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Bridging in Network Organisations
the Case of International Panel on Climate Change (IPCC)

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Abstract

In this paper, we investigated the relational architecture of the Intergovernmental Panel on Climate Change (IPCC) focussing on the individuals that, in the thirty years of its existence, have assured the connection between its different temporal, thematic and functional divisions. To study the relational bridging within the IPCC, we create an exhaustive database of all the individuals who have ever contributed to the organisation and noted in which particular workstream they participated. From this database we extract the participants-workstreams affiliation network and use it to compute several metrics of bridgeness, which we discuss, validate and compare. We use these metrics to investigate the general distribution and evolution of bridging in the IPCC, but also to single out individuals who more actively provided connections between science and diplomacy (functional bridges), working groups (thematic bridges) and assessment cycles (temporal bridges). Zooming on the role of some of these bridges and on their trajectories within the organisation, we provide insights on the IPCC as a network organisation.

Introduction

The Intergovernmental Panel on Climate Change (IPCC) is a fascinating institutional puzzle. Despite its gruelling mission – building a consensus on climate change in the academic community and between world governments – the IPCC has prospered as no expert organisations before. While not exempt from criticisms (Lidskog & Sundqvist, 2015), it has thrived under several respects. In its thirty-year existence, the IPCC has produced five assessment reports (ARs) whose length has grown from the 1,222 pages for the first to the 5,021 pages for the fifth; the number of its authors by assessment cycles has quadrupled (from 437 to 1887 including all types of contributions); the number of national delegates almost tripled (from 590 to 1569). The growth of the IPCC is not only quantitative. In each successive report, the IPCC has strengthened its authority and consolidated its position at the interface between scientific research and diplomatic negotiations to the point of being awarded, jointly with Al Gore, the Nobel Prize for Peace in 2007 "for their efforts to build up and disseminate greater knowledge about man-made climate change, and to lay the foundations for the measures that are needed to counteract such change[1]". As such, its assessment reports represent key scientific inputs in the negotiations under the United Nations Framework Convention on Climate Change (UNFCCC) (Fogel, 2005; Devès et al., 2017). The IPCC success has also inspired the creation of several other global environmental assessments including the Intergovernmental Science-Policy

[1] https://www.nobelprize.org/prizes/peace/2007/ipcc/facts/ (accessed 8 February 2021)

Platform on Biodiversity and Ecosystem Services, IPBES (often described as the IPCC for biodiversity).

Remarkably, this expansion has not been accompanied by organisational hardening. Apart from a secretariat of a dozen members, the IPCC has no permanent organs and no stable employees. All of the eight thousand individuals who contributed to its assessment reports did it on a voluntary basis and on the payroll of other institutions. Unlike other international organisations (Reinalda & Verbeek eds., 1998), the IPCC has not entrusted its activities to a group of hired bureaucrats. Instead, it has remained a "network organisation" (cf. Corbera et al., 2015), ruled by a complex architecture of rules of procedures more than by a stable bureaucratic apparatus and whose contributors are generally replaced at every assessment cycle and maintain their primary affiliation to other institutions. As noted by Oestreich (2011: 168) international organisations exist "not just as bureaucracies [...] but as social networks and patterned sets of interactions that take on a life of their own".

In this paper, we use social networks analysis (SNA) to study the networked organisation of the IPCC. While SNA techniques have already been used to examine the scientometrics patterns of co-publication by the authors of the IPCC Working Group 3 (Corbera et al., 2015; Hughes and Paterson, 2017), this paper is the first to investigate network connections within the IPCC itself. We contend that the stabilisation of the IPCC in the international climate regime (Hughes, 2015) in the absence of hard organisational structures is due to the dovetailing of its practice fastened by the relational glue provided by individuals who served in multiple parts of the organisation or in different assessment cycles. We follow the IPCC's own terminology by calling these individuals "bridges", but we note that the term resonates with a central theme in social networks analysis (SNA). It is well known that graph theory itself was initiated by Leonhard Euler (1736) to solve the puzzle of the Königsberg bridges and, since then, the notion of bridges has intrigued scholars – especially in its social applications. Jacob Moreno (the father of SNA) dedicated particular attention to the nodes connecting distant regions of his "sociograms" (Moreno, 1934). Yet, it is with the influential paper of Mark Granovetter on *The Strength of Weak Ties* (1973) that the importance of social bridges came into full view. Central to the paper is the idea that weak ties are crucial relational assets precisely for their capacity to connect distant social worlds. The same idea is developed by Ronald Burt (2005) who highlights the importance of brokering nodes "connecting across clusters to engage diverse information" (Burt et al. 2013, p. 530). In a different tradition, Luc Boltanski (1973) argued that "multipositionality" – the property of occupying multiple positions in different social fields – is a crucial source of social capital (see also a network analysis of this phenomenon in Venturini et al., 2016) and similar observations have been made about corporate interlocking (Allen, 1974).

We aim to contribute to the literature on relational bridges, using the case study of the individuals connecting the different divisions of the IPCC. By providing an empirical example of the role of bridging in a complex organisation, we hope to contribute to the understanding of an international organisation that is increasingly taken as an example of multilateral scientific diplomacy (Ruffini, 2017). Doing so, we explore a key topic of discussion in the organisation, that is the *integration* between the different 'parts' of the IPCC – i.e., between its working groups (WGs), between delegates and scientists and across assessment cycles (ARs) (Klenk and Meehan, 2015).

Our research aims to speak to a defining claim of social network analysis (Scott, 1991; White, 1992; Freeman, 2004) and more generally of relational sociology (Tarde, 1893; Emirbayer, 1997; Latour, 2005) that the essence of collective phenomena lies not in external structures but in the internal connections between their parts. This claim is easier to defend when studying dynamics and change, but more difficult when considering continuity and persistence, which, in social sciences, are traditionally associated with macro-structures. The decisive test for relational sociology is therefore to explain the continuity of social organisation and account for the kind of stable empirical regularities that, since Durkheim, represent the bedrock of structural sociology. In contrast to Durkheim's *Rules of*

Sociological Method (1884/1982), we need to ground continuity and persistence not on the "solid foundation" of structures but on "shifting sand" of relations[2] and show that *collective phenomena are in the whole because they are in the parts and not in parts because they are in the whole*[3].

The IPCC as a complex international organisation

While bridging is a node-level property that can be measured in any network, we are in this paper particularly interested in bridging in large and complex organisations – that is, organisations that are composed of subparts which differ in several respects. The IPCC is clearly one such organisation, as its work is divided across three different dimensions: temporal, functional and thematic.

First, its activities are not carried out as a continuous process, but divided in "assessment report cycles", each driven by a different leadership and bound by a specific thematic outline. Since its establishment in 1988, the organisation has completed five assessment reports, which thus constitute the five temporal divisions of the IPCC considered in this paper. Each assessment is also subdivided in different phases (definition of the outline, election of the leadership, selection of the authors, writing and reviewing of drafts, approval of summaries, etc.) and punctuated by yearly or bi-yearly plenary sessions and Lead Author Meetings (LAMs), which constitute the main physical gatherings between IPCC participants. Virtual meetings and email exchanges between participants also play a key role in the process of assembling the assessment reports.

Second, the IPCC is a hybrid organisation, characterised by the cohabitation of scientists coming from different disciplines and diplomats representing different countries (Ho-Lem et al. 2011). Not only do these two populations often have different professional backgrounds, but they serve different functions in the IPCC: while the *authors* are tasked with reviewing and summarising the scientific literature, the *delegates* are in charge of managing the process and making sure that its outcomes are politically relevant and politically acceptable through the review and approval processes (De Pryck, 2021). In this paper, we therefore consider authors and delegates as two different functional divisions of the IPCC.

