate change in more developed countries tend to focus on mitigation aspects, while in developing countries issues of adaptation and human or social impacts (droughts and diseases) dominate. Based on these findings, this paper discusses the gap between the supply of and need for climate change knowledge, the potential causes and constraints behind the imbalanced distribution of knowledge, and its implications for adaptation and policymaking.

1. Introduction

In the past few decades, climate change has become a central theme in many political and public debates on the local and global scene. The scientific community has contributed extensively to these debates with various data, projections and discussions on the future climate, as well as on the causes and effects of the expected climatic changes. Notably, the impacts of a warmer, more unpredictable and extreme climate are not expected to be evenly distributed across the globe. Some regions will experience potentially detrimental changes such as increased drought or flooding, while others may find that conditions for agricultural production improve (Hare et al., 2011; IPCC, 2007; Richardson et al., 2009; Stern et al., 2006). Many regions with a high risk of negative impacts from climate change are found in the less developed parts of the world and often have a low adaptive capacity (Preston et al., 2011; Richardson et al., 2011). Scientific knowledge has been shown to play an increasing role in understanding potential climate change impacts and in forming debates and policies (Dessler and Parson, 2010) at global, regional and national scales. Increasing scientific knowledge transfer may contribute to decreased uncertainties and increased adaptive capacity of individuals, institutions or governments (Adger et al., 2009). However, scientific research on climate change appears to focus predominantly on the more developed and less vulnerable regions of the world (e.g. Felton et al., 2009; Ho-Lem et al., 2011; Kiparsky et al., 2006). Indeed, the Intergovernmental Panel of Climate Change (IPCC) notes a ‘‘lack of geographical balance in the data and literature on observed changes in natural and managed systems, with a marked scarcity from developing countries’’ (Rosenzweig et al., 2007, p. 117). This leaves a potential gap or

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http://dx.doi.org/10.1016/j.gloenvcha.2013.08.013

mismatch between the supply of and the need for knowledge on climate change to be explored and addressed.

This study is one of the first to analyze for congruence between research efforts and research needs at the country scale in relation to climate change. We expand by analysing the potential causes of global distribution of climate change research. With a bibliometric analysis we aim to identify potential mismatches between the global need for knowledge, measured as climate change vulnerability, and the supply of knowledge, measured by scientific publications. The analyses presented here include country level indicators on wealth, education, research expenditures, press freedom, state stability, corruption, development assistance and environmental footprint. These explanatory factors are included in order to facilitate a discussion on some of the potential causality and reasons for any mismatch between recent supply of and need for scientific knowledge in climate change. As in Sarewitz and Pielke (2007) we borrow from economics the concepts of "supply" and "demand" of knowledge to discuss the relationship between the production of scientific results and their potential use for filling the knowledge gap in different regions of the world.

The use of bibliometric analyses as a method to study trends and patterns in the published scientific literature has gained interest in the past few decades with the increasing number of (easily accessible) online databases as well as software programs for various analyses and statistics. In environmental science, for instance, the method has been used to study which themes, key words or sub-fields are the most common within a given research field (e.g. Fu et al., 2010; Janssen et al., 2006; Kiparsky et al., 2006; Mao et al., 2010; Preston et al., 2011; Zhang et al., 2010) or to study which authors, journals or countries contribute to the literature within a given field (e.g. Aksnes and Hessen, 2009; Fu et al., 2010; Janssen et al., 2006; Kahn, 2011; Karlsson et al., 2007; Kiparsky et al., 2006; Ma and Stern, 2006; Smith et al., 2009; van der Zaag et al., 2009). Several studies have addressed the link between scientific publications and environmental or climatic changes. Janssen et al. (2006) analyzed the relationship between different knowledge domains (resilience, vulnerability and adaptation) within the research activities on human dimensions of global environmental change. van der Zaag et al. (2009) studied the gap in water research on adaptation to climate change published by developing countries, and Felton et al. (2009) assessed climate change literature that considered the conservation management of biodiversity and ecosystems Finally, Karlsson et al. (2007) take the analysis a step further with a quantitative study of the generation of scientific knowledge in environmental research between developed and developing countries in relation to geographic, social, political and economic characteristics.

It is widely understood in the scientific community that scientific evidence supports that the global climate system is moving beyond the patterns of natural viability and the natural range of the human living conditions (Richardson et al., 2011). Knowledge exists on potential impacts and the literature has extensively discussed the potential instruments that could effectively deal with climate change. The great challenge is to develop more geographical specific knowledge and to integrate this knowledge into the development of country or regional level trajectories. One important precondition is to understand how the level of scientific information on climate change in a particular geographical setting varies with characteristics of the socio-economical and socio-political system. To our knowledge, bibliometric analysis has not been applied to analyze potential gaps between climate change research needs and supply at a global scale, and more specifically not on how economic, institutional and political factors could influence the supply of climate change research on a particular geopolitical setting (country or region).

To address the gaps outlined above this study explores the following questions: How does the number of climate change publications match the vulnerability in a country to climate change? How is this relationship related to the socioeconomic and institutional characteristics of a country? Finally, how is the number of publications *concerning* climate change across countries related to the first author *affiliations* of the publications? These questions are addressed in the remaining parts of the paper, which are structured as follows. Section 2 briefly presents the methods used for searching climate change publications and sorting the dataset. The model and variables used for the analyses are presented in Section 3. In Section 4, the results are presented, and in Section 5 the findings and implications of the analyses are discussed.

