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Exploring the impact of the IPCC Assessment Reports on science

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ABSTRACT

Even though critique to IPCC is certainly not new, the climate controversies of 2009 and 2010 brought this critique again to the fore in public media. The paper contributes to this ongoing debate, and investigates empirically the impact of the four Assessment Reports of the IPCC on scientific publications and science, through scientometric analyses of cited references to IPCC reports. The results indicate, among other things, that the aggregate impact of IPCC reports on scientific publications has increased through each consecutive assessment report, independently from the increase of the climate change field, showing a pattern which suggests that the references are quite generic. Both disciplinary distribution and geographical distribution of the impact of the reports are skewed, the former towards geophysical sciences, the latter towards western/developed countries. However, this skewness is decreasing over time. Given the increasing impact further away from the climate change field, it is important that the IPCC becomes more transparent about its internal processes and main conclusions.

1. Introduction

The climate controversies of 2009 and 2010 resulted in an extensive public debate, both online and offline, around the functioning and role of the Intergovernmental Panel on Climate Change (IPCC) (Leiserowitz et al., 2010; Nerlich, 2010; Schiermeier, 2010). Its management and peer-review processes came under question, often under fire. Historically, the IPCC was established to present international policy-makers with undisputed, policy-relevant knowledge, while acknowledging uncertainties (Agrawala, 1998a,b; Petersen, 2006). It has been argued that the intensity of the recent public controversies over the IPCC is emblematic of the increased mediatization and politicization of the boundary between science and society (Berkhout, 2010; Hajer, 2009). The IPCC has arguably been very influential in bringing the issue of climate change to the attention of policymakers and the media all over the world (Hulme, 2009a), resulting in, among other things, the Nobel Peace Prize in 2007.

Even though the role of the IPCC has been so prominent in societal and policy debates, we have no clear understanding of its impact on the field of climate science itself, or on other scientific fields. There have been only few critical voices warning against the growing epistemological influence of the IPCC, as the only spokesperson for climate change (Mayer and Arndt, 2009), without systematic empirical research. As Hulme indicates "there remains considerable detailed empirical work to be done on exactly where, how and why the practices of climate change knowledge production developed by the IPCC have altered scientific practice"(Hulme and Mahoney, 2010). This paper aims to start filling in this gap by contributing to our understanding of the impact of the IPCC on scientific knowledge production. More precisely, with the use of

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scientometric analyses, we study how the knowledge produced by the IPCC is being picked up and utilized in different scientific fields. We aim to examine this over time. As the work for the Fifth Assessment Report has begun, it becomes more important to understand the role of the IPCC in science as it has evolved since its establishment in 1988. When an increased impact of the IPCC on science is indeed found, this adds to the need to reflect on the soundness and transparency of the IPCC processes and outcomes.

Still, there has been extensive study of the disciplinary biases of ''IPCC knowledge'' (that is, the knowledge contained in IPCC Assessment Reports). Numerous studies have shown a strong bias of earth sciences in Assessment Reports, with a lack of interpretative social sciences (Malone and Rayner, 2001; Yearley, 2009). Further, there is a strong bias of knowledge produced in western countries (Hulme and Mahoney, 2010). Our aim thus here is to trace the impact of the IPCC on scientific knowledge production and to address the following research questions:

1. What is the impact of the IPCC on different scientific fields and different geographical areas?
2. How does the impact of the IPCC on science evolve over time?

In what follows, we first position the role and impact of the IPCC, and we distill a set of hypotheses. After a brief explanation of the methodology, we move to a presentation and discussion of our results. Finally we conclude with practical implications of our work, as well as directions of future research.

2. Theoretical background

2.1. *The role and function of IPCC*

The formation of the IPCC in 1988 as the primary intermediary institution to synthesize scientific knowledge for policymakers is not unique among scientific fields. A number of developments over the last two decades have led to a proliferation and increasing importance of scientific intermediaries: organizations whose purpose is to connect the science system to other social sectors (Van der Meulen and Rip, 1998; Vasileiadou and Van den Besselaar, 2006). Still, the IPCC is unique as such an intermediary institution in terms of its scope: it synthesizes the scientific knowledge of an entire scientific field for policymakers. Even though the IPCC has been recently under attack, its role and authority remain unique in this respect. Furthermore, its global scale is also unparalleled, even acknowledging the geographical biases that exist in IPCC knowledge.

How can we understand the evolution of the IPCC over time? Elsewhere we have described sciences as communication systems, whose boundaries co-evolve with societal developments (Heimeriks and Vasileiadou, 2008). Further, we have suggested that we may expect an increasing heterogeneity of the science-society interface, partly because of the emergence and increasing use of information and communication technologies for the interaction between scientists and non-scientists. We would argue that in a field such as climate science, with a strong societal relevance and problem-solving orientation, the evolution of scientific knowledge would be even more strongly connected to societal and policy related needs. Therefore, we can understand the IPCC as operating on this science-policy interface (Girod et al., 2009) and more specifically as embodying the *co-evolution between scientific knowledge and policy needs*.