Third, IPCC assessment reports are divided into three volumes each produced by a dedicated thematic Working Group (WG): WG1 focuses on the physical basis of climate change; WGII on impacts, adaptation and vulnerability and WGIII on mitigation[4]. Because of this specialisation, the working groups tend to be composed of scientists coming from different disciplines, with a prevalence of natural scientists (climatologists) in WG1 and of social scientists (economists) in WG3. WG2 is more diverse (Bjurström and Polk, 2011). Each working group is led by two co-chairs and is supported by a dedicated *Technical Support Unit*. Besides the volumes produced by the three working groups, IPCC reports also contain (from AR2 on) a Synthesis Report (SYR), which combines the results of the three WGS. This work of integration has become a key aspect of the policy relevance of the organisation

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[2] "Collective habits are expressed in definite forms such as legal or moral rules, popular sayings, or facts of social structure, etc. As these forms exist permanently and do not change with the various applications which are made of them, they constitute a fixed object, a constant standard which is always to hand for the observer, and which leaves no room for subjective impressions or personal observations… In order to proceed methodically *we must establish the prime bases of science on a solid foundation, and not on shifting sand*." (Durkheim, 1884, pp. 82-83 in the 1982 translation, emphasis added).

[3] "if [a phenomenon] is general it is because it is collective (that is, more or less obligatory); but it is very far from being collective because it is general. It is a condition of the group repeated in individuals because it imposes itself upon them. *It is in each part because it is in the whole, but far from being in the whole because it is in the parts.*" (p. 56, Durkheim, 1884 (1982 translation), emphasis added)).

[4] The IPCC also established in 1998 a Task Force on National Greenhouse Gas Inventories (TFI). In this paper, however, we focus on the assessment work of the IPCC and not on its (also relevant) activities of developing greenhouse gas inventory-related methodologies and practices.

and the SYRs are particularly awaited documents. The thematic divisions of the IPCC correspond therefore to the four authors groups responsible for the three thematic volumes and for the SYR. Each volume is subdivided into different chapters (whose number varies from 7 in AR1-WG2 to 30 for AR5-WG2).

The intersection of the three dimensions described above divides the operations of the IPCC into 24 different "workstreams", each defined by a particular temporal, functional and thematic combination, as illustrated by table 1. According to the Oxford Dictionary, a workstream is "a particular project, process, or area of operations within a business or organisation". In the context of the IPCC, two individuals are therefore affiliated to the same workstream if they share the same function in the same working group during the same assessment cycle. The idea of “workstream” captures the fact that each of these combinations defined in table 1 designates a distinct group of people who collaborate for several years on the same task and who, therefore, have multiple opportunities to meet and interact.

Table 1. The 5 temporal, 2 functional and 3 thematic divisions of the IPCC and the 24 workstreams they form.

Functional divisions	Thematic divisions	Temporal divisions				
		AR1	AR2	AR3	AR4	AR5
Authors	WGI	ar1-author-wg1	ar2-author-wg1	ar3-author-wg1	ar4-author-wg1	ar5-author-wg1
	WGII	ar1-author-wg2	ar2-author-wg2	ar3-author-wg2	ar4-author-wg2	ar5-author-wg2
	WGIII	ar1-author-wg3	ar2-author-wg3	ar3-author-wg3	ar4-author-wg3	ar5-author-wg3
	SYR	/	ar2-author-syr	ar3-author-syr	ar4-author-syr	ar5-author-syr
Delegates		ar1-delegate	ar2-delegate	ar3-delegate	ar4-delegate	ar5-delegate

While this organisational architecture has allowed the IPCC to accommodate the work of thousands of scientists and delegates from all over the world, it also raised coordination problems that had not been lost on the organisation. In particular, the importance of securing a thematic integration between WGs has become a key concern in the IPCC, especially concerning topics that cut across two or more WGs. In AR3, the IPCC produced guidance papers on "cross-cutting issues" with the objective of achieving a consistent use of terms and approaches (Pachauri, Taniguchi and Tanaka, 2000). Integration has nevertheless remained problematic, notably because of an increase in the volume of the literature to be assessed and of the fact that WGs work separately. The IPCC has been criticized for issuing inconsistent and sometimes conflicting messages within and between WGs, as well as between ARs. Gleditsch and Nordas (2014) for instance highlighted how the scattering of the discussions about human security in the AR5 WG2 report led to conflicting interpretations of the link between climate change and violent conflict. The controversy around the melting of the Himalaya glaciers, which damaged the credibility of the organisation in 2009, could also have been avoided if greater coordination had occurred between WG1 and WG2 (Beck, 2012). Finally, O'Reilly et al. (2012) also observed inconsistencies in the assessment of sea level rise between AR3 and AR4, attributable not only to new information, but also to changes in the architecture of the report and group dynamics between authors.

The IPCC takes the question of thematic integration very seriously and encourages authors to review other chapters within and across WGs, and in some cases, to act as Contributing Authors (CA) or reference persons on cross-cutting topics. In 2010, it formalized the role of "bridge authors": a Lead Authors (LA) of one WG who serves as CA in another WG in the same assessment report[5]. While the official IPCC's definition focuses on **thematic bridges**, who serve in *different WGs during the same*

[5] https://www.ipcc.ch/site/assets/uploads/2018/03/doc12_p32_wg_III_progress_report.pdf

AR, this paper also considers **functional bridges**, who serve as *authors and delegates during the same AR*, and **temporal bridges**, who participate in *more than one AR with the same function and within the same WG*. While these forms of bridging are not officially recognized by the IPCC, they are key to understanding the integration between science and diplomacy and the institutional continuity across assessment cycles. Note that the definitions above exclude *mixed bridges*, individuals who contributed to different ARs with different functions or in different WGs.

The IPCC affiliation network

To investigate the bridges uniting the IPCC across its different workstreams, we constructed a dataset containing information about all the individual contributions to the IPCC's first five assessment cycles[6]. We put great effort to disambiguate homonyms and merge different names of the same person (though errors may remain given the complexity of this task). As the same individual can be involved in different assessment reports, functions and working groups, he or she can be affiliated to multiple workstreams, which in fact correspond to our definition of organisational bridges. Although we collected data on all individuals who contributed to the IPCC, for our analysis we focused on a subset of 5,554 participants that have served at least once as a delegate or as an author selected by the IPCC Bureau in a role of coordination and responsibility, namely as a Coordinating Lead Author (CLA), Lead Author (LA) or Review Editor (RE). We thus exclude from our analysis those authors whose only contribution to the IPCC was as a Contributing Author (CA); while CAs are important in the IPCC, their participation is often limited to the submission of written contributions and generally does not involve attending the author meetings, thus reducing their importance as bridges[7].

We then organize our data as an affiliation network (Borgatti & Halgin, 2011), that is, as a 2-mode rectangular matrix, with the rows representing the participants and the columns representing the 24 workstreams described above. The edges of our network represent individuals-workstreams affiliations[8]. Figure 1 provides a visual representation of our IPCC affiliation graph. We used grey versus colour to differentiate the two modes of our bipartite network and sized nodes according to their weighted degree.

