

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

Tommaso Venturini ¹ Kari De Pryck ² Robert Ackland ³

1. Centre Internet et Société, CNRS, Paris, France

2. CERi Sciences Po Paris, France; Fonds national suisse

3. Australian National University, Canberra, Australia

Abstract

In this paper, we investigate 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 components. To study relational bridging within the IPCC, we created a unique database of all the individuals who have contributed to the organisation since its establishment and noted in which workstream they participated (i.e., function + Working Groups + Assessment Reports). 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 identify individuals who more actively provided connections between its authors and diplomats (functional bridges), its Working Groups (thematic bridges) and its assessment cycles (temporal bridges). Focussing on the role of key bridge individuals and their trajectories within the organisation, we provide insights on the IPCC as a network organisation.

Introduction

The Intergovernmental Panel on Climate Change (IPCC), established in 1988 under the auspices of the World Meteorological Organisation (WMO) and the UN Environment Programme (UNEP), is a fascinating institutional puzzle. Despite its gruelling mission – building a consensus on climate change between different scientific communities and world governments – the IPCC has prospered as few other international 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 (AR1) to the 5,021 pages for the fifth (AR5); the number of its authors by AR 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. Its ARs represent key scientific inputs in the negotiations under the United Nations Framework Convention on Climate Change (UNFCCC) (Fogel, 2005; Lahn & Sundqvist, 2017; Devès et al., 2017).

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 the eight thousand individuals who contributed to its assessments did it on a voluntary basis and on the payroll of other national or international institutions. More than any other international organisations

(Littoz-Monnet, 2017), the IPCC relies on external expertise rather than entrusting its activities to a group of hired scientific and technical bureaucrats. The IPCC has thus remained a ‘network organisation’, ruled by a complex architecture of rules and procedures more than by a stable bureaucratic apparatus, whose contributors are generally replaced after every assessment cycle and maintain their primary affiliation to other institutions.

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 **patterns of co-publication and institutional connections** between the authors of the IPCC Working Group (WG) III (Corbera et al., 2015; Hughes and Paterson, 2017), this paper is the first to investigate network connections within the whole organisation. We contend that the stabilisation of the IPCC in the international climate regime 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 components of the organisation or in different assessment cycles. This argument speaks to an increasing interest in studying international institutions “not just as bureaucracies [...] but as social networks and patterned sets of interactions that take on a life of their own” (Oestreich, 201, p. 168, see also Hafner-Burton et al., 2009; Morin et al., 2017).

We follow the IPCC’s own terminology by calling individuals serving in multiple positions ‘bridges’, but we note that the term also resonates with a central theme in 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 bridge 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 components of the IPCC. By providing an empirical study of the role of bridging in a complex organisation, we hope to contribute to the understanding of an international organisation that is increasingly regarded as an exemplar of multilateral scientific diplomacy (Ruffini, 2017). In doing so, we explore a key topic of discussion in the organisation, that is the integration and coordination between the different components of the IPCC – i.e., between its Working Groups (WGs), between delegates and authors and across assessment cycles (Klenk and Meehan, 2015).

Our research aims to speak to a defining claim of SNA (Scott, 1991; White, 1992; Freeman, 2004) and more generally of relational sociology (Tarde, 1893; Emirbayer, 1997; Latour, 2005): the idea that the essence of collective phenomena lies not in external structures but in the internal connections between their components. This claim is easier to defend when studying dynamics and change, but more difficult when considering continuity and persistence, which 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 relations¹ 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*².

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 components 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 divided in assessment cycles, each driven by a different leadership (the Bureau) and bound by a specific thematic outline. Since its establishment in 1988, the organisation has completed five ARs, which thus constitute the five temporal divisions of the IPCC considered in this paper. Each assessment is also subdivided in different phases (election of the Bureau, definition of the outline, selection of the authors, writing and reviewing of drafts, approval of Summaries for Policymakers, 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 ARs.

Second, the IPCC is a hybrid organisation, characterised by the cohabitation of scientists coming from different disciplines and diplomats representing different countries. Not only do these experts 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* oversee the process and make sure that its outcomes are politically relevant and acceptable (De Pryck, 2021). In this paper, we therefore consider authors and delegates as two different functional divisions of the IPCC (although, as we will see, this separation is far from clear-cut).