Co-evolution between two systems denotes that both systems exercise selection pressure upon each other; this selection pressure stimulates changes in diversity in the two systems, which means the systems co-evolve (van den Bergh et al., 2007). Policy needs create a selection mechanism for climate science through science programming and funding of specific research projects on climate science; especially climate modeling, which is so costly in equipment and manpower, is dependent on policy decisions for public funds.

Policy needs also presumably create a selection mechanism for the knowledge included in the IPCC; governments are involved in the scoping of Assessment Reports and in approving the summaries. For instance, the IPCC's policy orientation became evident when the recent PBL report concluded that positive impacts of climate change tended to be underplayed in the AR2007. This was related to the framing of climate change as a global problem that policymakers need to provide solutions for. Therefore, the focus was more on vulnerability and risks than on opportunities created by climate change (PBL, 2010). Another finding of that report was that the impact of climate change is not always distinguished from the impact of other changes, such as by suggesting that the projected 3000–5000 additional heat-related deaths per year in Australia in 2050 are all dependent on an increase in temperature, while actually a large part of this increase is solely due to changes in population size and age distribution.

At the same time, what we call policy environment and policy needs is also a result of the selection mechanisms in science, as specific types of knowledge are being favored over others, and feed into policy debates on climate change. As scientific knowledge over global warming accumulates (e.g., more detailed modeling results are produced), policy responses become shaped (e.g., European policymakers – and since recently also the delegations in the UNFCCC – feel the need to commit to a specific target of 2 °C).

Studying the impact on science through the use of citations is certainly not new. Many bibliometric assessments are based on the assumption that the number of citations to a document can be considered to reflect its impact on the scientific community (Moed, 2005). In each published article, the authors decide whether they will use knowledge claims from the IPCC ARs, whether they can use these claims to advance their work. This decision is reflected in the references of that specific article (Bjurström and Polk, in press). Therefore, an author who cites an IPCC Assessment Report utilizes the knowledge claims there in some way, e.g., for underpinning, for criticism, or for expansion. This means that the IPCC AR has had an impact on that specific article. While the citations of a single paper may reflect the preferences and interests of the individual researchers involved, on an aggregate level citation patterns reflect the collective knowledge base of a discipline.

So far there is only anecdotal evidence of the impact of IPCC on climate change science (Hulme and Mahoney, 2010). For instance, it has been claimed that the IPCC exercises some sort of ''epistemological hegemony'' on the issue of global warming (Mayer and Arndt, 2009). This claim, however, was made without providing any systematic empirical evidence. Our paper aims at providing empirical material to test the assumption of great impact of IPCC on climate change science.

The focus of our work here is on the dynamic of this impact over time: even though the IPCC has operated since 1988, there are very few comparative analyses examining how its dynamics have changed over time (Siebenhüner, 2002). Our paper starts to address this gap by examining the impact of the IPCC on science, from the beginning of its operation until 2009. Other studies have suggested that climate change research has been growing rapidly (Stanhill, 2001), so we may also expect the impact of the IPCC on science (measured as the number of references to ARs) to also increase over time. An additional aim of our work is to distinguish between the dynamics of climate change research and the dynamics of the impact of the IPCC itself. Is the increase related to the overall increase of the climate change field, or does it have an independent dynamic?

H1. The impact of the IPCC on science, as reflected by references to IPCC work, increases over time, independently from the increase of the climate change field.

2.2. *Disciplinary differences and the IPCC*

The disciplinary origins of the knowledge contained in the IPCC Assessment Reports have come under scrutiny, and sometimes criticism. Studies indicate how biased the Assessment Reports are towards natural sciences and especially earth sciences (Bjurström and Polk, in press), how social sciences, and especially interpretative studies have a limited role, and how issues of adaptation, of socio-economic activity and GHG emissions, as well as issues related to social systems and climate change (all topics that social sciences can have a leading role) are underdeveloped (Hiramatsu et al., 2008). The subsidiary role of social sciences is not exclusive to IPCC reports, but seems to reflect its limited role in understanding climate change in general (Yearley, 2009). This subsidiary role of social sciences in IPCC ARs could be related to different factors, such as the perceived epistemological supremacy of natural sciences over social sciences, or the domination of natural sciences in defining climate change as a topic.