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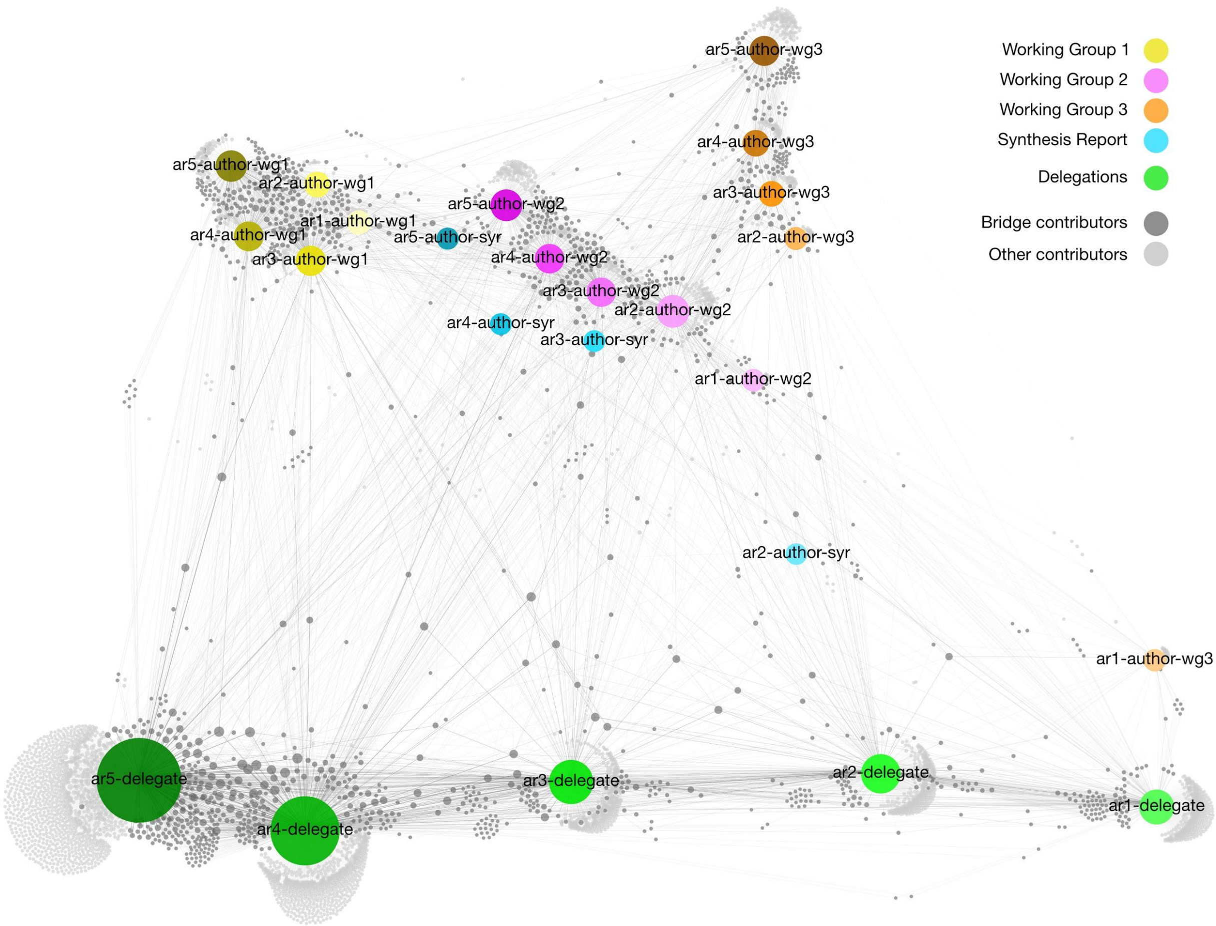
[6] The dataset described in this paper has been initiated thanks to the support of the ANR project MEDEA and about half of it completed at the médialab of Sciences Po, through the work of Ian Gray, Nicolas Baya Laffite and Audrey Banneyx, which we greatly thank for their contribution.

[7] However, it is important to note that we do include in our analysis the CA contributions of individuals who have also been CLA, LA, RE or delegates. We did so because our ethnographic observation revealed that these individuals are often invited as CA in working groups other than their main one, precisely to serve as thematic or functional bridges.

[8] For the purpose of the visualization on figure 1, the edges of our graph are weighted according to the number of times that each individual has been affiliated to the same workstream, i.e. by authoring two or more chapters within the same WG in the same AR cycle or by attending several delegate plenaries during the same AR. Weights, however, are not used in the computation of the metrics described below.

Figure 1. bipartite network of the IPCC participants and the workstream to which they are affiliated. Workstreams are coloured according to their functional and thematic division; bridges are dark grey nodes. Nodes are sized according to their weighted degree, colored according to functional and thematic divisions and shaded according to temporal recency.



Before moving to mathematical analysis, a visual inspection of the network in figure 1 can yield interesting insights. The network in figure 1 has been spatialised with a force-directed layout (Jacomy et al., 2014), which draws closer the nodes with more direct (and indirect) connections between them and pushes away nodes that are less connected to one another. This means that spatial proximity is a good indicator of structural grouping (Noack, 2007 & 2009; Venturini et al., 2021). The clustering in the figure appears to reflect above all the functional division of the IPCC, with authors and delegates clearly separated in the upper and lower part of the network. Less clear, but still easily discernible is the thematic division between the three WGs. As expected, the SYR authors are positioned between the three working groups, reflecting their role in providing a synthesis of the three thematic reports.

We coloured the nodes according to these divisions precisely to highlight the fact that they do not mix in the force-directed layout. It is interesting that the only mixing concerns the capacity "ar1-author-wg3", which is positioned close to the delegates' cluster. This offers a confirmation of our method, because in the first assessment cycle, the WG3 was mandated with the highly politicised task of formulating response strategies to climate change and involved many government officials and negotiators (Skodvin, 2000). It is also interesting to note that the middle position occupied by the SYR of AR2, which is distinctively closer to the delegates than the other Synthesis Reports; this can be explained by the fact that in its first edition (the SYR being introduced in AR2), the Synthesis Report was authored mostly by members of IPCC Bureau many of whom were also members of their national delegation.

In contrast to the high functional and thematic clustering, the temporal articulations of the IPCC in different ARs does not seem to produce much clustering, as nodes of the same AR are generally far one from another. Note, however, that in each WG cluster and in the cluster of delegates, the ARs tend to be ordered chronologically (as revealed by the increasingly dark shading of the nodes), which indicates that more bridges exist between temporally adjacent ARs. It is also interesting to note that more recent authors' workstreams tend to be further away from the delegates, thus indicating a growing separation between the two functions in the IPCC. The fact that no temporal clustering is visible in the figure suggests that there are more bridges between the same functional or thematic division in different ARs, than between different functional or thematic divisions in the same AR.

Bridgeness by betweenness centrality and Jaccard distance

The visual inspection of our bipartite network of IPCC participants and workstreams has provided interesting insights that we now investigate further using numerical methods. We start by computing the bridgeness of each of the individuals of our networks, that is the extent to which she or he helps to keep the network together, connecting its different parts. To do so, we rely on a classic measure of relational bridging, *betweenness centrality* (Freeman, 1977; Brandes, 2001). Betweenness centrality is calculated for a particular node i by first finding the shortest paths (or geodesic paths) between all other pairs of nodes in the network, and then summing up the proportion of those paths that passes through node i. This measure is a perfect fit for our investigation as it can be used to measure the influence of individuals through their capacity to facilitate or hinder communication flows within a network organisation. As remarked by Freeman: "when a person is strategically located on the communication paths..., that person... can influence the group by information withholding or distorting in transmission" (1979:221).