2. Data collection

In order to analyze the potential gap between the supply of and need for climate change knowledge, data was collected on the global distribution of the *supply of knowledge* (measured by climate change publications) and the *need for knowledge* (measured by climate change vulnerability). In order to analyze and explain this relationship, data was collected on various socio-economic and socio-political variables. The search and review of climate change publications follow guidelines for systematic reviews (Pullin and Stewart, 2006; Davies and Pullin, 2007) adapted to the research questions and purpose of this study.

2.1. Climate change publications

To assess the supply of climate change knowledge in terms of research publications, two types of data were collected: (1) *case country publications*, the number of publications concerning climate change (effects, impacts, mitigation, etc.) for a specific country, and (2) *first author publications*, the number of publications by first authors based in a specific country (their institutional affiliation).

Country publications were obtained from the Web of Science database (part of Web of Knowledge databases provided by Thomson Reuters) between July 12 and July 16, 2010. The database was searched for articles, proceedings papers and reviews within the time span 1999 to July 2010 using the search phrases *climat* AND change** and *global warming* (with asterisk wildcards). In order to focus the search on knowledge domains within climate change research, including human dimensions, and to reduce redundancy in the dataset, the search was run with related phrases such as *effect*, *impact* and *adaptation* (using the appropriate search wildcards). The search was run for a total of 197 countries of the world based on the United Nations list of recognized countries (UN, 2006) and including Antarctica and Greenland. In each case the search was made by adding country name (e.g. France) and adjectives (e.g. French) to the search history. Subsequently, the search was narrowed by excluding selected "Subject Areas" in Web of Science, and finally, the country publications were manually checked to exclude irrelevant publications from the database, such as terminological or geographical noise (see Appendix). For the manual check, all retrieved publications were exported into EndNote X3 software (see also McAllister et al., 2009). In order to analyze first author affiliations, the data was exported from EndNote to the bibliometric software HistCite™ with a custom designed EndNote reference style. The first author publications (analyzed in Section 4.4) obtained with HistCite™ was used to sort the publications in the final dataset by the country and institution of the first author.

Finally, in order to supplement the quantitative analyses presented above, we did a qualitative screening of titles and abstracts of a randomly selected sub-set of publications to assess certain knowledge domains, which were found relevant to investigate for the study of the supply and need for climate change research. These domains were categorized as *primary research focus* (mitigation or adaptation), *climate change effects* (natural or social/human), *scale* (large or small), *dominant scientific approach* (natural or social science), and whether an *economic perspective* was present.

3. Models and explanatory variables

We used the negative binomial count data model for the statistical analysis (Cameron and Trivedi, 2005) because of the non-negative and integer nature of research publication data.

We expect the number of publications to depend on a variety of parameters. To analyze the generation of climate change knowledge, measured by the number of research publications, we test the relationship between the number of research publications and demographical, geographical, economical, educational, institutional, environmental and climate vulnerability factors assessed for each country (Table 1).

We test if there is a significant positive correlation between vulnerability to climate change and research quantity, which would then indicate that supply of geopolitical/local knowledge, may be correlated with the potential need for research. However, the research effort on climate change could be linked with the economic situation of the country (see e.g. Ho-Lem et al., 2011). In such case we would expect that the number of publications increases with economic capacity measured by gross national income of the country studied in the publication. One argument supporting this hypothesis would follow that increasing wealth leads to greater spending on science and climate change research. We included data on Official Development Assistance (World Bank, 2011b) to test for the correlation between publications and a development indicator. Countries which are large carbon dioxide emitters may have an incentive to invest in climate change research compared to low emitters. Country data on the total carbon dioxide emission from energy consumption is applied to test for such relation. We would also expect that public investment in education may also lead to higher research productivity (e.g., Karlsson et al., 2007). We use data on public spending on education as a percentage of gross domestic product, GDP (World Bank, 2011c,d) as well as data on school enrolment to secondary level as a percentage of total enrolment, and expenditures on research and development as explanatory variables. Since we do not know if this is connected with the country studied or the country undertaking the research (may not be the same), we include data on the first authors as well to test for any significant relation between knowledge generation and the

Table 1
Data variables and description.

