

# A Topography of Climate Change Research

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**The massive expansion of scientific literature on climate change challenges the Intergovernmental Panel on Climate Change (IPCC)’s ability to assess the science according to its objectives. Moreover, the number and variety of papers hinders researchers of the science-policy interface from making objective judgements about those IPCC assessments. In this paper, we present a novel application of a machine-reading approach to model the topical content of 400,000 papers on climate change. This topic model provides the basis for a *topography* of climate change literature. By comparing the climate change literature as a whole to that which is cited by IPCC reports, we show that, contrary to previous estimations [1], social science research on climate change is relatively well represented by IPCC reports. Conversely, topics on technical solutions to climate change, and knowledge from Engineering and the Agricultural Sciences in general, are under-represented.**

We live in an age of “Big Literature” [2, 3], where the science of climate change is expanding exponentially [4, 5]. In the five years since the publication of the last IPCC assessment report [6], 202,000 papers were published in the Web of Science (WoS) (see Table 1). This is almost as much as the 205,000 papers published during the first five assessment periods; a period of nearly 30 years. A total of around 350,000 new publications can be expected for the current sixth assessment cycle of the IPCC, based on current growth patterns (Figure 1). Moreover, the literature has also become more diverse. This is reflected in the expansion of the literature’s vocabulary - from 2,000 unique words in the first assessment period to 95,000 words so far in the sixth - indicating that the field has incorporated new content. For example, the zika virus, which was mentioned in 182 articles from 2014-2018, had never before been discussed in the titles or abstracts of articles relating to climate change. Yet it has emerged as a topic of high relevance: the incidence of the virus, the outbreak of which in Brazil in 2016 was declared a public health emergency by the WHO, is set to increase under rising global temperatures [7]. Similar rapid emergence patterns can be seen for INDCs and SDGs in AR6, and Biochar and REDD in AR5, among others<sup>1</sup>.

Big literature poses at least three challenges for scientific policy advice and science itself: *First*, established procedures in scientific assessments like those conducted by the IPCC fail to address the exploding literature base. For example, the ratio of studies cited in IPCC reports to the number of relevant studies has declined from 60% to 20% [3], posing a rapidly growing risk of selection bias. More generally, the provision of comprehensive, objective, open and transparent assessments of the available scientific literature, as defined in the principles governing IPCC work [8], is no longer possible for authors or author teams by traditional means. Machine reading and learning methods as well as other data science applications are required to enable an understanding of the field of climate change research at scale (REFs). *Second*, evidence synthesis - the enterprise of reviewing the literature based on a formal and systematic set of methods [9] - becomes increasingly important for aggregating and consolidating the rapidly emerging knowledge and

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<sup>1</sup>The glossary in SI contains a complete list of the acronyms shown in the table