Because we are working with an affiliation network, we also compute a version of betweenness centrality that is suitable for bipartite graphs (see, for example, Borgatti & Everett, 1997; Faust, 1997; Borgatti & Halgin, 2011). Bipartite betweenness centrality is calculated by first computing "standard" betweenness centrality and then applying a separate normalisation to each set of nodes reflecting the fact that the maximum betweenness centrality that a node in a bipartite network can achieve will be a function of the number of nodes in each mode of the network. In our example, we found that "standard" and bipartite betweenness centrality differed in only the 4th decimal place for all nodes and provided an almost identical ranking of participants (the normalisation factors were very close to the factor used in calculating standard betweenness, due to the fact there is a large disparity in the number of nodes in each mode). Because standard and bipartite betweenness do not differ for our network, from now on, we refer to them jointly with the generic name of betweenness. Finally, since we are most interested in how participants act as local bridges (making connections between pairs of workstreams), we also computed 2-step betweenness centrality (also known as 2-betweenness), taking into consideration only geodesic paths of length two (Borgatti & Everett, 2005; Brandes, 2008).

None of these versions of betweenness centrality, however, allow us to distinguish the different types of bridging discussed above, because they do not consider the different nature of the workstreams to which individuals are affiliated. Our objective is to measure bridgeness of individuals on three dimensions reflecting the nature of the pairs of workstreams that they bridge:

1. *Temporal bridgeness* – the property of being affiliated to workstreams of the same function and of the same WG but during different ARs (i.e., two or more cells in the same row of table 1).
2. *Functional bridgeness* – the property of being affiliated to workstreams of different function during the same AR (i.e., one cell in the first three rows and one cell in the last row of table 1 within the same column).
3. *Thematic bridgeness* – the property of being affiliated to workstreams of different WGs during the same AR (i.e., two cells in the first three rows of table 1 within the same column).

We do *not* consider *mixed bridgeness* – the property of having participated in different ARs with different functions or in different WGs (i.e., two or more cells not aligned in one row or column of table 1). The complexity of the definitions of our three dimensions of bridgeness makes it difficult to measure them using the three versions of betweenness centrality discussed above.

The easiest way of computing this threefold bridgeness is to count the number of pairs of workstreams directly bridged by each IPCC participant, distinguishing these pairs according to the definitions just provided. This solution, however, does not account for the fact that some pairs of workstreams are more rarely bridged than others. Considering thematic bridgeness, for instance, there is a much rarer interlock between WG1 and WG3 (with only 18 individuals having served in both during the same AR, in the first five IPCC's assessments) than between WG1 and WG2 (with 96 thematic bridges) or WG2 and WG3 (with 51 thematic bridges).

To account for these differences, we weigh the sum of the number of workstream pairs bridged by an individual by the dissimilarity of those pairs (based on the number of bridging individuals they share in common). The Jaccard index is a classic measure of similarity of two sets: in our example the sets are the network neighbors (individuals) of the workstream pairs, and we therefore use the inverse of the Jaccard index (Jaccard distance) as the weight in the construction of our measure of bridgeness. In other words, we define the Jaccard bridgeness (JB) of an individual α as the summation, for each pair of workstreams i, j bridged by α, of the size of the union of their neighbours divided by the size of the intersection of their neighbours.

$$J(\alpha) = \sum_{i,j} \frac{|\,neighbours(i) \cup neighbours(j)\,|}{|\,neighbours(i) \cap neighbours(j)\,|}$$

$$= \sum_{i,j} \frac{1}{Jaccard(neighbours(i), neighbours(j))}$$

Being defined as a weighted sum of the number of pairs of workstreams bridged by an individual, our measure is correlated with the degree of the individual in the bipartite network (the number workstreams this individual is affiliated with). However, because each workstream pair is weighted by their inverse Jaccard distance, Jaccard bridgeness offers a more nuanced way of identifying the individuals occupying key bridging positions in our complex organisation, measured by their ability to connect workstreams that few or perhaps no other individuals are bridging[9]. Because Jaccard bridgeness is computed for each pair of workstreams bridged by an individual, it can be easily decomposed into three dimensions – temporal, functional and thematic – defined above. And, since we excluded mixed bridgeness from our definition, the sum of the three components is equal to the overall Jaccard bridgeness of a given individual.

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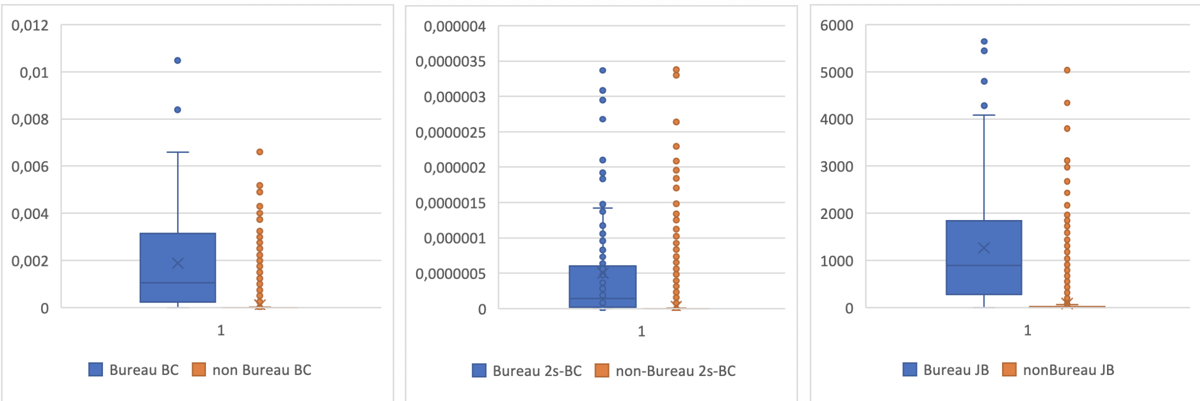
[9] Note that our measure of bipartite bridgeness is also a direct implementation of the idea of "weak ties" imagined by Granovetter in the article cited in the introduction of this paper:

> Consider, now, any two arbitrarily selected individuals-call them A and B-and the set, S = C, D, E, ... , of all persons with ties to either or both of them. The hypothesis which enables us to relate dyadic ties to larger structures is: the stronger the tie between A and B, the larger the proportion of individuals in S to whom they will both be tied, that is, connected by a weak or strong tie. This overlap in their friendship circles is predicted to be least when their tie is absent, most when it is strong, and intermediate when it is weak. (Granovetter, 1973:1362).

Metrics validation

Before we move to discuss the ranking provided by the three measures we considered – betweenness centrality (BC)[10], 2-step betweenness (2s-BC) and Jaccard bridgeness (JB) – we should provide some evidence that these metrics do indeed capture the kind of organisational bridgeness we are interested in. We derive this evidence from the comparison with another piece of information which we have not yet exploited. In table 1, we purposely omitted another crucial role in the IPCC: that of Bureau members. The Bureau supervises the work of the IPCC and its members are selected by the Member states at the beginning of each evaluation cycle. Having held back the information about Bureau membership in our network, we can now use it to validate our measures of bridgeness. Because Bureau members are in charge of coordinating the work of the IPCC, we expect them to have on average a higher bridging score than other IPCC members. On the one hand, their election to the IPCC leadership is facilitated by a long and varied engagement with the organisation. On the other hand, their role necessitates involvement in different divisions of the organisation. Indeed, we find that most Bureau members are also bridges: 88% of Bureau members have BC and 2s-BC>0 and 87 have JB>0, against only 27% and 25% of all the other participants. Even focusing exclusively on the sub-population of Bureau members and non-Bureau members that are bridges, average BC, 2s-BC and JB are considerably higher for Bureau (avg-BC = 0,002, avg-2s-BC = 6E-07 and avg-JB = 1450) than for non-Bureau (avg-BC = 0,0001, avg-2s-BC = 1E-07 and avg-JB = 334). The distributions of the two populations (figure 2) convey the same idea.