Third, IPCC ARs are divided into three volumes each produced by a dedicated thematic Working Group (WG): WG1 focuses on the physical basis of climate change; WG2 on impacts, adaptation and vulnerability, and WG3 on mitigation³. Because of this specialisation, the WGs tend to be composed of scientists coming from different disciplines, with a prevalence of natural scientists (climate scientists) in WG1, and of social scientists (economists) in WG3. WG2 is more diverse (Ho-Lem et al. 2011; Bjurström and Polk, 2011). Each WG is led by two co-chairs and is supported by a dedicated Technical Support Unit (TSU). Besides the volumes produced by the three WGs, IPCC reports also contain (from AR2 on) a Synthesis Report (SYR), which combines the results of the three WGs. The thematic divisions of the IPCC correspond therefore to four groups of authors responsible for the three thematic volumes and for the SYR. Each volume is subdivided into different chapters.

¹ "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).

² "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.*" (Durkheim, 1884, p. 56 in the 1982 translation, emphasis added).

³ 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 methodologies for greenhouse gas inventories.

The intersection of the three dimensions described above divides the activities of the IPCC into 24 different ‘workstreams’⁴, each defined by a particular temporal, functional and thematic combination, as illustrated by Table 1. In the context of the IPCC, two individuals are therefore affiliated to the same workstream if they share the same function in the same WG 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 in person or virtually.

Table 1. The 5 temporal, 2 functional and 3 thematic divisions of the IPCC and the 24 workstreams formed by their combinations.

Functional divisions	Thematic divisions	Temporal divisions				
		AR1	AR2	AR3	AR4	AR5
Authors	WG1	ar1-author-wg1	ar2-author-wg1	ar3-author-wg1	ar4-author-wg1	ar5-author-wg1
	WG2	ar1-author-wg2	ar2-author-wg2	ar3-author-wg2	ar4-author-wg2	ar5-author-wg2
	WG3	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

The networked structure of the IPCC is not exempt from challenges. 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 raises coordination problems that have 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 & Tanaka, 2000). The IPCC also 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 issues. It also formalised the role of so-called ‘bridge author’: a Lead Author (LA) of one WG who serves as CA in another WG in the same AR⁵.

While the official IPCC's definition focuses on **thematic bridges**, who serve in *different WGs during the same AR*, this paper also considers **functional bridges**, who serve as *author and delegate 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 recognised by the IPCC, they are key to understanding coproduction (Jasanoff, 2004) between science and diplomacy and 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.

Despite efforts to increase coordination within the organisation, integration remains challenging, notably because of an increase in the volume of the literature to be assessed and of the fact that the WGs work separately and are dismantled after each assessment cycle. The organisation has been

⁴ According to the Oxford Dictionary, a workstream is "a particular project, process, or area of operations within a business or organisation".

⁵ https://www.ipcc.ch/site/assets/uploads/2018/03/doc12_p32_wg_III_progress_report.pdf (accessed August 6, 2021)

criticised at times for issuing inconsistent and sometimes conflicting messages within and between WGs, as well as between ARs (O'Reilly et al., 2012; Beck, 2012; Gleditsch & Nordas, 2014).

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 ARs⁶ (but excluding the participation in Special Reports, SRs). We made 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 ARs, functions and WGs, 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, in this analysis, we focused on a subset of 5,554 participants that have served at least once as a delegate or as an author in a role of 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 bridges⁷.

We then organise 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 individual-to-workstream affiliations and Figure 1 provides a visual representation of our IPCC affiliation graph.⁸ We used grey versus colour to differentiate the two modes of our bipartite network (Guillaume & Latapy, 2004) and sized nodes according to their weighted degree.