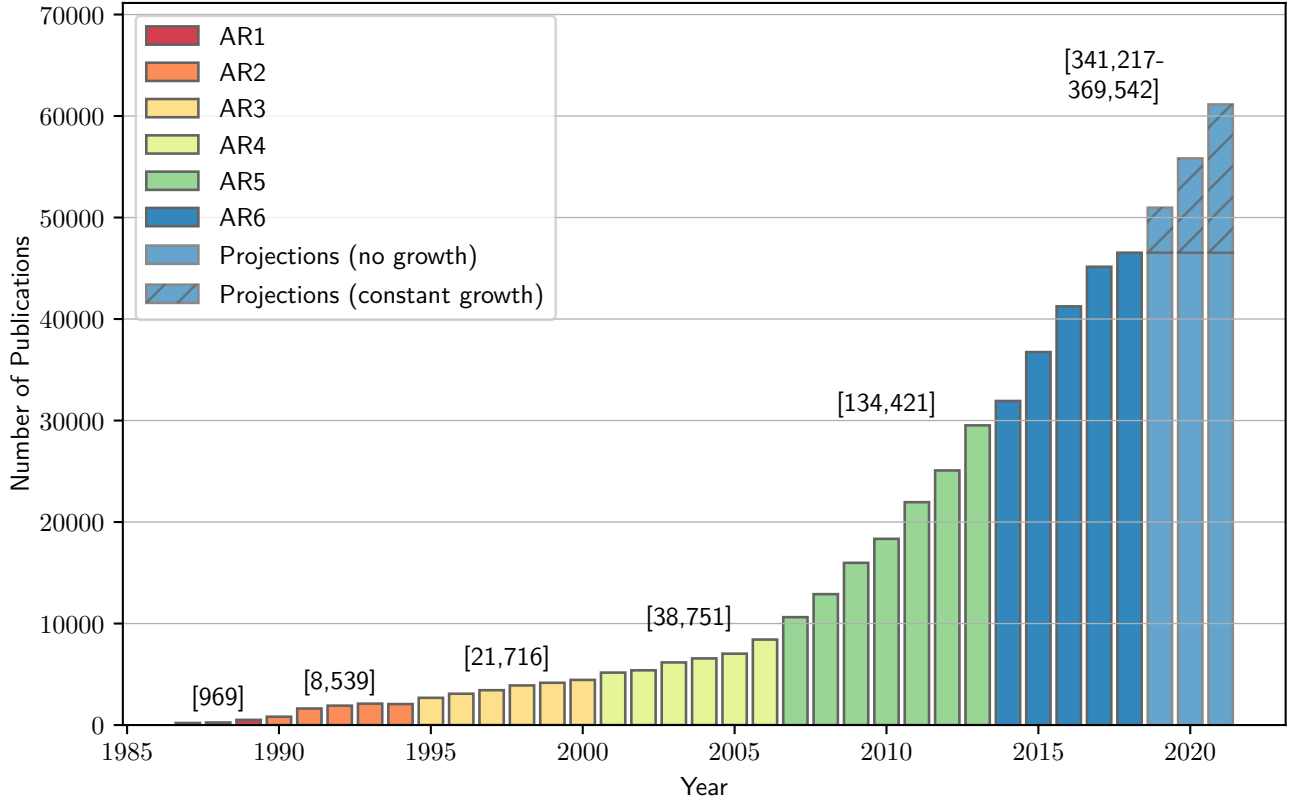


Figure 1: The number of climate change documents in the Web of Science in each year. For 2019-21 we project the number of papers assuming there is no more growth, and assuming that growth continues at the same rate as over the past five years

	AR1	AR2	AR3	AR4	AR5	AR6
<b>Years</b>	1986-1989	1990-1994	1995-2000	2001-2006	2007-2013	2014-
<b>Documents</b>	1,167	8,539	21,716	38,750	134,413	201,606
<b>Words</b>	2000	12480	23346	34637	71867	94746
<b>New words</b>	change (560)	oil (287)	downscaling (217)	sres (234)	biochar (1791)	mmms (313)
	climate (428)	deltac (283)	degreesc (187)	petm (95)	redd (1113)	cop21 (234)
	co2 (318)	whole (256)	ncep (130)	amf (88)	cmip5 (679)	c3n4 (214)
	climatic (289)	tax (254)	fco (107)	sf5cf3 (86)	cmip3 (587)	sdg (187)
	model (288)	landscape (249)	pfc (98)	clc (81)	mofs (299)	zika (182)
	atmospheric (281)	alternative (243)	otcs (98)	embankment (81)	sdm (297)	ndcs (168)
	effect (280)	availability (242)	dtr (95)	cwd (79)	mof (275)	indc (164)
	global (224)	life (239)	nee (89)	etm (75)	biochars (252)	indcs (134)

Table 1: Growth of Literature on Climate Change. A glossary of acronyms is provided in SI

enabling scientific assessments to do their job. Yet, traditional methods of evidence synthesis themselves are pushed to their limits by the large amount of scientific publications. Whilst the field of evidence synthesis technology that tries to streamline human tasks through machine learning at the different stages of the review process is still in its infancy [10]. *Finally*, overwhelming amounts of literature may be a major reason why studies of scientific assessments [1, 11, 12, 13] do not offer robust quantifications, for claims about the relationship between report citations and the underlying literature.

This study uses topic modelling [14] to map out the vast body of evidence on climate change. Topic modelling is an unsupervised machine-learning technique, where patterns of word co-occurrences in documents are used to learn a set of topics which can be used to describe the corpus. The word topic derives from the Greek word for place (topos), and by *situating* the documents in a reduced-form projection of their thematic content (see Figure 2), we create a *topographic map* of the literature on climate change. Such a systematic engagement with the thematic content of the climate science is missing from the literature so far. We apply this map in a second step to understand how the IPCC reports have represented the available climate change literature and re-evaluate claims of bias based on a more comprehensive understanding of the available climate science. We enrich the discussion of representation in the literature by discussing topics as well as disciplines.