Variable name	Description
Climate vulnerability	Vulnerability index (Maplecroft, 2011). The index varies in the range between 1 and 10 where 1 is the highest vulnerability and 10 the lowest. The Maplecroft climate change vulnerability index is an assessment of vulnerability of human populations to extreme climate related events and changes in major climate parameters 2010–2040. The index combines the risk of exposure to climate change and related extreme events (drought, cyclones, landslides, flooding and sea-level rise), with the degree of current sensitivity to that exposure and the ability of the country to adjust to, or take advantage of existing or anticipated stresses resulting from climate change.
Demographic	
- Population	Total number of inhabitants in millions (US Census Bureau Population Division, 2011)
Geography	Classification of a country as an island state or not. A dummy getting the value of 1 if country *i* is an island state, 0 otherwise. Member list of the Alliance of Small Island states was used for making the classification (AOSIS, 2011).
Economic	
- GDP–PPP	Average Gross Domestic Product normalized by Purchasing Power Parity (GDP–PPP) (million current US$) between 2000 and 2009 (World Bank, 2011a)
- GNI–PPP	Average Gross National Income per capita normalized by Purchasing Power Parity (GDP–PPP) (current US$) between 2000 and 2009 (World Bank, 2011f)
- Official Development Assistance	Average net Official Development Assistance received (current US$) (ODA) between 2000 and 2009 (World Bank, 2011b).Net official development assistance consists of disbursements of loans made on concessional terms (net of repayments of principal) and grants by official agencies of the members of the Development Assistance Committee (DAC), by multilateral institutions, and by non-DAC countries to promote economic development and welfare in countries and territories in the DAC list of ODA recipients. It includes loans with a grant element of at least 25 percent (calculated at a rate of discount of 10 percent).
Education	
- Expenditures on education	Average public spending on education in % of Gross Domestic Product between 2000 and 2009 (World Bank, 2011c).
- School enrolment	Average school enrolment to secondary level in % of total enrolment between 2000 and 2009 (World Bank, 2011d).
Research & Development	
- Expenditures on Research and Development	Average expenditures on research and development in % of Gross Domestic Product between 2000 and 2009 (World Bank, 2013).
Governance	
- State Fragility Index	Average State Fragility Index (SFI) between 2000 and 2009. The index combines scores measuring two qualities of state performance: effectiveness and legitimacy. The index varies in the range from 0 to 23, where 0 is the lowest fragility and 23 the highest fragility (World Data Center, 2011).
- World Governance Index on corruption	Average World Governance Index on Control of Corruption (WGI) between 2000 and 2009. The index is one of six dimensions of the Worldwide Governance Indicators (World Bank, 2011e). The lower end of the index indicates the countries with the lowest control of corruption.
- Press Freedom Index	Average Press Freedom Index (PFI) between 2000 and 2009. The index varies in the range of 0 to more than 115, where 0 represents the highest press freedom (Reporters without Borders, see RSF, 2012).
Environmental footprint	
- Carbon emissions from energy consumption	Average carbon emissions from energy consumption measured in million metric tons per year between 2000 and 2009 (EIA, 2011).

economic and political situation of the country the first authors are based in.

A whole suite of institutional governance characteristics could be influential (either directly or indirectly) on the supply of research (Ho-Lem et al., 2011; Moustakas and Karakassis, 2009). We test if the number of publications decreases with instability of the country applying the state fragility index (World Data Center, 2011). Other studies have demonstrated that research output may be indirectly negatively affected by a lack of governance and economic performance (Karlsson et al., 2007). Chowdhury (2004) found that democracy and press freedom can have significant impact on corruption. Furthermore, the value of research may depend on the likelihood of research being disseminated to the public. If civil freedom, as well as the ability of researchers, journals, newspapers and other media to communicate with the general public, is low then adaptive capacity could be weakened (Pahl-Wostl, 2009). We therefore tested if the number of publications was positively related to the freedom of the press.

We apply correlation analysis between the number of publications and the suite of possible explanatory variables mentioned above. Furthermore, the negative binomial count regression model (GENMOD procedure in SAS 9.2) was applied to identify determinants. The models' explanatory variables were categorized into a range of categories as presented in Table 1.

There may be a high chance of covariance between explanatory variables which we would like to minimize in the statistical models. Information on correlations, variance influence analysis, and cluster analysis were applied to preclude inappropriate combinations of variables.

4. Results

The raw data included 32,072 climate change research publications produced over the 11-year period (1999–July 2010). After a filtering by Subject Area, the number of publications was reduced to 24,098. A manual check of the relevance of each publication (see Appendix) further reduced the number of publications to 15,582. Table A3 (see Appendix) presents the descriptive statistics of the variables applied in the analysis.

Fig. 1 and Table 2 illustrate the geographical distribution of case country-publications and shows how the number of publications is biased toward the developed, less vulnerable parts of the world. The top three countries, United States of America, China, and Canada, account for almost 30% of the total number of publications. India is the only highly vulnerable country in the top 10 list of total number of publications (Table 2). The total number of publications may correlate with the size of the population of a country (see Fig. A1 in Appendix). The top 10 changes significantly when ranking the countries according to the highest number of publications per capita. Small Island States dominate the highest ranked countries and in general these countries are considered more vulnerable (Table A4).

Specifying this pattern, the country-level distribution of publications was compared with country specific indicators on climate vulnerability, demographics, geography, economic development, education, governance, and environmental footprint.

4.1. Correlations between indicator variables

The Pearson correlation coefficients were estimated for the total number of publications per country for all indicator variables (see Appendix, Section 3.3 for details). The number of publications is generally negatively correlated with increased climate change vulnerability (Maplecroft, 2011) and institutional weakness and positively correlated with economic development and support. The Pearson correlation coefficients of the independent indicator variables confirm that many of the independent variables also are correlated (see Table A5 and Appendix for details). Out of the twelve variables only total carbon emissions, the gross domestic product GDP–PPP (Purchase Power Parity corrected) and the dummy variable Small Island State are not significantly correlated with vulnerability. Typically richer countries have higher school enrolment, state stability, and corruption control. All three governance variables are moderately correlated and conclusions about a model including more than two of the variables should be carefully considered.