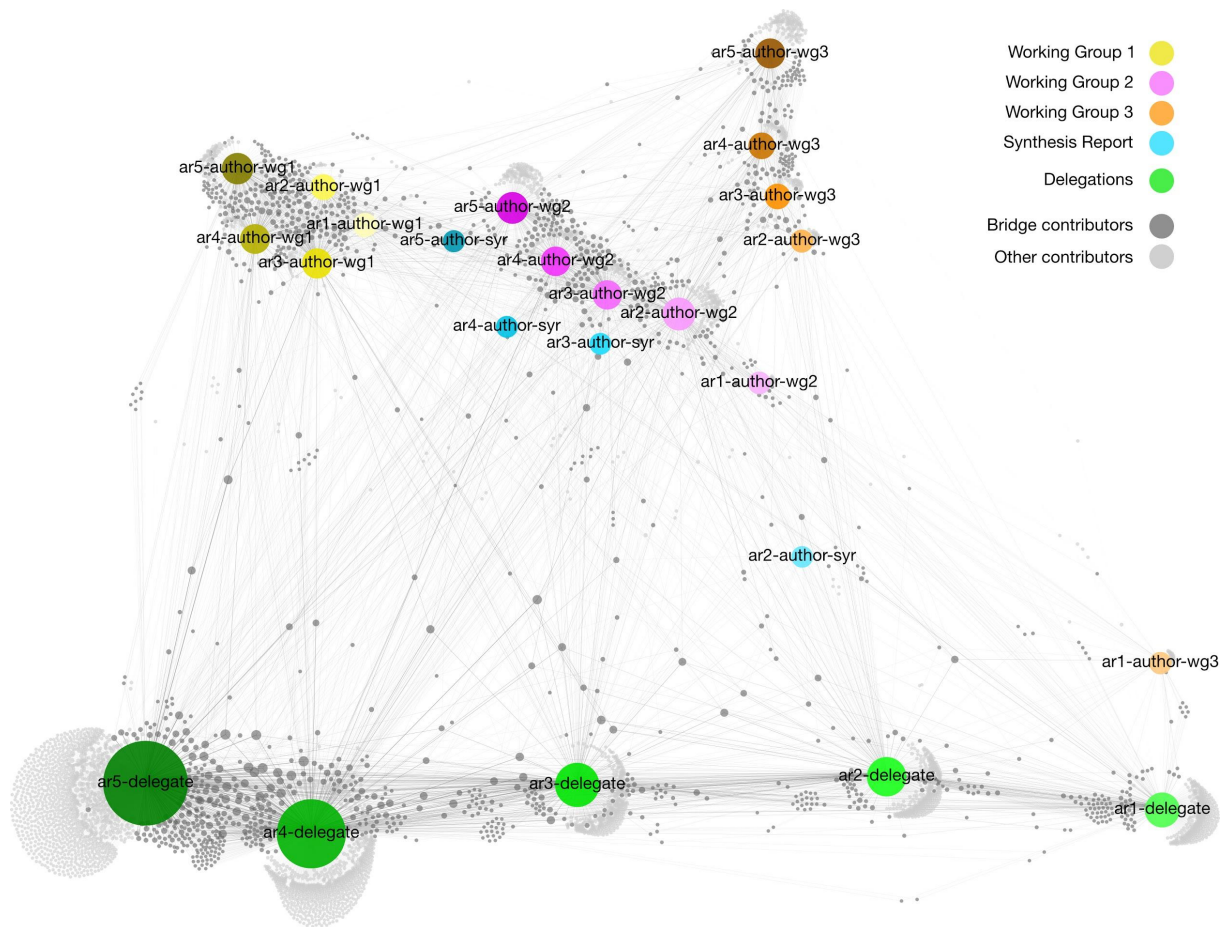
Figure 1. Bipartite network of the IPCC participants and the workstream to which they are affiliated. Nodes representing workstreams are coloured according to their functional and thematic division and are shaded

⁶ The dataset described in this paper has been initiated thanks to the support of the ANR project MEDEA and about half of it (pertaining to the authors) 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. The other half of the database (the delegates) was completed by Kari De Pryck and Tommaso Venturini.

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 delegate. We did so because our ethnographic observation revealed that these individuals are often invited as CA in other chapters or WGs, precisely to serve as thematic bridges. Likewise, individuals who played a coordination role in one assessment cycle may be invited to join the following cycle as CA to provide some form of memory and continuity (a clear form of temporal bridging).

⁸ For the purpose of the visualisation 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 plenary sessions during the same AR. Weights, however, are not used in the computation of the metrics described below.

according to temporal recency. Nodes representing participants are coloured grey, with dark grey indicating bridges. Nodes are sized according to their weighted degree.



Before moving to the 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). Above all, the clustering in the figure appears to reflect 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. WG2 is situated between WG1 and WG3, suggesting greater proximity, while WG I and WG3 are further apart. SYR authors are positioned between the three WGs, reflecting their role in providing a synthesis of the three thematic reports.