## Mapping out the landscape of climate change literature

Figure 2 shows a *thematic* or *topographic map* of the 400,000 publications on climate change in our dataset with a total number of 140 topics. The number of topics must be defined exogenously, but the results are robust to different specifications. Using non-negative matrix factorization [15], the topics are machine-learned from the papers' abstracts (see methods for details, examples of different model specifications, and a thorough explanation of model selection), and the topic scores of each document are reduced to the two dimensions shown through t-distributed stochastic neighbour embedding [16]. <sup>2</sup>.

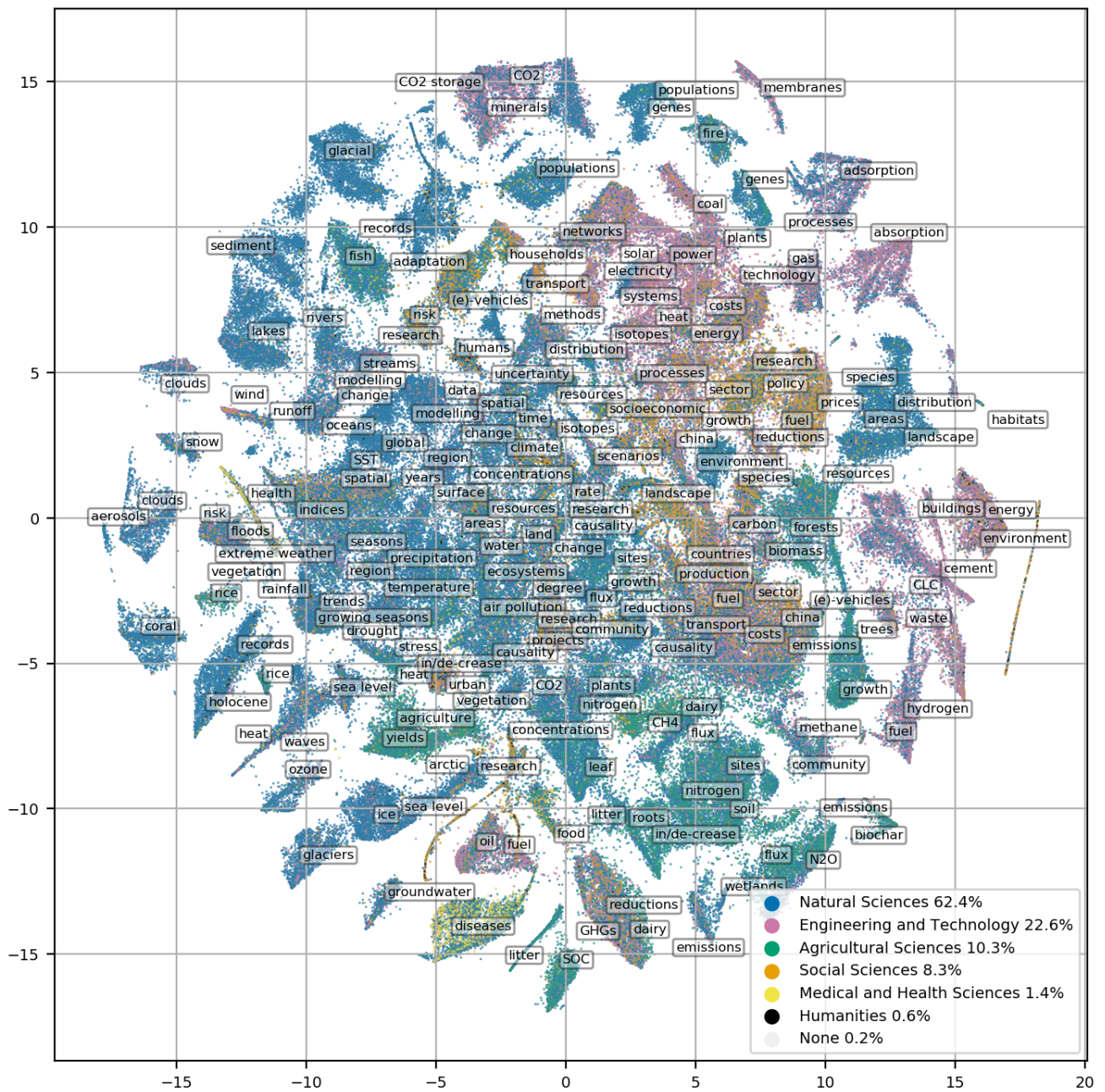
The map shown covers a broad range of topics, with related topics shown in clusters. In general, topics related to climate science and impacts are in the West, while solution-oriented topics are in the East. More fine-grained research areas can also be distinguished. For example, publications related to urban infrastructure (**buildings**, **energy**, **cement**, **waste**) are located in the East, physical climate impacts such as **sea-level**, **droughts** or [crop] **yield** are in the South-West and energy systems are in North-East. There are larger groups of documents at the fringes of the map that relate mainly to one or two specific topics such as **biochar**, **coral**, or **CO2 storage**. Interestingly, scenarios feature centrally in the map, at the interface between different scientific communities. This corresponds to their integrative nature in IPCC reports (REF). This map of the thematic structure of the literature could be useful for individual communities or for climate change assessments.