Figure 2. Boxplots of the distribution of Bureau members and non-Bureau members according to betweenness centrality (BC left), 2-step betweenness centrality (2s-BC) and Jaccard bridgeness (JB right).



We can also test the capacity of BC, 2s-BC and JB to discriminate between Bureau members and non-Bureau members in two other ways. First, we can rank all IPCC participants by both metrics and compute the average ranking of Bureau and non-Bureau. Because Bureau members have the official role of bridging the different subparts of the IPCC, they should rank consistently higher than all other participants according to our metrics – a significant difference between Bureau average ranking and non-Bureau average ranking should therefore confirm the value of our metrics as proxies for bridgeness. Second, we can use the test of the area under the ROC curve, a standard in machine learning literature (Mandrekar, 2010). The results presented in table 2 (which includes degree for comparison) confirm the excellent discrimination capacity of all bridgeness metrics.

[10] Note that since betweenness centrality and bipartite betweenness centrality were almost identical in our example, we do not present bipartite betweenness centrality in what follows.

Table 2. Comparing degree, betweenness centrality, 2-step betweenness and Jaccard bridgeness by their capacity to discriminate Bureau members.

	Difference of average ranking of Bureau and non-Bureau	Area under the ROC curve
Degree	2030	0.855
Betweenness	2132	0.874
2-step betweenness	2082	0.866
Jaccard bridgeness	2141	0.874

Being normalized tests, both the difference of the average ranking and the area under the ROC curve can also be used to compare the performance of BC, 2s-BC and JB. The comparison reveals that (for our purpose and our network) Jaccard bridgeness works as well as the measures of betweenness centrality, while having the advantage of being easily decomposed in its temporal, functional and thematic dimensions.

Results and discussion

Having validated our metrics of bridgeness, we can now use them to investigate the practices of bridging in the IPCC. We start by considering the general evolution of the different practices of bridging through the five assessment cycles completed by the organisation, we then move to consider the individual participants who are highest ranked according to the different metrics of bridgeness and finally we zoom in on the bridges of the last IPCC assessment cycle (AR5).

Temporal evolution of bridging in the IPCC

Tables 3 and 4 display the number of bridge participants connecting different functional (top half of table 3), thematic (bottom half of table 3) and temporal divisions of the IPCC (table 4). The cells of both tables are colored according to the same heatmap color scheme in order to reveal the most common types of bridges (the darker the background, the higher is the percentage of that type of bridge over the total number of participants for the corresponding AR).

Overall, the comparison between the two tables shows a greater presence of temporal bridges than of functional and thematic ones. In total, our dataset contains 1316 temporal bridges, 318 functional bridges and only 226 thematic bridges. The first finding of our analysis is therefore that the type of bridging explicitly encouraged by the organisation and acknowledged in its procedures, the thematic one, is the least common in our dataset.

Table 3. Number and percentage of functional (top half of the table) and thematic bridges (bottom half) in general and between different workstreams pairs over the total of individuals who contributed to each of the five assessment cycles (a darker background a indicates higher ratio, the colour scale is the same for table 3 and table 4).

All ARs (duplicates removed)		**AR1** (772)	**AR2** (1125)	**AR3** (1344)	**AR4** (1991)	**AR5** (2495)
51	**Delegations** (4143) + **SYR** (126)	/	20 (1,8%)	13 (1,0%)	12 (0,6%)	15 (0,6%)
103	**Delegations** (4143) + **WG1** (600)	15 (1,9%)	11 (1,0%)	27 (2,0%)	37 (1,9%)	36 (1,4%)
146	**Delegations** (4143) +**WG2** (870)	15 (1,9%)	44 (3,9%)	42 (3,1%)	32 (1,6%)	38 (1,5%)
99	**Delegations** (4143) + **WG3** (611)	22 (2,8%)	12 (1,1%)	17 (1,3%)	42 (2,1%)	24 (1,0%)
318	**All functional bridges**	**49** (6,3%)	**87** (4,3%)	**82** (6,1%)	**108** (5,4%)	**97** (3,9%)
		AR1	**AR2**	**AR3**	**AR4**	**AR5**
38	**SYR** (126) + **WG1** (600)	/	6 (0,5%)	11 (0,8%)	13 (0,7%)	14 (0,6%)
50	**SYR** (126) + **WG2** (870)	/	9 (0,8%)	12 (0,9%)	13 (0,7%)	21 (0,8%)
41	**SYR** (126) + **WG3** (611)	/	7 (0,6%)	12 (0,9%)	11 (0,6%)	16 (0,6%)
81	**WG1** (600) + **WG2** (870)	9 (1,2%)	18 (1,6%)	26 (1,9%)	23 (1,2%)	20 (0,7%)
18	**WG1** (600) + **WG3** (611)	4 (0,5%)	1 (0,1%)	6 (0,4%)	1 (0,1%)	6 (0,2%)
47	**WG2** (870) + **WG3** (611)	4 (0,5%)	10 (0,9%)	12 (0,9%)	14 (0,7%)	11 (0,4%)
226	**All thematic bridges**	**17** (2,2%)	**43** (3,8%)	**73** (5,4%)	**73** (3,7%)	**75** (3,0%)

Table 3 shows that the proportion of functional and thematic bridges tends to increase in the first assessment cycles and then to decrease in the last ARs. With regard to functional bridging, this is not a surprising finding since functional bridging, contrary to thematic bridging, is generally discouraged by the IPCC, which seeks to keep "the science" separated from "diplomacy" to preserve the integrity of its assessments and avoid political interference. For instance, in its "conflict of interest policy", introduced in 2011, the organisation notes that "to prevent situations in which a conflict of interest may arise, individuals directly involved in or leading the preparation of IPCC reports should avoid being in a position to approve, adopt, or accept on behalf of any government the text in which he/she was directly involved" (IPCC, 2010:4). O'Reilly et al., 2012 discuss, for example, the case of Stefen Rahmstorf, a Lead Author of WG1 during AR4, who also sat in the German delegation during the negotiation of the Summaries for Policymakers and intervened on several statements of the report, on which he was himself an interested party.

For thematic bridges the interpretation of the peak in the percentage of bridging authors in AR3 and the decrease in the later assessment cycles may be a simple effect of the overall increase in the size of the IPCC. Looking at the absolute numbers, the thematic bridges slightly decrease from AR3 (79) to AR4 (75), but then increase again in AR5 (88). Considering cross-WG bridging, we observe a greater connection between WG1 and WG2 (96 bridges) than between WG2 and WG3 (51 bridges) and WG1 and WG3 (18 bridges). This might be explained by the fact that the work of the WGs is shifted in time with WG1 starting a few months before WG2 and half a year (or more) before WG3. Also, the disciplinary diversity of WG2 may facilitate the cooperation with the other two working groups. Keeping in mind the scarcity of bridges with WG3 is important because it significantly impacts both betweenness and Jaccard bridgeness. Often assuring a rare connection (particularly between WG1 and WG3) can propel an author high in the bridging ranking.