Further, the structure of the work of IPCC has been characterized as ''unidisciplinary'', as it is based on a clear separation between natural sciences and social sciences, and an understanding that social sciences are based on natural sciences (Godal, 2003). Following this work, we would expect that the impact of the IPCC on different disciplines would reflect the distinctive disciplinary knowledge used in the reports: if interpretative social sciences are relatively neglected, one would expect that the impact of IPCC on interpretative social sciences would also be relatively minor. A previous scientometrics analysis of the references listed in AR2001 showed that ''[t]he journal references in the IPCC Third Assessment Report (TAR) are strongly dominated by Natural sciences, especially the Earth sciences. Social sciences are dominated by Economics, mirroring the emphasis of climate change research''(Bjurström and Polk, in press). In that study, earth sciences were taken to be: geosciences, oceanography, meteorology. We would expect to find the same differences between disciplinary distinctions in the citations to the ARs.

H2. The disciplinary distinctions of the material in the IPCC reports is reflected on the impact of the IPCC reports on different disciplines.

H2a. The impact of the IPCC reports is greater in natural sciences, than in social sciences.

H2b. Among natural sciences, its impact is greater on earth sciences.

H2c. Among social sciences, its impact is greater on economics.

However, one would expect that over time, the relative impact of the IPCC on social sciences is increasing, as the overall influence of the IPCC increases. As climate change is becoming a loose signifier in different sciences (Hulme, 2009b) and results on climate change are being mainstreamed in different fields (e.g., health, crisis management etc.) the impact of IPCC report would become broader, and differences in impact on different disciplines would be alleviated.

H3. The differences among disciplines of the impact of IPCC decrease over time.

2.3. *Geographical differences and the IPCC*

Previous studies have also scrutinized the geographical distribution of the institutes of the authors (and reviewers) of IPCC reports (Hulme and Mahoney, 2010), the geographical distribution of the knowledge summarized in the reports, such as emission scenarios, the different impact of the IPCC in countries in the South (Biermann, 2001, 2002) and the overall framing of climate change knowledge (Lahsen, 2007). These have been found to be greatly biased towards developed countries[1], perhaps not surprisingly: these countries invest more in research and climate science, which means that there are more relevant institutions there producing climate science than in other countries (Haas, 2005; Kiparsky et al., 2006).

We argue that this skewed distribution of the countries would be reflected on the impact of IPCC on science: first, because indeed there would be more relevant research institutes in those countries; and second because it would be more relevant for authors in those countries to cite work that is about locations in these countries.

[1] Instead of developed and developing countries, Hulme and Malone make the distinction between OECD and non-OECD countries. Lahsen (2007) talks more generally about developed and less developed countries, and the North and South without further specification. Biermann (2001, 2002) uses the North-South distinction.

H4. The geographical distribution of the knowledge contained in the IPCC reports is reflected on the impact of the IPCC reports on different countries.

H4a. The impact of the IPCC reports is greater in articles produced in developed countries, than in developing countries.

However, one would expect that over time the relative impact of the IPCC on knowledge produced in developing countries would be increasing[2]. This would be related to two trends: first, the increasing globalization of science (Wagner, 2008), together with the growth of international collaborations. These trends have been documented in other fields as well. Globalization of science means that scientific research is becoming an increasingly international endeavor, as research activities are occurring on more and more regions and countries, including developing countries. Second, since developing countries tend to be generally more vulnerable to climate change impacts (because of the combined effect of lack of resources, limited institutional capacity, low levels of technology, poor infrastructure etc.) (Patt and Gwata, 2002; Smit and Pilifosova, 2001), one would expect increasing focus of the research community on developing countries, and from developing countries, on climate change research. That could create a growing body of research originating from developing countries (maybe in collaboration with scientists from developed countries) for which the results of the IPCC reports would be highly relevant, and would thus tend to refer to it. On the other hand, previous bibliometric research in journals in environmental studies suggested a growing North-South divide in knowledge production (Karlsson et al., 2007).

H5. The geographical distribution of the impact of the IPCC reports becomes less skewed over time.

H5a. The impact of the IPCC reports on knowledge produced in developing countries increases more over time, compared to its impact on knowledge produced in developed countries.

Related to both geographical and disciplinary diversity, elsewhere we have suggested that developments such as the increasing use of ICTs in science, increasing contact with, and valorization from, societal actors, and increasing focus on the context of application, have resulted in increasing diversity in scientific practices, but also intellectual (disciplinary) focus (Heimeriks and Vasileiadou, 2008). This increasing diversity means, on one hand increasing variety (of e.g., tools, methods, practices links etc.) and on the other hand, more even distribution of these elements. Following this thesis, one can expect increasing diversity (as increasing variety and evenness of distribution) for both disciplinary fields and geographical areas utilizing the knowledge claims of IPCC reports.