The disciplinary composition of this research topography indicated by the different colours in Figure 2 highlights the dominance of natural sciences in climate change research. More than 60% of the literature is published in natural science journals. Similarly, in 115 out of 140 topics the contribution of publications in natural science journals is greater than any other discipline. We calculate disciplinary entropy of topics as a measure of their degree of interdisciplinarity (see Figure SI.1 and methods for details). This shows how research on health, food, or policy comes from a range of disciplines, while research on ice and oceans comes almost exclusively from the natural sciences).

Finally, the topography shows the thematic evolution of the literature, with topics exhibiting distinct patterns of growth. Fast-growing topics in the last three assessment periods have included, among others, **coral**, **risks**,

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<sup>2</sup>A full list of topics and related words, and a list of documents and related topics are given in the SI



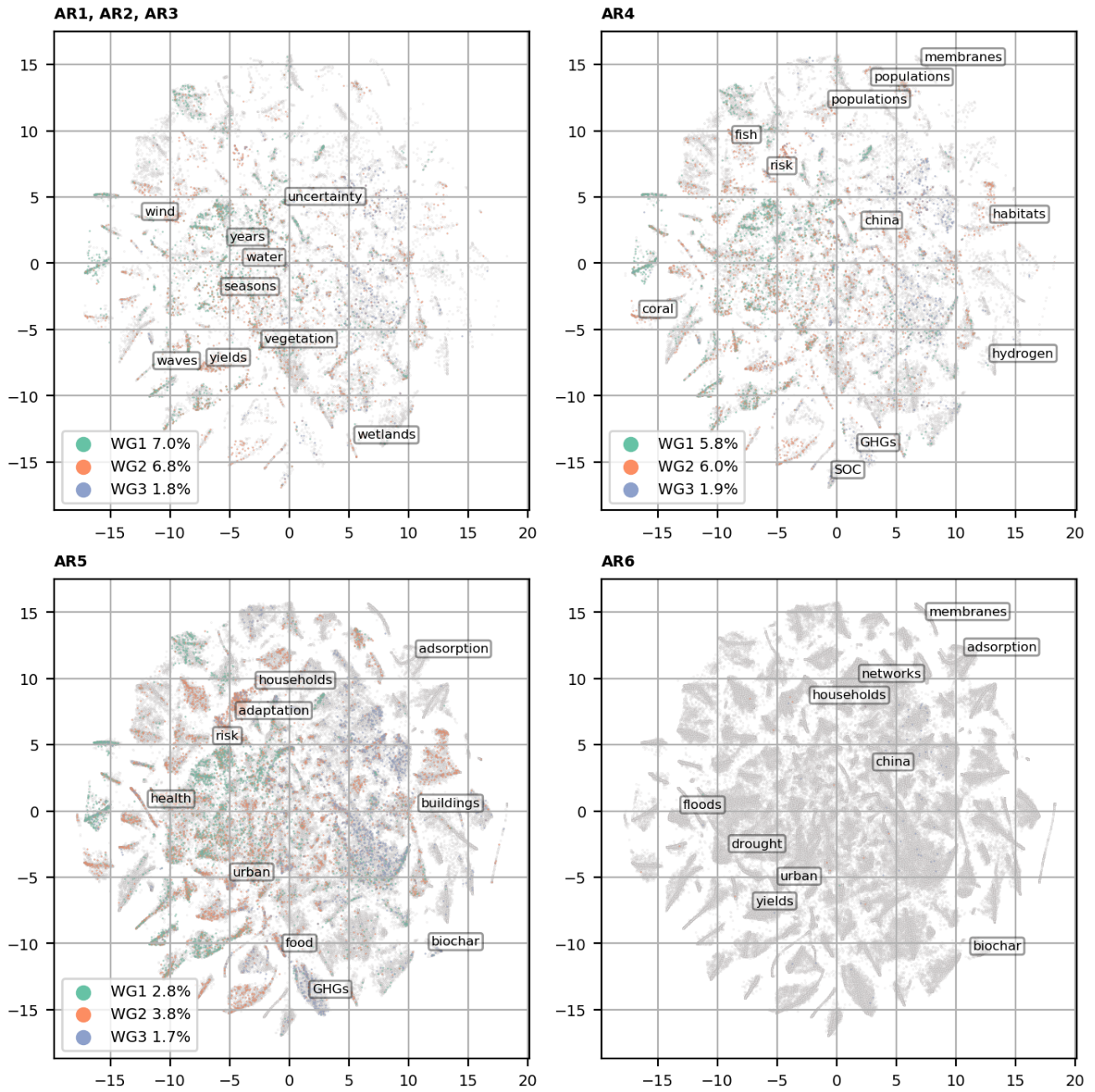


Figure 3: Evolution of the landscape of climate change literature. In each period, the 10 fastest growing topics are labelled. Where documents could be matched to IPCC citations, they are coloured by the working group citing them.

71 **adaptation, hydrogen, buildings, CO2 removal, networks and biochar.** Biochar is particularly remarkable in  
72 that the sizeable literature which emerged in AR5 was completely absent from the climate change literature beforehand.  
73 The identification of new topics as they emerge, particularly as these are identified without prior knowledge of the  
74 literature, can help researchers and assessment-makers to keep abreast of a quickly evolving field.

## 75 Research representation in IPCC reports

76 We apply our topic map to understand the representation of science in IPCC assessments and how it manages to  
77 respond to demands for more solution-oriented knowledge [18]. Several studies have identified, made, or repeated  
78 claims of a disciplinary bias of IPCC assessments towards the natural sciences, and within the social sciences towards  
79 economics [1, 12, 11, 13]. Where these claims were based on an analysis of IPCC citations [1], they fail to assess  