We coloured the workstream nodes according to these divisions precisely to highlight the fact that they do not mix in the force-directed layout. It is interesting to note that only the workstream ‘ar1-author-wg3’ is positioned close to the delegates’ cluster. This is because in the first AR, WG3 was mandated with the highly politicised task of recommending response strategies to climate change and involved many government officials and negotiators (Skodvin, 2000). It is also interesting to note the middle position occupied by the SYR of AR2, which is closer to the delegates than the other SYRs; this can be explained by the fact that in its first edition (the SYR being introduced in AR2), the SYR was authored mainly by members of the IPCC Bureau, many of whom were also members of their national delegation.

In contrast to the high functional and thematic clustering, the temporal division of the IPCC 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 delegates' cluster, the ARs tend to be ordered chronologically (as revealed by the ordered shading of the nodes), which indicates that more bridges exist between temporally adjacent ARs – e.g., between AR4 and AR5 delegates. It is also interesting to note that more recent authors' workstreams tend to be further away from the delegates, thus suggesting a growing separation between the two functions in the IPCC.

Bridgeness by betweenness centrality and Jaccard bridgeness

The visual inspection of our bipartite network of IPCC participants and workstreams has provided insights to investigate through 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 components. 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, p. 221).

Because we are working with an affiliation network, we also compute a version of betweenness centrality 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 find that "standard" and bipartite betweenness centrality differ in only the fourth decimal place for all nodes and provide an almost identical ranking of participants⁹. 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, however, allows 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 within 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).

⁹ The normalisation factors used to calculate bipartite betweenness centrality 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.

3. *Thematic bridgeness* – the property of being affiliated to workstreams of different WGs during the same AR (i.e., two cells in the first four 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 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 assessments) than between WG1 and WG2 (with 96 thematic bridges) or WG2 and WG3 (with 51 thematic bridges).

To account for these differences, we weight 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). The Jaccard index (Jaccard, 1912) is a classic measure of similarity of two sets: in our example, the sets are the network neighbours (individuals) of the workstream pairs, and we therefore use the inverse of the Jaccard index 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 their intersection

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

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

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 individuals (the number workstreams individuals are affiliated with). However, thanks to the weighting by inverse Jaccard index, 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 bridging¹⁰. 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.

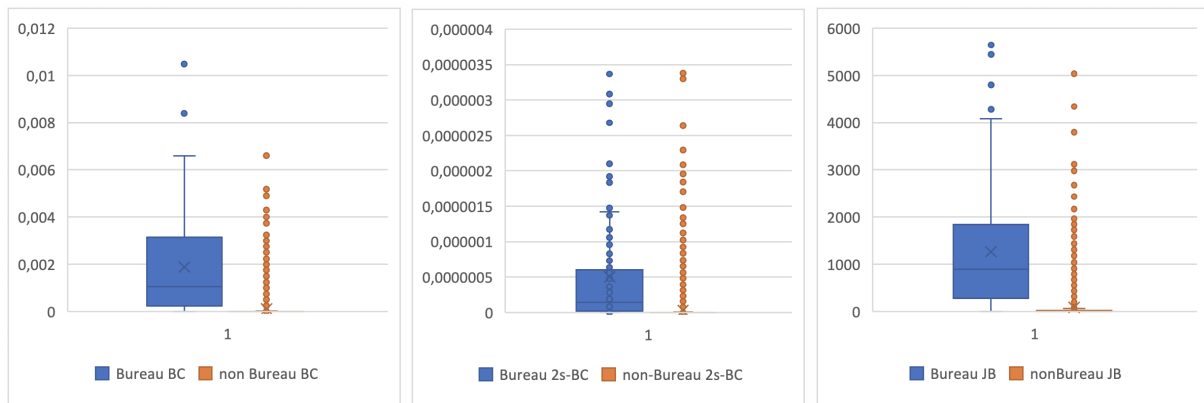
¹⁰ Note that our measure of bipartite bridgeness is also a direct implementation of the idea of "weak ties" imagined by Granovetter in the article cited in the introduction of this paper:

Consider, now, any two arbitrarily selected individuals-call them A and B-and the set, $S = C, D, E, \dots$, 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)¹¹, 2-step betweenness (2s-BC) and Jaccard bridgeness (JB) – we should provide 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 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, 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 generally 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 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 each metric and compute the average ranking of Bureau and non-Bureau. Because Bureau members have the official role of bridging the different components of the IPCC, they should rank consistently higher than other participants. 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 compute the area under the ROC curve, a standard test 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.