4.2. Clusters of model variables

A number of models including variables within and across the twelve independent variables could be tested. However, as presented above some of the independent variables are highly correlated, in particular with the climate vulnerability index, the governance, and economic indicators. This restricts the possibilities to present reasonable and robust models. For this reason cluster analysis was run on the independent variables to identify

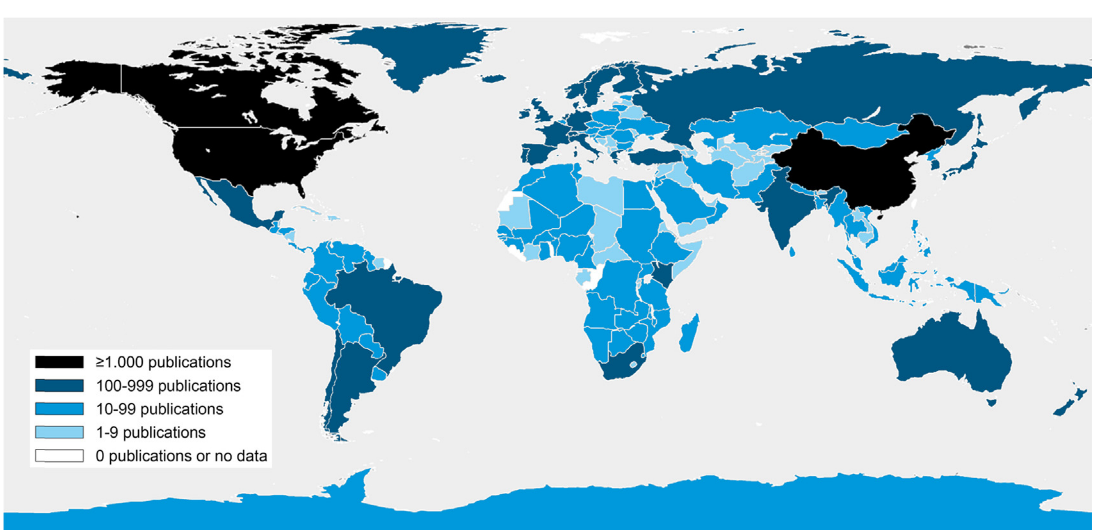

Fig. 1. Geographical distribution of climate change publications in the dataset.

Table 2
Top 10 countries or nations according to climate change research publications and information on climate vulnerability, demographics, geography, economic development, education, governance, and environmental footprint.

Country/nation	Number of publications	Vulnerability	Population (mill)	Small Island State	GDP–PPP (mill US$)	GNI–PPP (US$)	Official development assistance (mill US$)	Expenditures on education (% of GDP)	School enrolment, secondary (% gross)	Expenditures on R&D (% of GDP)	State Fragility Index	World Governance Index on corruption	Press Freedom Index	Carbon emissions from energy consumption (mill. tons)
United States of America	1974	6.09	310	No	1,218,803	41,639		5.6	93.6	2.7	1.5	1.51	9.25	5841.7
China	1423	3.66	1337	No	550,412	4202	1494	.	68.2	1.3	10	−0.52	89.03	5053.7
Canada	1226	7.49	34	No	109,318	33,224		5.1	102.3	2.0	0	2.01	3.76	588.1
Australia	850	7.02	22	No	66,438	31,368		4.9	152.1	1.9	1.7	1.99	6.81	391.6
United Kingdom	683	6.5	62	No	192,602	32,329		5.3	101.5	1.8	1.1	1.85	5.74	567.3
Germany	438	6.19	82	No	256,134	31,314		4.6	100.5	2.6	0	1.84	3.59	844.1
Spain	435	6.05	47	No	118,867	26,922		4.3	115.5	1.2	0.6	1.19	9.36	353.5
India	406	1.6	1173	No	251,797	2278	1562	3.6	51.1	0.7	12.9	−0.41	32.77	1209.1
France	383	6.24	65	No	186,170	30,056		5.7	110.4	2.2	1	1.38	7.52	410.7
Brazil	375	4.68	201	No	158,087	8299	249	4.3	104.3	1.0	5.7	−0.03	17.71	374.6

clusters of variables which should be avoided in the models. A hierarchical cluster analysis (SAS 9.2, PROC CLUSTER Ward method with a $1-r^2$ distance measure between correlations of variables) was used to identify clusters of correlated variables. Four clusters were separated at semi-partial R-squared values between 0.08 and 0.11 (see Fig. A2 in Appendix):

Cluster 1: Vulnerability, GNI–PPP, World Governance Index on corruption, School enrolment, Expenditures on research and development, and State Fragility Index.
Cluster 2: Small Island States and Expenditures on education.
Cluster 3: Official Development Assistance and Press Freedom Index.
Cluster 4: Population, GDP–PPP, and Carbon emissions from energy consumption.

The resulting clusters of variables are subsequently combined into models including all combinations of the variables.