[2] Hulme and Mahoney (2010) claim that the percentage of authors and reviewers from developed countries has not changed over time, without providing, however, any empirical support for the claim.

3. Methodology

The articles were obtained from the Web of Science[3]. The search terms we used were: for cited reference

1. Cited reference ''IPCC'' and year (1990; 1996; 2001; 2007). This search included the policy makers' summary, but did not include Guidelines, Greenhouse Reports, Special reports etc.
2. Cited reference and ''Name of first author of each Working Group'' and years (1990; 1996; 2001; 2007). We manually selected the Assessment Reports from this set[4].

The program ISI.EXE was used for organising the set downloaded from the Web-of-Science into databases for relational database management[5] in order to explore the set of articles and journals thus obtained. In this way, the information about all 21.246 publications referring to the IPCC were obtained until (and including) 2009.

Disciplinary differences: Further, we have used the subject code, provided by the Web of Science, as a proxy for the discipline in which the citing paper belongs to. There are limitations to this indicator as a top-down classification approach (Wagner et al., 2011), but for the purposes of this study it is valuable to explore, since it is often-used and broadly accepted.

Geographical differences: We used as an indicator the geographical location (country) provided by the Web of Science. Each publication in the dataset contains one or more addresses that enable us to specify the geographical location of each university and industry and therefore derive information about the geographical distribution of the authors.

Diversity: In order to compute diversity of disciplines, and diversity of geographical locations, we used Shannon's h index of diversity. Shannon's index is essentially an index of any given distribution, or rather it indicates the information entropy of the distribution, treating categories as symbols and their relative population sizes as the probability. The advantage of this index is that it takes into account the number of categories (e.g., here countries referring to IPCC reports) and the evenness of the categories. The index is increased either by having additional unique categories (more countries referring to IPCC reports), or by having a greater categories' evenness (more even distribution of the references of the different countries).

[3] The search was conducted in September 2010. It should be noted that ISI Web of Science does not include many developing country journals, especially in local languages, which could limit visibility of authors from developing countries. Furthermore, it has been pointed out that the WoS coverage has biases toward natural science and engineering and toward English language publications. However, the database remains quite authoritative for scientometrics analyses.

[4] For the AR1990 we only downloaded Houghton et al. (1990) and Tegart et al. (1990), since the last volume has no clearly identifiable lead editor. No references to individual chapters were included in the dataset.

[5] Available from http://www.leydesdorff.net/software.htm Leydesdorff, L. (1989). Words and Co-Words as Indicators of Intellectual Organization. Research Policy, 18, 209–223.

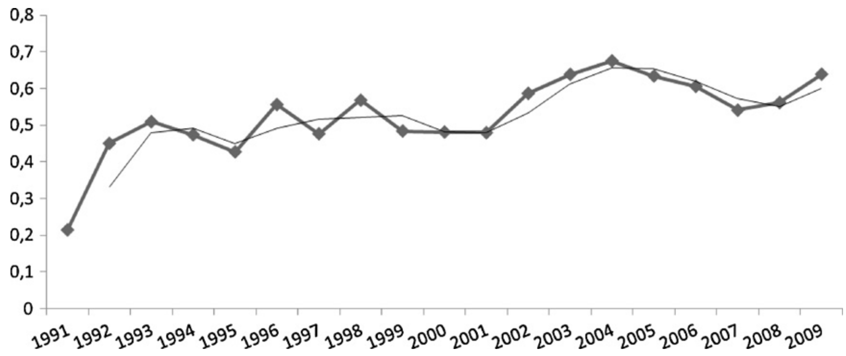

Fig. 1 – References to all ARs, normalized.

4. Results

4.1. *Overall impact*

First we wanted to have an overview of the impact of IPCC ARs on science, and how it evolves over time. The following figure (Fig. 1) presents the total number of articles referring to all four ARs, per year of publication, divided by the total set of articles having as topic ''climate change''[6]. This normalization helped us see identify the trend of the ARs, independently from the trend of the publications dedicated to ''climate change'' in general. It lends support to the suggestions that IPCC is an ''epistemological monster'', and that it has had a considerable impact to climate change science, with 21.000 articles referring to knowledge claims of the ARs in a period of 18 years. It also means that the scientific credibility of the IPCC is quite high, and it draws out the fact that besides policymakers also scientists make heavy use of the IPCC ARs.

The figure also indicates a moving average line (period = 2). It is very clear that, independent of the increase of the topic of climate change, the impact of ARs is increasing over time: there are three identifiable periods: 1990–1995; 1995–2001; and 2001–2007. With each consecutive AR there is an increase of the total impact of the ARs; this is even more obvious with the AR2001. We can also see that the citation impact of each AR decreases 1–2 years before the publication of the new AR. This indicates that probably these references function as generic references and not as specific references to concrete results, hypotheses etc. For this generic function, the most recent IPCC report is the one to refer to. Therefore it seems that the citation impact of the IPCC reports is quite generic.