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

¹¹ 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.

	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 normalised 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 these practices through the five ARs, we then move to consider the individuals who ranked high according to the different metrics of bridgeness. Finally, we focus on the bridges of 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 coloured according to the same heatmap colour 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 IPCC, the thematic one, is the least common in our dataset.

Table 3. Number of functional (top half of the table) and thematic (bottom half) bridges. Number of bridges as a percentage of the total number of individuals who contributed to each of the five ARs is in brackets (a darker background indicates higher percentage, 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 also shows that the proportion of functional and thematic bridges tends to increase in the first ARs and then to decrease in the most recent.

With regard to functional bridging, this is not a surprising finding since this type of bridging has been over time discouraged by the IPCC, which seeks to keep its ‘scientific’ and ‘diplomatic’ parts separated 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 "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, p. 4). O'Reilly et al. (2012) discuss, for example, the case of Stefan Rahmstorf, a LA for AR4, who sat in the German delegation during the negotiation of the WG I Summary for Policymakers and intervened on several statements of the report, on which he was himself an author. In general, however, these cases are rather rare. Functional bridging is usually provided by Bureau members who lead the work of authors but are also often listed as members of the delegation that nominate them.

For thematic bridges, the interpretation of the peak in the percentage of bridging authors in AR3 and the decrease in the later ARs may be a simple effect of the overall increase in the size of the IPCC. Looking at the absolute numbers, the thematic bridges are 73 in both AR3 and AR4, and increase to 75 in AR5. Considering cross-WG bridging, we observe a greater connection between WG1 and WG2 (81 bridges) than between WG2 and WG3 (47 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 WGs. Keeping in mind the scarcity of bridges with WG3 is important as it significantly impacts both betweenness and Jaccard bridgeness. Making a rare connection (particularly between WG1 and WG3) can often propel an author high in the bridging ranking.

In general, 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 WG1 tend to think that we are the 'real scientists' in IPCC and thus quite superior to the WG2 and WG3 people." (IAC, 2010, p. 84). **Thematic bridging is also generally more demanding than functional bridging. In our definition, functional bridging only requires for authors to have accompanied a national delegation at one plenary meeting, while contributing to chapters on distant topics demands a high level of interdisciplinary expertise and a simultaneous engagement with the different WG processes¹².**

Table 4. Number of temporal bridges between workstreams. Number of bridges as a percentage of total number of individuals who contributed to each of the five ARs is in brackets (a darker background indicates a higher percentage; the colour scale is the same for Table 3 and Table 4).

¹² This might explain why thematic bridges are less common than functional one (226 to 318). This interpretation is supported by the analysis of mixed forms of bridging. As explained above, this paper only considers synchronous form of functional and thematic bridging (i.e., individuals who have served *at the same time* as authors and delegates or in different WGs). If we release this synchronicity condition and consider also forms of mixed bridges, then thematic bridges largely surpass functionals ones (649 to 418).

	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%)
bridging 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 ARs. Unsurprisingly, the greatest intersections exist between consecutive assessment cycles, but the red cells indicate there is also a peak of temporal bridges in AR3 (similarly to what we observed for functional and thematic bridges). In the last two rows of the table, we separated authors from delegates to reveal that the formers have a much lower turnover than the latter (apart from AR2, in all other assessments more than one fifth of the individuals have previous experience of the IPCC, compared to less than one tenth of delegates).

In general, temporal bridges are the most frequent type of bridge in our dataset (**1316 if we consider only the individuals who hold the exact same role through different ARs and 1435 if we consider mixed bridges as well**) 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. The dominance of these participants over the process, however, might also create asymmetries and club formation (Hughes & 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 TSU is actually running the show" (IAC, 2010, p. 364). Aware of such critique, the IPCC clarified its procedures in the 2010s noting the need to reflect "a mixture of experts with and without previous experience in IPCC" in the selection of authors (IPCC, 2013, p.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 individuals who have extensive experience of the assessment process and act as bridges 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 of their top-20 names, which highlight their similarities but also their differences. 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 is 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 local (because it only considers nodes up to two degrees of separation from each individual), and is also sensitive both to the *size of the union* of the bridged workstreams and to the *rarity of the intersection* between them¹³.

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.