4.3. Negative binomial regression modeling

We used the negative binomial count data model in econometric analysis because of the non-negative and integer nature of research publication data. We began with the assumption of the model to follow a Poisson distribution and then tested for negative binomial. Testing and evaluation include residual analyses and goodness-of-fit measures based on comparing the log likelihood values of the Poisson and negative binomial models (Cameron and Trivedi, 1998). The 72 potential model combinations ($6 \times 2 \times 2 \times 3$) of the four cluster variables were analyzed using the SAS PROC GENMOD procedure. All four variable coefficients were significant in 20 of the models. The results are shown in Table 3 for the 8 models with the lowest AIC and BIC scores (further results are presented in Table A6 in Appendix). The dispersion factor as well as the log likelihood test show that the negative binomial model fit better than Poisson model. The signs of the coefficients are similar to the correlation coefficients (see Fig. A1 in Appendix). The number of publications increases with population, size of the economy, development assistance, education, governance, energy consumption, and decreasing vulnerability. Lack of stability and press freedom reduce research effort and the number of publications.

4.4. Relationship between case country publications and first author publications

In the previous part we analyzed for significant relationships between the number of publications concerning climate change in a country and a range of indicator variables based on the hypothesis that the number of country publications is relevant for exploring the potential *supply* of climate change knowledge. However, it could be equally relevant to measure whether the number of publications by first authors was determined by the same factors to explore the *production* of this knowledge. We expect a higher number of publications by first authors based in wealthy countries compared to poorer ones. Therefore we tested the relationships between first author publications from a country and the same independent variables. Comparing Tables 3 and 4 (see also Table A7 in Appendix) it appears as there are many similarities between the two data sets. This is also supported by the significant correlation between the number of first author publications and the number of publications reported for that particular country ($r = 0.92$, $p < 0.0001$).

4.5. Size effects

The scientific productivity of a country may be biased from size effects. We, therefore, adjust the number of publications and the

Table 3
Model results for the negative binomial regression for the total number of publications reported for each country.

	Models							
	1	2	3	4	5	6	7	8
Intercept	$3.5286^{\dagger\dagger}$	$2.8724^{\dagger\dagger}$	$2.2586^{\dagger\dagger}$	$3.6448^{\dagger\dagger}$	$3.4284^{\dagger\dagger}$	$3.617^{\dagger\dagger}$	$3.7946^{\dagger\dagger}$	$2.2558^{\dagger}$
Vulnerability								0.2109^{***}
Population (million)					0.0040^{***}		0.0049^{***}	$0.0175^{\dagger}$
Small Island States	-1.4004^{***}	-0.5937^{**}	-1.0542^{***}	-0.7536^{**}	$-1.3270^{\dagger}$	-1.4153^{***}	-0.7797^{**}	
GDP–PPP (10^{12} US$)	8.0272^{***}	$15.7718^{\dagger\dagger}$						
GNI–PPP (10^{12} US$/inhabitant)								
Official Development Assistance (million US$)		0.0004^{**}	0.0003^{*}	0.0005^{**}			0.0004^{**}	
Expenditures on education								0.1415^{**}
School enrolment			0.0114^{***}					
Expenditures on R&D	$0.6196^{\dagger\dagger}$				$0.9913^{\dagger\dagger}$	$0.7271^{\dagger\dagger}$		
State Fragility Index				$-0.0697^{\dagger}$			$-0.0795^{\dagger\dagger}$	
World Governance Index on corruption		$0.4628^{\dagger}$						
Press Freedom Index	-0.0114^{**}				-0.0110^{*}	-0.0112^{**}		$-0.0285^{\dagger}$
Carbon emissions from energy consumption			$0.0018^{\dagger}$	$0.0018^{\dagger\dagger}$		$0.0011^{\dagger}$		
Dispersion factor	0.9723	0.8933	1.0700	0.9994	1.0203	1.026	1.0205	1.3381
−2(Log Likelihood (Poisson) − Log Likelihood (Negative Binomial)	13,676	3708	4714	4768	14,010	12,362	4394	18,674
AIC	1165	1182	1187	1192	1192	1193	1200	1427
BIC	1181	1199	1204	1209	1208	1210	1217	1444

† $p < 0.001$.
†† $p < 0.0001$.
* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.

Table 4
Model results for the negative binomial regression for the total number of publications reported for each country. The number of publications per country is replaced by the number of publications in a country where the first author is based in that particular country.