80 this claim against a reasonable, measurable benchmark. We argue here that the composition of the climate change  
81 literature as a whole provides such a benchmark, in view of the organisation’s mandate to provide “comprehensive,  
82 objective, open and transparent” assessment of the available science [8]. Our comprehensive database allows us to  
83 study representation with such a benchmark, and over time rather than for single assessment cycles.

84 Figure 4.a shows that the social sciences were indeed under-represented in the third assessment report, but by  
85 the fifth assessment report were over-represented. Likewise, other social sciences than economics have become better  
86 represented since AR3 (see figure SI.3f) with social & economic geography (4.3% of the literature), political science  
87 (1.0%), and sociology (0.8%) showing improved representation in AR5 compared to AR3, and social and economic  
88 geography, political science, and other social sciences better represented than economics.

89 This challenges what we think we know about the IPCC. The social sciences, by now, are actually the best  
90 represented field, with a share in the literature cited by IPCC reports 1.32 times as high as in the literature at large.  
91 On the other hand the Agricultural Sciences and Engineering & Technology have been consistently under-represented,  
92 with 2.27 and 3.49 times the share of studies in the wider literature than in the literature cited by the IPCC in AR5  
93 respectively.

94 The topography allows us to delve deeper into the subject matter that receives more or less attention in the IPCC.  
95 Figures 4b and 4c plot the representation of the topics shown in the map. Figure 4c shows that topics more commonly  
96 cited by IPCC working group I are older and largely better represented in IPCC reports. These topics, for example  
97 **ozone, oceans, clouds, aerosols and sea levels** make up some of the core topics of the physical science of climate  
98 change.

99 The topics in the lower right of the graph are the most pertinent to the question of whether the IPCC is well  
100 representing knowledge on climate change. These topics are newer and until now have been under-represented in  
101 IPCC reports. Because they are new areas of knowledge, they may be highly salient in a periodic assessment process.  
102 These topics are primarily in working group III, on mitigation <sup>3</sup>.