In general, however, thematic bridging between the WGs is challenging. As one author noted in AR4, "the three working groups were essentially sealed off from one another, so we had no idea what WGs 2 and 3 were doing. [...] Obviously, there is some physical science vs. social science snobbery in play here, just as in universities. We physical scientists in WGI tend to think that we are the 'real scientists' in IPCC and thus quite superior to the WG2 and WG3 people." (IAC, 2010:84).

Table 4. Number and percentage of temporal bridges between workstreams over the total of individuals who contributed to each of the five assessment cycles (a darker background indicates a higher ratio, the color scale is the same for table 3 and table 4).

	AR2 (1125)	**AR3** (1334)	**AR4** (1991)	**AR5** (2495)
also in AR1	103 (9,2%)	88 (6,5%)	73 (3,7%)	40 (1,6%)
also in AR2	\	200 (14,9%)	148 (7,4%)	111 (4,4%)
also in AR3		\	221 (11,1%)	168 (6,7%)
also in AR4			\	224 (9,0%)
briging from one or more previous AR	**103** (9%)	**213** (16%)	**253** (13%)	**256** (10%)
bridging as authors from previous AR (same WG)	**58** (5% - 11% of authors)	**144** (11% - 22% of authors)	**181** (9% - 25% of authors)	**183** (7% - 20% of authors)
bridging as delegates from previous AR	**51** (5% - 8% of delegates)	**85** (6% - 11% of delegates)	**94** (5% - 7% of delegates)	**101** (4% - 6% of delegates)

Table 4 shows the distribution of temporal bridges across the different ARs. Unsurprisingly, the greatest intersections exist between consecutive assessment cycles, but the table also reveals a peak of temporal bridges in AR3 (similarly to what observed for functional and thematic bridges). In the last two rows of the table, we separated authors from delegates to reveal that the former have a much lower turnover than the latter (with the exception of AR2, in all other assessments more than one fifth of authors have previous experience in the WG, compared to less than one tenth of delegates).

In general, temporal bridges are the most frequent type of bridges in our dataset and seem to play a crucial role in the IPCC, passing on the memory of past debates and controversies. Temporal bridges have a crucial influence in the assessment work and a considerable advantage over other participants, thanks to their familiarity with the codes, practices and norms of the IPCC and to their ability to navigate them. The dominance of these participants over the process, however, might also create power asymmetries and club formation (Hughes and Paterson, 2017). As argued by an IPCC author: "at least in WG2 there is a subset of authors who continue to maintain influential roles in assessment after assessment. [...] This does lead to an insider outsider problem, where a much smaller group often working in tandem with [the Technical Support Unit] TSU is actually running the show" (IAC, 2010:364). In response to this critique, the IPCC clarified its procedures in the 2010s and noted the need to reflect "a mixture of experts with and without previous experience in IPCC" in the selection of authors (IPCC, 2013:6).

Top overall bridges

Table 5 displays the top-20 bridges according to their degree, their betweenness centrality and their overall Jaccard bridgeness (left half) and by types of bridging (right half). It allows us to identify authors, Bureau members and delegates who have gained extensive experience of the assessment process and have acted as brokers between different epistemic and political communities.

Looking at the left half of table 5, it is interesting to note that the bridgeness metrics share many but not all their top-20 names, which highlight their similarity but also their difference. The degree ranks IPCC participants simply according to the number of workstreams to which they have been affiliated. Betweenness ranks them based on their global centrality in the graph and it's highly sensitive to the capacity of creating network shortcuts. 2-step betweenness is also sensible to shortcuts but consider only the workstreams to which each individual is directly affiliated. Finally, Jaccard bridgeness offers a measure that is equally local (because it only considers nodes up to two degrees of separation from each individual), and which is sensitive both to the *size of the union* of the bridged workstreams and to the *rarity of the intersection* between them[11].

[11] Because of the way participants are distributed in the IPCC affiliation matrix, the rarity of the intersection dominates the Jaccard bridgeness for the handful of workstream pairs that are bridged by one or two individuals only, while size of the union tends to weigh in for the other pairs.

Table 5. Top-20 bridges for each bridgeness metric and bridgeness type. Bureau members are in bold. Cells are highlighted in grey when the same individual occurs in the top-20 for different bridgeness metrics or when he or she appears in the ranking of different types of bridgeness. Women are in italics.

top-20 degree bridges	top-20 between. bridges	top-20 2-step bet. bridges	top-20 Jaccard bridges	top-20 thematic bridges	top-20 functional bridges	top-20 temporal bridges
Watson, R.	**Zillman, J. W.**	***Christ, R.***	**Watson, R.**	Harvey, D.	**Qin, Dahe**	**Zillman, J.W.**
Qin, Dahe	**Ding, Yihui**	**Pachauri, R.**	**Zillman, J. W.**	Van Vuuren, D.P.	**Pachauri, R.**	Abuleif, K.M.
Pachauri, R.	Abuleif, K.M.	Tirpak, D.	**Qin, Dahe**	Grubb, M.	**Pichs Madruga, R.**	Clini, C.
Houghton, J.	Clini, C.	**Parry, M.**	Harvey, D.	*House, J. I.*	**Watson, R.**	*Jorgensen*, A.M.
Zillman, J. W.	Jorgensen, A.M.	**Vellinga, P.**	**Pachauri, R.**	**Fuglestvedt, J.**	**Canziani, O.**	Penman, J.M.
Parry, M.	Penman, J.M.	**Watson, R.**	**Houghton, J.**	Kheshgi, H.S.	**Davidson, O.**	**Izrael, J. A.**
Vellinga, P.	**Izrael, J. A.**	**Lee, Hoesung**	Grubb, M.	Toth, F.L.	**Houghton, J.**	**Majeed, A.**
Bolin, B.	**Majeed, A.**	**Houghton, J.**	**Parry, M.**	**Watson, R.**	**Van Ypersele, J.P.**	**Zatari, T. M.**
Davidson, O.	**Wratt, D.**	Grubb, M.	**Vellinga, P.**	Richels, R.	**El Gizouli, I.A.**	Bodin, S.
Canziani, O.	**Watson, R.**	Lin, Erda	**Bolin, B.**	Houghton, R.A.	**Edenhofer, O.**	Miotke, J.A.
Cramer, W.	**Petit, M.**	**Wratt, D.**	**Davidson, O.**	Rasch, P.	Cramer, W.	Teuatabo, N.
Field, C.	**Pachauri, R.**	Hourcade, C.	**Canziani, O.**	Smith, S.J.	**Parry, Martin**	**Vellinga, P.**
Richels, R.	Lin, Erda	Harvey, D.	Abuleif, K.M.	Minx, J.C.	**Manning, M.**	**Watson, R.**
Fitzharris, B.	**Bolin, B.**	**Sokona, Y.**	Clini, C.	*Seyboth, K.*	**Field, Chris**	**Houghton, J.**
Marengo, J.	Cramer, W.	Oppenheimer, M.	Jorgensen, A.M.	**Bolin, B.**	Friedlingstein, P.	**Lee, Hoesung**
Mearns, L.	**Sharma, S.**	**Field, C.**	Penman, J.M.	Scholes, R.J.	**Metz, Bert**	**Ding, Yihui**
Lin, Erda	**Zatari, T. M.**	**Davidson, O.**	**Izrael, Y.**	**Vellinga, P.**	**Barros, V.**	Tirpak, D.
(27 ex aequo)	Hourcade, C.	Richels, R.	**Majeed, A.**	Jefferson, M.	**Lee, Hoesung**	Andrasko, K.
(27 ex aequo)	**Jallow, B. P.**	**Qin, Dahe**	**Lee, Hoesung**	**Davidson, O.**	**Sokona, Y.**	Kobayashi, K.
(27 ex aequo)	**Semenov, S.**	Pittock, A.B.	**Pichs Madruga, R.**	Marengo, J. *Mearns, L.*	**Stocker, T.**	**Bolin, B.** **Meira Filho, G.**