	M1	M2	M3	M4	M5	M6	M7	M8
Intercept	$3.0366^{\dagger\dagger}$	$3.3823^{\dagger\dagger}$	$2.5550^{\dagger\dagger}$	$2.4710^{\dagger\dagger}$	$3.8232^{\dagger\dagger}$	$4.3925^{\dagger\dagger}$	1.2863^{*}	$2.1149^{\dagger\dagger}$
Vulnerability							0.1802^{*}	
Population (million)					$0.0182^{\dagger\dagger}$			
Small Island States	$-2.5253^{\dagger}$	$-2.2199^{\dagger}$	-2.4052^{***}	-1.6173^{**}		$-3.5973^{\dagger\dagger}$		$-2.9986^{\dagger\dagger}$
GDP–PPP (10^{12} US$)	$22.7600^{\dagger\dagger}$		$10.7030^{\dagger\dagger}$			$13.2132^{\dagger\dagger}$	$21.2474^{\dagger\dagger}$	$13.5612^{\dagger\dagger}$
GNI–PPP (10^{12} US$/inhabitant)								$77.7207^{\dagger\dagger}$
Official Development assistance (million US$)	0.0009^{**}	0.0008^{**}						
Expenditures on education					0.1854^{*}		0.1903^{*}	
School enrolment								
Expenditures on R&D			$1.0980^{\dagger\dagger}$	$1.3966^{\dagger\dagger}$				
State Fragility Index	$-0.1653^{\dagger\dagger}$	$-0.1787^{\dagger\dagger}$			$-0.2175^{\dagger\dagger}$	$-0.1599^{\dagger\dagger}$		
World Governance Index on corruption								
Press Freedom Index			-0.0194^{***}	-0.0139^{*}	-0.0135^{*}	-0.0153^{**}	$-0.0264^{\dagger}$	-0.0202^{***}
Carbon emissions from energy consumption		$0.0032^{\dagger}$		0.0014^{**}				
Dispersion factor	2.0698	2.3413	1.8394	1.9925	2.3217	2.2660	2.6784	2.2027
−2(Log Likelihood (Poisson) − Log Likelihood (Negative Binomial)	2732	3564	16,914	16,054	18,210	16,514	17,188	21,010
AIC	795	827	987	1020	1083	1125	1127	1156
BIC	812	844	1003	1036	1100	1143	1144	1175

n.s.: not significant.
† $p < 0.001$.
†† $p < 0.0001$.
* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.

independent variables carbon emission from energy consumption, Official Development Assistance, and GDP–PPP by the population of the country to separate the effect. Such adjustment of the independent variables may change the co-linearity patterns and semi-partial *R*-squared cluster analysis was run. The major difference to the previous analysis is that the number of publications per capita is relative higher for island states (see Table A8 in Appendix for more details).

Table 5
Model results for the negative binomial regression model when the number of publications is adjusted by the population of the country. Geographical effects are estimated relatively to Europe.

	Knowledge domain				
	Adaptation	Mitigation	Disease	Drought	Flood
Intercept	$-91.34^{\dagger}$	$-165.80^{\dagger\dagger}$	$-109.00^{\dagger}$	-51.20^{*}	83.63^{**}
Year	$0.22^{\dagger}$	$0.08^{\dagger\dagger}$	$0.05^{\dagger}$	0.02^{*}	-0.04^{**}
North America	0.21^{*}	−0.12	-0.34^{**}	−0.06	$-0.75^{\dagger\dagger}$
Australia and New Zealand	0.06	-0.80^{***}	0.22	0.20	-0.86^{***}
Africa	$1.09^{\dagger\dagger}$	$-0.83^{\dagger}$	0.40^{**}	$0.55^{\dagger\dagger}$	$-0.86^{\dagger}$
Asia	0.00	0.14	−0.17	$-0.48^{\dagger}$	$-0.57^{\dagger\dagger}$
Oceania	$1.90^{\dagger\dagger}$	0.01	−0.48	−1.18	−1.00
South and Latin America	−0.11	0.03	0.42^{*}	-0.45^{**}	$-1.80^{\dagger\dagger}$
−2 Log Likelihood	4479	4738	3073	5112	3286
AIC	4482	4740	3075	5114	3238
Wald	111.9	57.4	28.2	54.7	60

† $p < 0.001$.
†† $p < 0.0001$.
* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.

4.6. Knowledge domains

We tested for global patterns on the knowledge domains adaptation and mitigation, as well as a range of domains related to the potential effects of climate change, including: diseases, droughts and floods. The keywords of each publication were used for this analysis (procedure described in Appendix). The probability of each knowledge domain was estimated using the LOGIT procedure in SAS 9.2 depending on the year of the publication and geographical region (Table 5). The analysis shows that in regions, such as Europe and Northern America, research is more often biased toward issues of climate change mitigation (e.g. emission reductions) than it is in Africa, Australia, and New Zealand. In contrast and compared to Europe, relatively more of the publications concerning African, South and Latin American, and Oceanian countries (excluding New Zealand and Australia) deal with issues of climate change adaptation and impacts such as droughts and diseases. Strikingly, the probability of European studies on flood impacts is higher than in North America, Asia and South and Latin America. The YEAR parameter is significant for all knowledge domains and positive (except for the flood domain), which may indicate that the probability of all domains increases over the years. A qualitative assessment of all titles and abstracts in a sample of 613 publications and a logistic regression revealed that the probability of a study investigating any social or human impacts of climate change is significantly higher in Africa ($p < 0.06$) and lower in North America ($p < 0.093$) compared to Europe.

5. Discussion

There is a geographical knowledge gap on climate change research (Rosenzweig et al., 2007; Ho-Lem et al., 2011) with an apparent scarcity from developing countries. International bibliographic databases, related bibliometric indicators, and climate change vulnerability measures together provide an approach to measure both the ‘supply side’ (number of publications) and ‘need’ (climate change vulnerability) related to climate change research. This bibliometric study presents an analysis of the relationship between the scientific output and country level indicators based on 15,582 publications covering 197 recognized countries/states. The analyses included country level indicators on demography/geography, wealth, development assistance, education, institutional stability and capacity, and environmental footprint.