103 The difference between these under-represented new topics and other new topics that are better represented is  
104 intriguing. This difference is visible in figure 3, where in AR5, the clusters of documents around the **adsorption,**  
105 **buildings,** and **biochar** topics contain few IPCC citations, whereas the clusters around **food, health, adaptation,**  
106 and **GHGs** contain more. As shown in figure 4c, **adsorption, buildings and biochar** are 4.08, 3.34 and 3.61] times  
107 more prevalent in the literature than in IPCC citations, while food is 1.22 times more prevalent in the literature and  
108 health and adaptation are 1.02 and 2.22 times more prevalent in IPCC citations respectively. The IPCC, has been

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<sup>3</sup>see methods for a discussion of the categorisation of topics, including CLC, adsorption and hydrogen, which may more properly be described as relevant to WGIII



better at integrating new knowledge from these topics, and in general better at integrating new knowledge from WG II than WG III topics.

Further, within WG III topics, those that are well represented contain a greater proportion of social science research (figure 4b). The topics **countries**, **policy**, and **prices** are close to a proportional representation and are made up of around 30% social science research. **Waste**, **biochar**, **cement** and **coal**, are more than 3 times more prevalent in the wider literature than in the literature cited by the IPCC, and are made up of around 5% social science research. This pattern is not visible in other working groups (see Figure SI.4), and complicates the perception of the under-representation of the social sciences.

Recalling policymakers' demands for more solution-oriented assessments [18], we could also interpret the topics that are newer and under-represented as "solutions-relevant". However, while policymakers' demands for solutions-oriented knowledge were rather about policy options, these under-represented new topics deal with more technical solutions and are found rather in technical disciplines within engineering & technology and the agricultural sciences.

## Machine-learning for climate change assessments

We have shown that social science literature about climate change is over-represented in the IPCC, while technical literature on solutions is under-represented. A perfectly proportional representation of every part of the literature is of course not optimal, yet these two features represent new knowledge about the interaction between the IPCC and the literature, and have important implications for the community. The over-representation of the social sciences, combined with the perception that the IPCC needs to include more social science knowledge [12], suggests that doing so must involve the funding and production of more social science literature on climate change, not just greater efforts by the IPCC to include it. Moreover, the fact that solutions-relevant topics are under-represented - while policymakers demand more solutions-oriented assessments - and that these topics contain little social science research, suggests areas where social science research may be usefully conducted. Further, this fact can open a debate about the extent to which the IPCC should include more technical knowledge on solutions from disciplines within engineering and the agricultural sciences.

The map can also serve as a guide to future assessments, to ensure that decisions about how different areas of the literature are represented are well-informed. The map can contribute to these decisions as they are made from the scoping process, through to the selection by authors of individual studies. Beyond this, the methods shown here could aid other processes in the production of IPCC reports, such as the identification of potential authors to achieve a better balance across sectors, regions and genders [13]. Outside of the IPCC, this approach is part of ongoing attempts to make use of machine-learning within evidence synthesis. The topographic map presented is a new approach to rapidly mapping very large literatures.

The more than 400,000 publications we deal with here represent a wealth of knowledge on climate change and climate solutions. However, we acknowledge that our dataset is by no means exhaustive. We repeat an established query [5], granting that it may have imperfections. Beyond this we miss publications not in the Web of Science (some small journals, some books, and most grey literature, not to mention indigenous knowledge [19]); and studies relevant for the work of the IPCC, but that do not directly mention climate change (for example on energy policy). We argue that this remains a reasonable system boundary given data availability, and stress that the documents not included in our study alter our findings only if they have systematically different patterns of citation by the IPCC. In the future, making use of more sources climate change knowledge, and extracting and classifying information from full texts (here we only use abstracts), could improve the granularity of this topography. Most importantly, machine