The following figure, Fig. 2, shows the references to each AR, normalized by the total amount of articles with topic ''climate change''[7]. It clearly indicates that the AR1996 had lower impact than the AR1990. It is unclear why this is the case. It also shows that AR2001 had higher impact than bother previous ones. This could be related to the fact that it was certainly more comprehensive report, covering more social sciences and more economics. It could also be explained by the fact that with time the scientific credibility of IPCC increased, as its operation became more known to the scientific world. Another explanation could be the inclusion of the phrase ''discernible influence'' by the AR, which rose the stakes, and thus the statute of the report. Even though there is limited data from the AR2007, we can still see the same trend as the previous ARs.

Thus, H1, which poses that the impact of IPCC on science, as reflected by references to IPCC work, would increase over time, can be confirmed, by Fig. 1. This dynamic is independent of the increase of the climate change articles. This increase could also be related to an expansion of the topic climate change to other disciplines in the given period[8], which creates the need for scientists to use the ARs as a generic resource for specific topics in the field which they do not specialize in. However, that does not mean necessarily that the IPCC has high epistemic power, as the results suggest that scientists use references to ARs as generic references.

4.2. *Disciplinary differences*

In order to investigate the hypotheses related to the disciplinary differences of the impact of IPCC reports on science we used as an indicator the subject area recorded by the Web of Science for each article. The following Table 1 presents the percentage of articles on the given topics on the total amount of articles referring to each AR.

[6] We divided the references to ARs with the total amount of articles having as topic ''climate change'', to normalize for the increase in climate change articles in general. Thus the figure doesn't necessarily imply that 50% of articles with topic ''climate change'' refer to the IPCC, because the two data sets are different. The figure can only indicate the trend of the ARs, taking out the trend of the subject ''climate change''. For Figs. 1 and 2 the units in the Y axis are the share of references to ARs (our total dataset) over the total number of articles having as topic ''climate change''.

[7] There is a slight increase in the rate of increase for the last AR (AR1990 $B = 0.172$; AR1996 $B = 0.174$; AR2001 $B = 0.174$; AR2007 $B = 0.200$). These are statistically significant. However, the rate of increase is overall not dramatic.

[8] Indeed if one takes the articles with topic ''climate change'' in the given period, there is exponential growth of the number of articles.

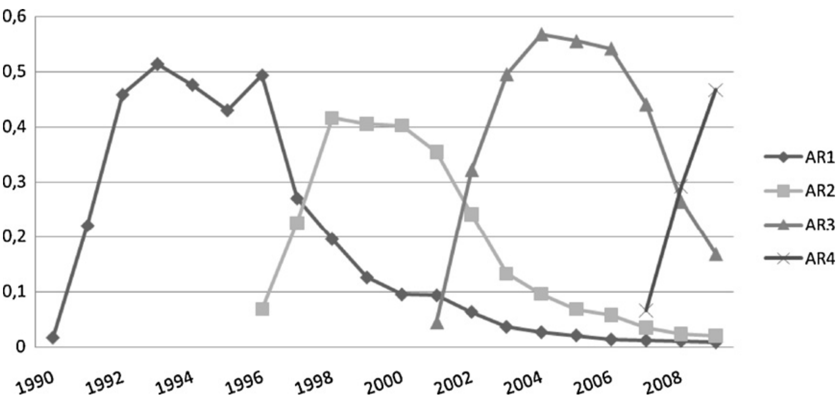

Fig. 2 – References to each AR, normalized.

Since the citation impact of the AR2007 is not yet complete, we should be careful at reading the last column of the table. Since different disciplines have different publication rates (Kling and Swyngart-Hobaugh, 2002) we may expect the percentages in the last column to change. However, overall there are striking similarities in the percentages of most disciplines, over the four ARs. Articles published in journals classified as economics, engineering, energy issues, geosciences, social sciences, chemistry, soil, forestry, oceanography have retained more or less their relative importance in the citation environment of the IPCC reports. The impact is greater in the natural sciences than in the social sciences (including economics and policy studies); among the natural sciences the impact is greater on the earth sciences; and among the social sciences its impacts is greater on economics. The table thus confirms H2a, b and c.

Even though still the most relevant scientific environment for the IPCC reports, meteorology has relatively decreased in importance. Sciences focusing on living things, such as biology, and ecology, have increased, suggesting more emphasis on the impact of climate change on living organisms and on the role of biota in the climate system in general. The results of this preliminary analysis are, however, not conclusive about H3, which poses that the differences among disciplines of the impact of IPCC would decrease over time. Most of the disciplines in the table have the same relative place in the citation environment of IPCC reports. It is especially striking that the position of journals classified as social sciences and economics has not changed since AR1990.