Unsurprisingly given what we have said in the section on the validation of the metrics, the right half of table 5 contains several Bureau members (in bold). Most have occupied various roles as delegate or author over several ARs. During their term, Bureau members are also generally listed as members of one or more national delegations. The first three IPCC chairmen are identified as top bridges by all measures: the Swedish, Bert Bolin, the British, Robert T. Watson, and the Indian, Rajendra K. Pachauri. The current chair, the South-Korean Hoesung Lee is ranked 19th according to the Jaccard bridgeness and is one of the 27 ex aequo in the 20th position according to degree. In general, Bureau members occupy a central role as "boundary entrepreneurs" or brokers (Bergeron et al., 2013) between the scientific and the diplomatic parts of the organisation. These individuals have multiple positions and can access resources and networks from both science and policy. Their unique positioning means that they embody much of the institutional memory of the IPCC and that their personality can facilitate or hinder the coordination of the organisation.

It is also interesting to consider the individuals who are singled out by one metric only. The 2-step betweenness, for instance, features at the top of its ranking Renate Christ, the former secretary of the IPCC. Christ has a long experience of the organisation, having been involved in its work since AR1 and as a member of the Austrian delegation. As secretary of the IPCC (2004-2015), she oversaw the activities of the secretariat, the only permanent body of the IPCC. While small (employing a dozen people), the secretariat plays a key role in facilitating the communication between the different subparts of the IPCC. Dennis Tirpak, Michael Oppenheimer (both from the United States) and Ding Yihiu (China) are also important figures in climate science and politics, who were present in the IPCC since its onset, and even before it was established (see e.g., Hecht and Tirpak, 1995).

Considering the decomposition of the Jaccard bridgeness (right half of table 5), the diversity of the three types of bridging is confirmed by the fact that most participants are only present in one ranking (white background cells). Robert Watson is a notable exception and appears to be a thematic, functional and temporal broker. He was involved in AR1, became WG2 co-chair in AR2 and IPCC chair in AR3. Besides his role as Bureau member, Watson contributed to both WG1 and WG2 reports and to the production of the SYR. After losing the election for the AR4 chairmanship, he left the IPCC and moved to biodiversity assessments, becoming the chairman of the IPBES (Arpin et al., 2016).

Key thematic bridges are authors who have served as bridges between two or more WGs, and in particular between WG1 and WG3, a relatively "rare" combination in the IPCC. For instance, Danny Harvey, a professor at the Department of Geography of the University of Toronto, has contributed during AR4 to both WG3 as LA (chapter on *Buildings*) and WG1 as CA (chapter on *Understanding and Attributing Climate Change*). Detlef Van Vuuren (Netherlands Environmental Assessment Agency), Michael Grubb (University College London), Joanna House (University of Bristol), Jan Fuglestvedt (CICERO) and Haroon Kheshgi (ExxonMobile) were also all at some point cross-WG bridges between WG3 and WG1, and sometimes also WG2. The economist, Michael Grubb, professor of Energy and Climate Change at UCL, is a key figure in the IPCC, because of his long experience in the organisation (he has been involved since AR2) and his contribution to all WGs, as LA, CA or RE. He is currently a CLA of the AR6 WG3 report.

In general, Bureau members tend to be higher ranked as functional bridges than as thematic or temporal bridges. This is not surprising as, in order to be elected in the Bureau, candidates need to have both credible scientific credentials and close ties with the national delegation that nominates them. They play an important role in translating the expectations of the IPCC member states, and inversely to defend the position of the authors in the plenary sessions. Key functional bridges also include scientists who, while serving as authors, have also accompanied their delegation in one or more plenaries. This is for instance the case of Wolfgang Cramer, a geographer, ecologist and modeller working at the Institut Méditerranéen de Biodiversité et d'Ecologie Marine et Continentale. Cramer has been a key contributor to both WG1 and WG2 assessments since AR2. Previously affiliated to the Potsdam Institute for Climate Impact Research, he was scientific advisor of the German delegation in AR3 and AR5.

Temporal bridges include Bureau members and delegates who have been involved in several ARs. For instance, the meteorologist, John Zillman, has been participating in the IPCC since AR1 as head of the Australian delegation and later as Bureau member for AR2 and AR3. While serving in the Bureau, he also acted as a LA and RE in WG1. Zillman (2007; 2008) has written several articles on the history of the IPCC. Khalid Abuleif is a skilled Saudi delegate, affiliated to Saudi Aramco and the Ministry of Petroleum and Mineral Resources, who has been involved in all five assessment cycles. He is also the current IPCC "focal point" for Saudi Arabia, the reference person between the IPCC secretariat and the member states. Another Saudi with much experience of the IPCC process is Taha Zatari. He was the focal point between 2005 and 2012 and a three-time Bureau member in AR4, AR5 and AR6. Finally, Clini Corrado (Italy), Anne Mette Jorgensen (Denmark) and Jim Penman (UK) are all highly ranked because they were present (at least once) as delegates in all five assessment cycles.

Top AR5 bridges

In AR5, we noted 75 thematic and 97 functional bridges. Besides, 10% of the participants had previous experience of the IPCC process (20% of the authors and 6% of the delegates).

Table 6. Top-20 bridges for each bridgeness type for AR5. Bureau members are in bold. Women are in italics and the country of affiliation is in brackets. Participants who are also participating in AR6 are marked with an asterisk.

AR5, top-20 thematic bridges	Main WG → Secondary WG	AR5, top-20 functional bridges	Role	AR5, top-20 temporal bridges	Previous ARs involvement
* Van Vuuren, D. (NL)	WG3 → WG1/2	* **Sokona, Y.** (CH)	Bureau	**Zillman, J. W.** (AU)	AR1-AR5
* *House*, J. (UK)	WG3 → WG1/2	* **Pichs Madruga, R.** (CU)	Bureau	* Abuleif, K.M. (SA)	AR2-AR5
* **Fuglestvedt, J. (NO)**	WG1 → WG3	* **El Gizouli, I.A.** (SD)	Bureau	Clini, C. (IT)	AR1-AR5
Houghton, R. A. (UK)	WG1 → WG3	**Edenhofer, O.** (DE)	Bureau	*Jorgensen*, A. M. (DK)	AR1-AR5
Rasch, P. (US)	WG1 → WG3	**Qin, Dahe** (CN)	Bureau	Penman, J. M. (US)	AR1-AR5
Smith, Steven J. (US)	WG3 → WG1	**Stocker, T.** (CH)	Bureau	**Izrael, J. A.** (RU)	AR1-AR5
* Minx, J.C. (DE)	WG3 → WG1	Friedlingstein, P. (UK)	WG1	**Majeed, A.** (MV)	AR1-AR5
Seyboth, K. (US)	WG3 → WG2	* Cramer, W. (DE)	WG2/1	* **Zatari, T.M.** (SA)	AR1-AR5
Kheshgi, H.S. (US)	WG3 → WG2	**Field, C.** (US)	Bureau	Bodin, S. (SE)	AR1-AR5
* Toth, F.L. (DE)	WG3 & WG2	* **Van Ypersele, J-P.** (BE)	Bureau	Miotke, J.A. (US)	AR1/3/5
* Patt, A. (AT)	WG3 → WG2	**Barros, V.** (AR)	Bureau	Teuatabo, N.(KI)	AR1/3/5
Porter, J.R. (DK)	WG2 → WG3	* *Pereira, J.J* (MY)	WG2	* **Lee, Hoesung** (KR)	AR2-AR5
Zylicz, T. (PL)	WG3 → WG2	**Pachauri, R.** (IN)	Bureau	**Ding, Yihui** (CN)	AR1-AR5
Von Stechow, C. (DE)	WG3 → WG2	* **Lee, Hoesung** (KR)	Bureau	Kobayashi, K. (JP)	AR1/5
Kunreuther, H. (US)	WG3 → WG2	Meyer, L. (NL)	SYR	Fitzharris, B.B. (NZ)	AR1-AR5
(18 ex aequo)		Kwon, Won Tae (KR)	WG1	Anisimov, O.A. (RU)	AR1-AR5
		Nojiri, Y.(JP)	WG2/1	* **Semenov, S.** (RU)	AR1/3/4/5
		* Kopp, R. (US)	WG2/1	**Petit, M.** (FR)	AR2-AR5
		Shongwe, M. (ZA)	WG1/2	**Metz, Bert** (NL)	AR2-AR5
		(20 ex aequo)		**Sutamihardja, R.T.** (ID)	AR2-AR5