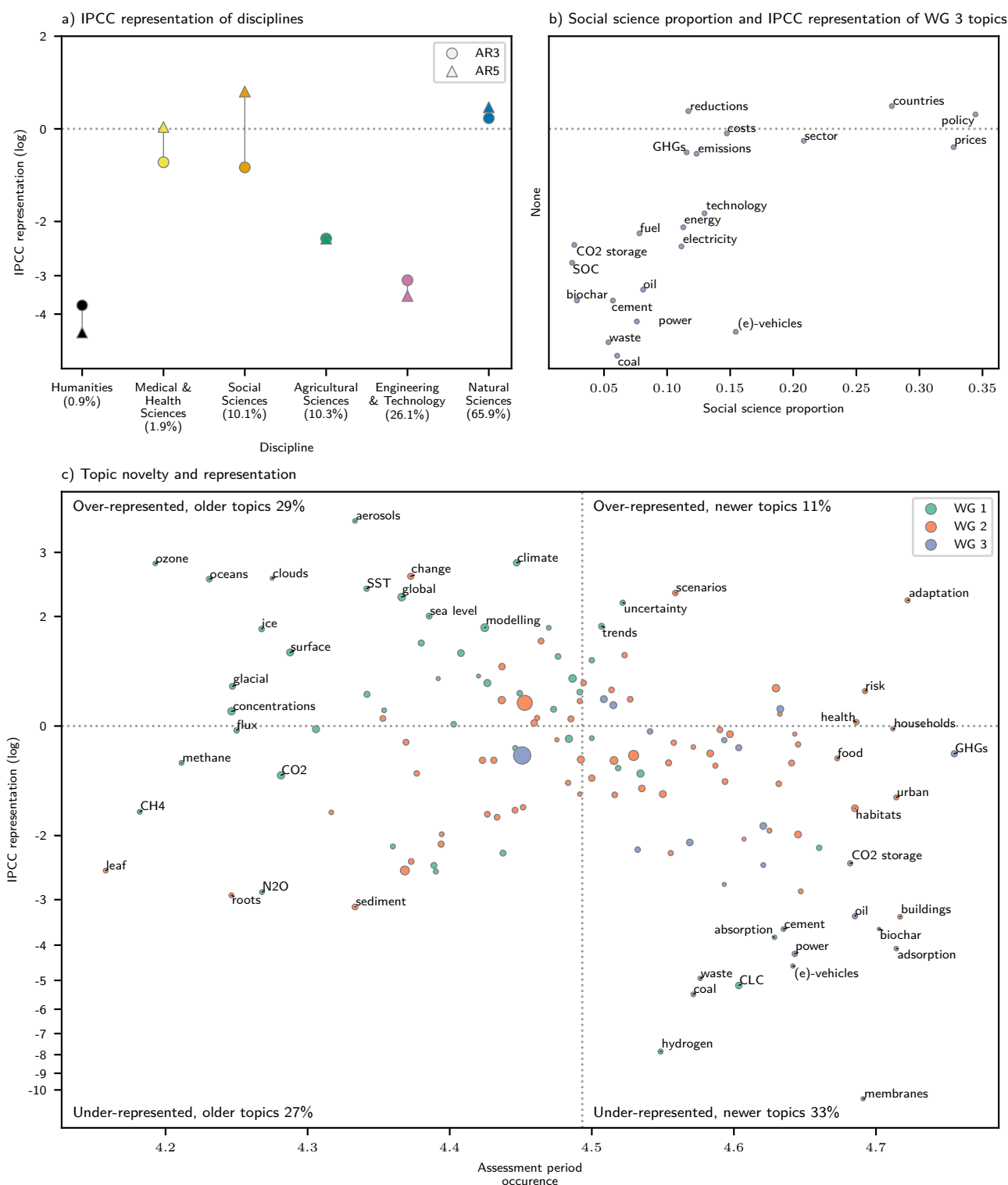


Figure 4: Representation in IPCC reports: **a)** by discipline, **b)** by social science proportion of WG 3 topics, **c)** and novelty of all topics, where topics in the highest and lowest 10% of either axis are labelled. Topics are coloured according to the working group from which they receive the most citations. Representation is the share of the subset of documents being cited by the IPCC divided by the share of the subset in the whole literature. The log is taken so that 0 is equal to perfectly proportional representation, and -1 and 1 are equally under and over represented.



149 learning applications should be explored that support IPCC authors in assessing the literature. This would prepare  
150 IPCC assessments for the age of big literature.