More than 63% of the publications in the dataset concern climate change in developed countries and 80% of the publications are published by authors based in developed countries although developed countries only constitute about 18% of the world population (regions as defined by the United Nations, see UN, 2011. Antarctica was treated separately in the dataset).

5.1. Global gap in supply of and need for climate change knowledge

Both the supply and production of climate change knowledge (measured as country publications and first author publications) are biased toward the wealthier, high emitting, less fragile and less vulnerable countries. The correlation analysis documents that the total number of publications is correlated with the GDP–PPP of the country and the environmental footprint measured by carbon emissions from energy production, means that countries that have a large economy and wealthy citizens with ecologically harmful lifestyle publish more (Moustakas and Karakassis, 2009). Environmental concerns may by highly correlated with economic development. Franzen (2003) found, using global International Social Survey Program data from 26 countries, that environmental concern was highly correlated with GDP ($r^2 = 0.79$, $p < 0.00$).

It is also found that the official development assistance may increase scientific research on climate change. Development Assistance may not directly affect scientific production but indirectly by increasing wealth through institutional stability (Stockemer et al., 2011). Thus, a mismatch seems to exist between the supply of, and need for, knowledge on climate change. We find that proportionally more research on climate change pertains to the developed and less vulnerable regions of the world (Felton et al., 2009; Karlsson et al., 2007; Kiparsky et al., 2006; Mao et al., 2010), This trend both raises concerns and poses several challenges. It indicates a North–South divide between exposure to risk, vulnerability and available knowledge. The results confirm that published research on countries which are assessed at high climatic vulnerability is lower than countries with less vulnerability. For instance, small island states, which in general are considered more climatic sensitive than other locations, are the subject of a significantly lower number of publications. We also find that the knowledge domains (e.g. adaptation, mitigation, and different types of effects) vary across geographical regions.

Countries at greatest risk of climate variability and change are those that face the multiple challenges of climatic extremes, acute and high institutional vulnerability, lower wealth and knowledge-base and low adaptive capacity. Kiparsky et al. (2006) argue that this trend exacerbates existing disparities in adaptive capacity, hinder local efforts to prepare, and ultimately worsen the consequences of climatic impacts in developing countries. The geographical imbalance in climate change research, and in particularly that the production of knowledge is skewed away from the more vulnerable regions, might affect the use and integration of locally generated knowledge to provide contextually relevant advice (Karlsson et al., 2007). Meaning that specific local factors are not considered or sufficiently accounted for in the generation and implementation of climate change knowledge. The imbalance between demand and supply is not only restricted to vulnerability but a wide range of knowledge domains. Despite the number of studies dealing with mitigation is higher in the richer part of the world there may still be a great need (demand) for knowledge on mitigation as input to the science policy decisions (Sarewitz and Pielke, 2007). Science can provide useful input to the political decision processes thereby increasing the likelihood of adequate and timely climate change adaptation. In contrast, the lack of a sufficient knowledge base may limit adaptive capacity. Initiatives and specific action required to overcome these knowledge gaps are essential in terms of increased regional collaboration, knowledge transfer and capacity building (Felton et al., 2009; Karlsson et al., 2007; van der Zaag et al., 2009). For instance, in relation to regional collaboration, Ponds et al. (2007) and Liang and Zhu (2002) highlight that geographical proximity is important for research collaboration and knowledge exchange. Specifically, Yarime et al. (2010) point out that regional "clusters", in which research collaboration tends to be conducted between countries which are geographically close, is an obstacle to the exchange of knowledge, especially when dealing with complex large-scale problems with long-term implications, such as climate change.

Accordingly, proximity contributes to the North–South divide of limiting the transfer between the wealthy North and the distant South. However, some of the more wealthy countries in the South may play an increasing role in creating potential spill-over effects on neighboring countries. Testing for such spatial effects is above the scope of this paper but worth considering for future research.

5.2. Data selection bias

Methodological limitations and potential biases are relevant to discuss in relation to publication analyses (see also Archambault et al., 2006; Kahn, 2011; van der Zaag et al., 2009). A language bias for instance, is evident and leads to an underestimation of publication written in non-English languages. Another bias exists against publications not meeting the Thomson Reuters quantitative and qualitative standards for inclusions in the Web of Science database (Thomson Reuters, 2012). As the selection method excludes scientific publications outside the published international peer-reviewed English language journals, it also excludes other kinds of knowledge in the analyses of the climate change knowledge supply. Consequently, the analyses presented in the paper are restricted to scientific knowledge and do not consider local or indigenous knowledge or knowledge from other sources than scientific publications.

Besides the publication data, the choice and range of explanatory variables is critical and autocorrelation needs to be accounted for. In particular, the challenges associated with mapping the geography of climate change vulnerability are multiple and several approaches exist (Hare et al., 2011; Preston et al., 2011). The choice of the Maplecoft index, which categorizes the geographic exposure and sensitivity to future climate change, was made to be able to quantitatively compare the supply of climate change knowledge (publications) with the need (vulnerability). The total number of publications was used as a measure to compare the relative capacity of different countries. There is a risk of bias arising from size effects since more populous countries are more likely to publish more research articles than smaller countries. The number of publications is denominated by population size to reduce the effect of that.