We subsequently investigated H3 in depth. We used again the subject code as a proxy for the discipline, and computed Shannon's h for the subject code of the papers citing each consecutive AR, to identify whether disciplinary diversity is increasing or decreasing. As Table 2 indicates, the distribution of the disciplines clearly increases over time: this is not only related to the increase of the number of subject codes, but also to a more balanced distribution between the subject codes. Even though there is decrease in the number of subject codes from AR2001 to AR2007, Shannon's h is higher, which indicates more balanced distribution between subject codes in the articles citing AR2007.

A word of caution relates to the interpretation of the subject codes as disciplines. Each journal is assigned a subject code, for instance ''Meteorology and atmospheric sciences'', or ''Ecology''. However, there is also the distinct subject code ''Environmental Sciences; Meteorology & Atmospheric Sciences''. Therefore, more subject codes could indicate more disciplines, but also more heterogeneous journals, that need two or even three categories together to be classified. So increasing diversity (Shannon's h) can mean one or more of the following: (i) more disciplines in the citation environment over time, (ii) more heterogeneous journals, (iii) more balanced distribution of articles across subject codes (especially in the case from AR2001 to AR2007).

Thus, H3, posing that the differences among disciplines of the impact of IPCC decrease over time, is confirmed with some caveats.

Table 1 – Percentage of articles for different disciplines in each AR.

	1990	1996	2001	2007
Meteorology	32%	30%	29%	21%
Ecology	9%	10%	12%	14%
Geosciences	11%	11%	13%	12%
Multidisciplinary	20%	17%	19%	20%
Economics	2%	4%	2%	2%
Engineering	8%	9%	7%	8%
Energy	4%	5%	4%	5%
Social sciences	1%	1%	1%	1%
Chemistry	3%	4%	4%	4%
Forest	3%	3%	3%	4%
Soil	3%	4%	3%	3%
Water	5%	6%	7%	8%
Oceanography	4%	2%	4%	4%
Biology	3%	4%	5%	7%
Physics	3%	4%	4%	3%
Policy studies	0.5%	0.5%	0.5%	1%

Table 2 – Shannon's h for the subject codes of the citing papers for each AR.

	Disciplinary diversity	Number of subject codes
Citing AR 1990	4.08	298
Citing AR 1995	4.21	339
Citing AR 2001	4.29	519
Citing AR 2007	4.61	501

Table 3 – Ranking of the twenty most frequently citing countries for each AR.

Country	AR1990	AR1996	AR2001	AR2007	Trend	Overall trend
USA	1	1	1	1	Stable	Decrease (1–1)
ENGLAND	2	2	2	2	Stable	Slight decrease[11] (3–3)
GERMANY	3	3	3	3	Stable	Slight decrease (4–4)
CANADA	4	4	5	6	Decrease	Stable [12](6–7)
AUSTRALIA	5	6	8	5	Stable	Increase (11–11)
NETHERLANDS	6	8	10	11	Decrease	Slight decrease (12–14)
FRANCE	7	9	7	7	Stable	Slight decrease (5–6)
CHINA	8	5	4	4	Increase	Increase[13] (9–2)
SWEDEN	9	10	13	13	Decrease	Slight decrease (14–19)
JAPAN	10	7	6	8	Increase	Decrease (2–5)
SWITZERLAND	11	12	11	9	Stable	Stable (15–17)
SCOTLAND	12	19	20	17	Decrease	–
RUSSIA	13	16	17	20	Decrease	Decrease (8–16)
NORWAY	14	18	15	15	Stable	Stable (25–28)
INDIA	15	13	16	18	Decrease	Increase (13–10)
ITALY	16	14	12	12	Increase	Slight increase (7–8)
BELGIUM	17	17	19	–	Decrease	Stable (17–21)
DENMARK	18	–	18	16	Stable	Stable (22–25)
FINLAND	19	11	14	14	Increase	Stable (23–27)
SPAIN	20	15	9	10	Increase	Increase (10–9)

4.3. *Geographical differences*

The table above, Table 3, shows the 20 most frequently citing countries for each consecutive AR (columns 2–5) in the complete dataset, and the resulting trend from this ranking (column 6). Column 7 will be discussed further on.

The table shows some interesting patterns. As expected, most countries are developed countries, indicating that H4 and H4a (higher impact of the reports on developed countries) are confirmed. There is a group of countries which retain, more or less, their position in the ranking (notably the first three, USA, England and Germany, Australia, France, Switzerland, Norway, Denmark[9]). But we also find countries which are gradually but surely decreasing in importance: Netherlands, Sweden, Russia, India, Belgium (more prominent) and Canada. The table also notes the gradual increase of China, Finland and Spain (more dramatic increase) and Japan, and Italy, less markedly.