## References

- [1] Andreas Bjurström and Merritt Polk. Physical and economic bias in climate change research: A scientometric study of IPCC Third Assessment Report. *Climatic Change*, 108(1):1–22, 2011.
- [2] Gabriela C. Nunez-Mir, Basil V. Iannone, Bryan C. Pijanowski, Ningning Kong, Songlin Fei, and Richard Fitzjohn. Automated content analysis: addressing the big literature challenge in ecology and evolution. *Methods in Ecology and Evolution*, 7(11):1262–1272, 2016.
- [3] Jan C. Minx, Max Callaghan, William F. Lamb, Jennifer Garard, and Ottmar Edenhofer. Learning about climate change solutions in the IPCC and beyond. *Environmental Science & Policy*, 2017.
- [4] Michael Grieneisen and Minghua Zhang. The Current Status of Climate Change Research. *Nature Climate Change*, 1:72–73, 2011.
- [5] Robin Haunschild, Lutz Bornmann, and Werner Marx. Climate Change Research in View of Bibliometrics. *PLoS ONE*, 11(7):1–19, 2016.
- [6] IPCC. *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. IPCC, Geneva, Switzerland, 2014.
- [7] V. Brahmananda Rao, K. Maneesha, Panangipalli Sravya, Sergio H. Franchito, Hariprasad Dasari, and Manoel A. Gan. Future increase in extreme El Nino events under greenhouse warming increases Zika virus incidence in South America. *npj Climate and Atmospheric Science*, 2(1):2–8, 2019.
- [8] IPCC. Principles governing IPCC work, 2013.
- [9] Iain Chalmers, Larry V Hedges, and Harris Cooper. A Brief History of Research Synthesis. *Evaluation & The Health Professions*, 25(1):12–37, 2002.
- [10] Elaine Beller, Justin Clark, Guy Tsafnat, Clive Adams, Heinz Diehl, Hans Lund, Mourad Ouzzani, Kristina Thayer, James Thomas, Tari Turner, Jun Xia, Karen Robinson, Paul Glasziou, and On behalf of the founding members of the ICASR group. Making progress with the automation of systematic reviews: principles of the International Collaboration for the Automation of Systematic Reviews (ICASR). *Systematic Reviews*, 7(1):1–7, 2018.
- [11] Mike Hulme and Martin Mahony. Climate change: What do we know about the IPCC? *Progress in Physical Geography*, 34(5):705–718, 2010.
- [12] David G. Victor. Embed the social sciences in climate policy - David Victor. *Nature*, 520:7–9, 2015.
- [13] Esteve Corbera, Laura Calvet-Mir, Hannah Hughes, and Matthew Paterson. Patterns of authorship in the IPCC Working Group III report. *Nature Climate Change*, 6(1):94–99, 2016.
- [14] David Blei, Lawrence Carin, and David Dunson. Probabilistic topic models. *IEEE Signal Processing Magazine*, 2010.

- [15] D D Lee and H S Seung. Learning the parts of objects by non-negative matrix factorization. *Nature*, 401(6755):788–91, 1999.
- [16] Laurens van der Maaten and Geoffrey Hinton. Visualizing Data using t-SNE. *Journal of Machine Learning Research*, 9:2579–2605, 2008.
- [17] Richard H. Moss, Jae A. Edmonds, Kathy A. Hibbard, Martin R. Manning, Steven K. Rose, Detlef P. Van Vuuren, Timothy R. Carter, Seita Emori, Mikiko Kainuma, Tom Kram, Gerald A. Meehl, John F.B. Mitchell, Nebojsa Nakicenovic, Keywan Riahi, Steven J. Smith, Ronald J. Stouffer, Allison M. Thomson, John P. Weyant, and Thomas J. Wilbanks. The next generation of scenarios for climate change research and assessment. *Nature*, 463(7282):747–756, 2010.
- [18] Martin Kowarsch, Jason Jabbour, Christian Flachsland, Marcel T. J. Kok, Robert Watson, Peter M. Haas, Jan C. Minx, Joseph Alcamo, Jennifer Garard, Pauline RiOUSset, László Pintér, Cameron Langford, Yulia Yamineva, Christoph von Stechow, Jessica O’Reilly, and Ottmar Edenhofer. A road map for global environmental assessments. *Nature Climate Change*, 7(6):379–382, 2017.
- [19] James D. Ford, Laura Cameron, Jennifer Rubis, Michelle Maillet, Douglas Nakashima, Ashlee Cunsolo Willox, and Tristan Pearce. Including indigenous knowledge and experience in IPCC assessment reports. *Nature Climate Change*, 6(4):349–353, 2016.