Measuring first author publications posed some challenges as well. Specifically, the HistCite™ software only allows for analysis of first author affiliations, thereby complicating analysis taking all authors into account, such as analysing attribution of fractional shares by authorship (see also Kahn, 2011; Karlsson et al., 2007), which had to be ignored in this analysis. The underlying assumption is that first authorship indicates a substantial contribution to the research publication (see Appendix for an elaborated discussion on methodological limitations). One obvious limitation is that the author and affiliation data does not reveal the nationality of the researchers. We do not know how many researchers from the most vulnerable and poor countries are working and based in the rich part of the world. This could have implications for brain drain and potentially limit knowledge transfer. It is tempting to speculate that the explanatory variables applied in this study may be directly related to the number of climate change publications in a case country. However, since our study was observational in nature, causality between these variables cannot be assumed. Some of the explanatory variables, e.g. expenditures on research and development, may directly affect the number of publications. Richer countries may invest a higher share of their GDP in research compared to poorer ones resulting in higher scientific production (Man et al., 2004). There are likely many other factors (not included in this study), which may influence which case countries are studied.

5.3. Policy perspectives

The divide in the capacity to generate climate change scientific knowledge, and the imbalance between supply in the north and need in the south of empirical research, could have consequences for policymaking. Climate change research has gathered increased attention in the policy arena, and supplied information and advice regarding not only the effects of climate change, but also on mitigation and adaptation strategies (Dessler and Parson, 2010, IPCC, 2007). However, this knowledge is not generated evenly nor distributed globally. Likewise, the dominant research themes and scientific approaches applied also differ across regions and level of development (see Section 4.6). The assessment of knowledge domains show that mitigation research is produced in polluting countries. Indeed, knowledge on climate change *mitigation* is also in high demand and needed for the long term fight against climatic changes, but first of all it needs to be backed up by political will and international binding agreements. Here and now, this study shows that urgent and serious impacts from climate change in vulnerable regions are not balanced by research supply and production. In that aspect, climate change research appears not to be "well-ordered", serving the collective good and satisfying the preferences from the larger population (see Kitcher, 2001). Similar trends were found by Ho-Lem et al. (2011) in an analysis of IPCC reports, and since publications cover the issues of primary concern in the respective regions, it does raise some concerns. For instance, many scientists and policymakers believe that changes are best understood and mastered by identifying causal forces, objectively mapping, measuring and analyzing them by using large-scale quantitative techniques and by using the assessments as input to policy (Forsyth, 2010; Jasanoff and Wynne, 1998). This focus and reliance on positivist science and method is problematic because issues considered global from some type of physical natural science perspective are prioritized by policymakers in the North, which renders environmental issues prioritized by the South relatively invisible (Karlsson et al., 2007). Thus, some researchers are able to contribute with scientific knowledge and raise their voice in policymaking with more effect than others (Ho-Lem et al., 2011), while much needed knowledge on urgent issues is scarce or overlooked in the political debates on climate change. A contributing factor to this mismatch between supply and need is the several requirements complicating the path to publication of scientific findings as discussed above (see Section 5.2 and Appendix). Hence, besides the significant differences in resources and capacities available to conduct research across regions, these requirements increase the global imbalance in the supply and production of climate change knowledge. Paradoxically, as presented and discussed in this paper, it is the regions most vulnerable to climate change and with the lowest capacity to adapt, who are short of the knowledge needed, contribute less to its generation and are excluded from policy-making. In order to overcome this gap, several challenges lie ahead. For instance, collaboration across geographical and cultural divides, as well as between practitioners and academics, should be encouraged, along with empowerment of researchers and resource transfer (see also Karlsson et al., 2007; Yarime et al., 2010). Stronger incentives structures and avenues for broader inter-regional linkages are needed, and these research networks could be build or strengthened through the educational system and international conferences, which ultimately needs to be backed up by political will and funding.

Besides the academic challenges, more attention from enterprise and international agencies needs to be given to the potential threats of climate change, with closer collaboration between all three areas in order to capitalize on possible synergies that can be achieved between them (Stordalen et al., 2013). Enterprises must start to recognize that climate change presents long-term threats to business, and international agencies and governments need to prioritize climate change above the interests from other sectors. In the end, these well-known challenges are embedded in global, regional and national political contexts with governance structures, democratization processes and institutional constraints acting on the integration of research in policy making. Indeed, the generation, publication and distribution of scientific knowledge on climate change to meet the rising need for knowledge do not stand outside the current and future political realms, which complicate both the implications of and needed response to the knowledge gap.

Acknowledgements

We would like to thank Anders Agerbæk Kjøller Nielsen and Adrian Price for invaluable support on methods to search and analyze publications. A special thank to Tony Martin from Thomson Reuters technical support, to Nayu Nuringdati Widianingsih for assisting with data restructuring, and to Martin Dalimer for providing constructive comments to an early version of the manuscript. We would also like to thank Ms. Aint Thiri Swe and Mr. Azeem Tariq for their kind data assistance and Dr. Thomas H. Lundhede for his help on creating the databases applied for the statistical analysis. NS would like to thank the Danish National Research Foundation for supporting the research at the Center for Macroecology, Evolution and Climate.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.gloenvcha.2013.08.013.

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