If one compares these trends with the general publication trends of these countries for the given period, some observations are noteworthy. We used the publication trends per country, for the period 1996–2009 provided by SCImago (2007) Journal & Country Rank[10]. We looked at the trend for the relative production of scientific papers (obtained by Scopus) of the countries noted above. This is indicated in the last column of Table 3 (column 7). In parenthesis we indicate the ranking of that country for 1996 and for 2009.

There are cases where the trend in the ranking of the country in the citational environment of the IPCC reports coincides (and could thus be explained by) the trend in the relative production of scientific articles in that country for all fields (in total nine cases). For instance, it is probably the case that part of the increase of the importance of China in the citational environment of the ARs can be explained by the overall dramatic increase of the relative production of scientific articles in the period 1996–2009 in China. The decrease of the importance of Russia in our data is also probably related to the overall decrease of the relative production of scientific articles in the period 1996–2009 in that country.

Looking at the ranking of the countries in scientific production in all disciplines (the numbers in the parentheses of the last column), we note that Canada, Australia, the Netherlands, all Scandinavian countries, and Switzerland outperform their relative ranking: the impact of the IPCC on their scientific publications is more pronounced that we would have expected, looking only at their scientific production. That could be the case because of the strong focus on environmental research in these countries, which could lead to more climate change-related publications in these countries. For other countries the impact of the IPCC is less pronounced than one would have expected given their ranking in that period, namely Italy and Japan.

Overall the table shows that developed countries dominate the citation environment of IPCC, but does not indicate anything about the diversity over time.

Next, we computed Shannon's h index for the geographical distribution of the citing papers for each AR. The result can be shown in the following Table, Table 4.

Table 4 clearly indicates the increase over time of the geographical diversity. There is a moderate linear increase of the geographical diversity ($B = 0.559$, $R^2 = 0.941$). It needs to be noted that the driving force behind the increase of diversity is not only globalization of the impact (increasing amount of countries, indicated in the third column): there are actually fewer countries citing the AR2007, as expected

[9] The ranking for the AR2007 is not taken into account for this analysis, as it may change with additional data.

[10] Retrieved March 01, 2011, from http://www.scimagojr.com.

[11] Also including Scotland, as United Kingdom in the SCImago database.

[12] With a slight decrease in the period 2000–2004.

[13] It is a dramatic increase from 2.4% of the total global production in 1996 to 13.8% in 2009.

Table 4 – Shannon's h for the geographical distribution of citing articles for each AR.

	Geographical diversity	Number of countries
Citing AR 1990	3.73	84
Citing AR 1995	4.37	95
Citing AR 2001	5.18	142
Citing AR 2007	5.32	123

Table 5 – Total articles citing each AR.

	AR1990	AR1996	AR2001	AR2007
Developed countries[14]	4707	7539	24,026	15,954
Developing countries	542	1134	4094	2701

since there are fewer available years in the dataset. So the increase of the diversity index, between the AR2001 and the AR2007 is due to more balanced distribution of the citing countries.

To clarify H5a, positing that the impact of the IPCC reports on knowledge produced in developing countries increases more over time, compared to its impact on knowledge produced in developed countries, we summarized the total amount of articles citing each consecutive AR from developed and developing countries, in Table 5.

Excluding the references to AR2007, the increase of articles from the developed countries has been 5-fold, whereas from the developing countries 7.5-fold. Even though the difference is not very big, it still suggests that the distribution of articles over countries is more evenly distributed for the case of AR2001, than the previous two reports, confirming H5a.

5. Conclusions and discussion

In this paper we have positioned IPCC at the interface of scientific knowledge production and policy needs, and suggested that the impact of IPCC on scientific knowledge production can be understood as the utilization of knowledge claims of the IPCC reports in subsequent scientific results, reflected in the references to the IPCC reports.

It is important to note here the political importance of the subsequent IPCC Assessment Reports; they have been very instrumental in intergovernmental climate policy making. In particular, the assessments of the human contribution to climate change have been important. The Third Assessment Report (AR2001) concluded that most of the recent warming is ''likely'' to be caused by anthropogenic greenhouse gases. That assessment report constituted a significant change from the qualitative statement of the Second Assessment Report (AR1996: ''the balance of evidence suggests a discernible human influence on global climate'') to a probabilistic expression. While the AR1996 paved the way for the Kyoto Protocol, the AR2001 was probably instrumental in getting that Protocol sealed in the Bonn Agreement. The Fourth Assessment Report (AR2007) subsequently continued in the same probabilistic framework when it increased the assessed likelihood from ''likely'' (>66% chance) to ''very likely'' (>90% chance).