Most top bridges for AR5 are male scientists from the developed world (from the US, UK, Germany, the Netherlands, etc.). This does not come as a surprise, since the IPCC (and the science in general) is known to be dominated by experts from the Global North (Ho-Lem et al. 2011) and men (Gay-Antaki and Liverman, 2018).

The top thematic bridges of AR5 create important connections between WG3 and WG1 and between WG3 and WG2. Detlef van Vuuren and the Joana House stand out as bridges between the three WGs. Van Vurren is a senior researcher at the Netherlands Environmental Assessment Agency and a professor in integrated assessment of global environmental change at Utrecht University. Involved in the IPCC since AR4, he became LA in AR5 in one of the key chapters of WG3 (*Assessing Transformation Pathways*) and also participated in the production of the SYR. In AR5, he is also listed as CA in WG1 (chapter 6) and WG2 (chapter 9). According to Hughes and Paterson (2017), Van Vuuren is among the authors whose careers are organized around producing knowledge for IPCC reports. Joanna House, one of the very few female bridges in our dataset, also ranks high because of her multiple CA roles. Besides being LA in WG3 chapter 11 (Agriculture, Forestry and other Land Use), she served as CA in WG1 (chapter 6), WG2 (chapter 18) and WG3 (chapter 14). House is a reader in Environmental Science and Policy at Bristol University and has been involved in the IPCC since AR3. Both van Vuuren and House are involved in the preparation of AR6.

As already observed previously, most of the top functional bridges are members of the AR5 Bureau – the WG3 co-chairs (Sokona, Pichs Madruga, Edenhofer) are particularly highly ranked. A few AR5 authors are also identified as functional bridges because they have occasionally accompanied the delegation of their country. This is the case of Pierre Friedlingstein and Wolfgang Cramer. Friedlingstein holds a Chair in Mathematical Modelling of the Climate System at the University of Exeter. He has been involved in the IPCC since AR3. In AR5, he has been LA in WG1 and SYR. He attended several IPCC plenary sessions as part of the French delegation in 2007 and 2008, when he was employed at the Institut Pierre Simon Laplace. Leo Meyer, a physical chemist who worked for many years at the PBL, also attended many plenary sessions in AR5 as head of the SYR Technical Support Unit (TSU). In AR4, he headed the WG3 TSU and was a member of the Dutch delegation.

The top temporal bridges of AR5 are delegates and authors with considerable experience of the IPCC process, sometimes having participated in all five assessment cycles. It is interesting to note that many of those bridges are not involved in the new AR6 cycle, most probably due to their age – most of them actually left the IPCC after the election of the AR5 Bureau in 2008. After more than 30 years of existence, it does not come as a surprise that a new generation of participants is taking over.

The question of bridging has gained even more attention in AR6 and it was a key topic in the run up of the election of the new Bureau (De Pryck and Wanneau, 2017). Jean-Pascal van Ypersele, running for the chairmanship, for instance claimed that he would work to "stimulate real collaboration and knowledge sharing across as many interfaces as possible: science-policy; IPCC-government Members of IPCC, IPCC-other institutions [...]; IPCC-stakeholders, discipline-discipline; people-people[12]". The integration between WGs in particular took center stage in the process of selecting the AR6 authors. The importance of choosing scientists capable of creating connections across WGs has been carefully considered by the co-chairs of the three WGs. They noted the need to invite authors from other WGs as CA, to establish ad-hoc task groups across WGs and to encourage "handshakes" among WGs. In this context, it should not come as a surprise that several of the top thematic bridges in AR5 have been nominated as authors for the AR6 cycle.

Conclusion

In this paper, we investigated the relational architecture of a particularly influential organisation in the international climate regime: the *Intergovernmental Panel on Climate Change* (IPCC). The IPCC is an interesting case study not only for its crucial role of "trading zone" (Collins et al., 2007) between the sciences of climate change and national and international policymaking, but also for its capacity to survive and prosper for more than thirty years despite its relatively light institutional structure. The IPCC produces its expert assessments, drawing on the voluntary contributions of a multitude of participants who maintain their primary affiliation to other institutions and are, in most cases, replaced at every new assessment cycle.

Besides its work practices and bureaucratic procedures, the IPCC owes its persistence and coordination to the few individuals that remained in the organisation for several assessments, or that served in more than one of its working groups, or who contributed to its operations simultaneously as scientific experts and as national delegates. These bridge individuals play a crucial role in the IPCC stabilizing its complex architecture and gluing together it's different (and otherwise quite independent) subparts. To identify these bridge individuals, we used and compared various metrics of betweenness. As we illustrated using a database of the eight thousand individuals who contributed to the IPCC since

[12] Available here: https://vanyp.elic.ucl.ac.be/assets/teclim/vanyp/docs/platform/JPvY_platform_EN.pdf

its foundation, this approach allows us to reveal various types of bridge and the way in which they help keep the organisation together.

Our analysis allowed us to single out the scientists who have facilitated the exchange of information between the three working groups of the IPCC, thus mitigating some of the shortcomings of their thematic and disciplinary division, which have been recognized as a potential source of errors and inconsistencies in the reports. Besides these thematic bridging, which is explicitly acknowledged and actively promoted by the IPCC, our analysis has highlighted the existence of two other forms of bridging, functional and temporal. Functional bridging – the fact of contributing to the IPCC simultaneously as an author and a delegate – is generally discouraged by the organisation, which prefers to keep its scientific and diplomatic parts separated to avoid political interferences, but we argue is nonetheless crucial to assure the smooth, discerning and diplomatic coordination of the assessment work. Finally, temporal bridging – the fact of remaining in the same position over several assessment cycles – appears as the most common type of bridging in our dataset. While the IPCC has exhibited mixed feelings about temporal bridges (praising their role, but also underlining the importance of renewing its participants to "bring new blood"), our analysis suggests that they may play a crucial role in keeping the organisation together and securing its institutional memory. Yet, as others have argued, temporal bridges may also exert too much influence on the process, preventing new ideas and views to emerge.

We believe that the protocol that we employed to investigate bipartite bridges in the IPCC can be fruitfully applied to other complex organisations that can be represented as bipartite networks of participants and workstreams.

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