In parallel to the political importance of the IPCC, the impact of IPCC reports on scientific knowledge, as reflected by the references to the IPCC reports, has been growing steadily and independently from the overall increase of scientific publications on climate change. Even though there was a relative decline of the impact of AR1996, compared to that of AR1990, the impacts of both AR2001 and AR2007 were substantially higher. This seems to provide some support for the ''hegemonic'' role of the IPCC, at least as authoritative resource of climate change related knowledge claims. For each assessment report, there is the same dynamic: rapid increase of the references the first two-three years after the report is published, a plateau after this, and decrease of references two years before the publication of the new report. This dynamic indicates that references are quite generic, and the IPCC reports may have a general ''encyclopedic'' function as the most authoritative resource in the field.

Disciplinary differences of the knowledge summarized in the reports are being reflected in the references to the reports. Natural sciences are more important than social sciences; within natural sciences earth sciences (meteorology, geosciences, etc.) are more important than other sciences. Economics are more important than other social sciences. The study of the trend for each consecutive AR shows that differences among disciplines decrease over time. There is indeed growing diversity of disciplines, as both growing variety of disciplines (more disciplines referring to the IPCC reports) as well as growing evenness of distribution (at least for the change between AR2001 to AR2007). For specific disciplines, such as social sciences, economics, geosciences etc., their relative importance has been surprising stable over time. Others, such as ecology and water studies are growing, whereas the relative importance of meteorology is declining (but still the single most important discipline).

Developed countries are overwhelmingly providing the publication context for most of the publications under study: it is indicative that eighteen out of the top twenty countries in the citation environment are developed countries. However, over time, and with each consecutive report the difference between developed and developing countries becomes less pronounced, probably because of a combined effect of globalization, together with growing realization and knowledge for the disproportionally large impact of climate change on developing countries.

What do these results tell us about the impact of the IPCC on science? As we discussed in the theoretical section, we can consider the IPCC as an institution involved in the process of co-evolution of the two systems. The IPCC has a considerable impact on science, as contributor of knowledge claims, as the paper suggests. It provides an authoritative resource of climate change knowledge not only internally (in disciplines closely studying climate change, such as e.g., meteorology) but also for other disciplines. In addition, we may expect that IPCC reports influence policy needs as well. What IPCC reports filter as relevant science is a selection of scientific results on climate change which in turn is presented to policymakers, and feeds into policy decisions. Through this function we may expect

[14] We have classified as developed countries the following: EU27, USA, Canada, Australia, Japan, New Zealand

IPCC to have an influence on the co-evolution of the two systems (science and policymaking) as well.

In this paper we measured the impact of IPCC with the use of references to its reports. Scientometric analyses are important if we are to understand how the reports are being picked up, and used as knowledge claims by scientists. This study has provided only an overview of such analyses. Although the use of bibliometric indicators for science studies and policy purposes has increased over the last decades, several limitations have been pointed out and should be borne in mind. For instance, the use of citation impact should be treated carefully when comparing between disciplines because the citation rate papers varies sharply between disciplines (Moed, 2005).

Further work in the line of bibliometrics can go deeper on specific topics, such as, e.g., how have the IPCC reports influenced the field of meteorology? Are suggestions for further work in IPCC reports being utilized by scientists? Analyses such as the current one should be also complemented with more qualitative work, based on interviews with scientists, which can probe deeper into the extent to which scientists read and consciously use the material in IPCC or utilize it indeed as a generic reference, which our analysis suggests. It is also interesting to combine such analyses with science funding analysis, and see how policy priorities are being turned into scientific priorities and scientific results, through the use of science funding and what role do the IPCC reports play in the organization of such funding.

We have found that the impact of the IPCC reports has spread beyond traditional climate change related fields into e.g., international relations, organization science, etc. Confirming previous anecdotal evidence of a ''hegemonic'' role of IPCC, we showed how IPCC reports are being increasingly used in many different disciplines, often further away from the climate change field, where details about the organization and the structure of IPCC work are probably unknown (e.g., how are the summaries constructed, how are comments dealt with, etc.). It therefore becomes even more vital for IPCC to be transparent about its work structures, and to deal with commentary and dissident voices in an open way. One would expect that such knowledge and details are known among researchers working on climate change mitigation and adaptation, but largely unknown among researchers in other disciplines.

From the results of the PBL (2010) evaluation report, one can conclude that the IPCC should become more aware of the inevitable role of 'expert judgments', in which experts conduct assessments despite high degrees of uncertainty and make these judgments more transparent. In an open assessment procedure the logic of the reasoning is made public; and users, both policymakers and scientists alike, can in that way regain trust in the quality of the IPCC Assessment Reports.

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