¹³ 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.

	top-20 degree bridges	top-20 between. bridges	top-20 2-step bet. bridges	top-20 Jaccard bridges	top-20 Jaccard bridges (thematic)	top-20 Jaccard bridges (functional)	top-20 Jaccard bridges (temporal)
1	Watson, R.	Zillman, J. W.	<i>Christ, R.</i>	Watson, R.	Harvey, D.	Qin, Dahe	Zillman, J.W.
2	Qin, Dahe	Ding, Yihui	Pachauri, R.	Zillman, J. W.	Van Vuuren, D.P.	Pachauri, R.	Abuleif, K.M.
3	Pachauri, R.	Abuleif, K.M.	Tirpak, D.	Qin, Dahe	Grubb, M.	Pichs Madruga, R.	Clini, C.
4	Houghton, J.	Clini, C.	Parry, M.	Harvey, D.	<i>House, J. I.</i>	Watson, R.	<i>Jorgensen, A.M.</i>
5	Zillman, J. W.	<i>Jorgensen, A.M.</i>	Vellinga, P.	Pachauri, R.	Fuglestedt, J.	Canziani, O.	Penman, J.M.
6	Parry, M.	Penman, J.M.	Watson, R.	Houghton, J.	Khesghi, H.S.	Davidson, O.	Izrael, J. A.
7	Vellinga, P.	Izrael, J. A.	Lee, Hoesung	Grubb, M.	Toth, F.L.	Houghton, J.	Majeed, A.
8	Bolin, B.	Majeed, A.	Houghton, J.	Parry, M.	Watson, R.	Van Ypersele, J.P.	Zatari, T. M.
9	Davidson, O.	Wratt, D.	Grubb, M.	Vellinga, P.	Richels, R.	El Gizouli, I.A.	Bodin, S.
10	Canziani, O.	Watson, R.	Lin, Erda	Bolin, B.	Houghton, R.A.	Edenhofer, O.	Miotke, J.A.
11	Cramer, W.	Petit, M.	Wratt, D.	Davidson, O.	Rasch, P.	Cramer, W.	Teuatabo, N.
12	Field, C.	Pachauri, R.	Hourcade, C.	Canziani, O.	Smith, S.J.	Parry, M.	Vellinga, P.
13	Richels, R.	Lin, Erda	Harvey, D.	Abuleif, K.M.	Minx, J.C.	Manning, M.	Watson, R.
14	Fitzharris, B.	Bolin, B.	Sokona, Y.	Clini, C.	<i>Seyboth, K.</i>	Field, Chris	Houghton, J.
15	Marengo, J.	Cramer, W.	Oppenheimer, M.	Jorgensen, A.M.	Bolin, B.	Friedlingstein, P.	Lee, Hoesung
16	<i>Mearns, L.</i>	Sharma, S.	Field, C.	Penman, J.M.	Scholes, R.J.	Metz, Bert	Ding, Yihui
17	Lin, Erda	Zatari, T. M.	Davidson, O.	Izrael, Y.	Vellinga, P.	Barros, V.	Tirpak, D.
18	(27 ex aequo)	Hourcade, C.	Richels, R.	Majeed, A.	Jefferson, M.	Lee, Hoesung	Andrasko, K.
19	(27 ex aequo)	Jallow, B. P.	Qin, Dahe	Lee, Hoesung	Davidson, O.	Sokona, Y.	Kobayashi, K.
20	(27 ex aequo)	Semenov, S.	Pittock, A.B.	Pichs Madruga, R.	Marengo, J. <i>Mearns, L.</i>	Stocker, T.	Bolin, B. Meira Filho, G.

Given the above discussion on the validation of the metrics, it is not surprising that Table 5 contains many Bureau members (in bold). Most have occupied various roles as delegate or author over several ARs. 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 brokers 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 also means that they embody much of the institutional memory of the IPCC.

It is also interesting to consider the individuals who are singled out by one metric only. Renate Christ, the former secretary of the IPCC, is top-ranked on the basis of 2-step betweenness. Christ has a long experience of the organisation, having been involved since AR1 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 components of the IPCC. Dennis Tirpak, Michael Oppenheimer (both from the United States) and Ding Yihui (China) are also important figures in climate science and politics, who pushed the climate agenda long before the establishment of the IPCC (see e.g., Hecht & Tirpak, 1995).

With regard to the decomposition of 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 as a thematic, functional and temporal bridge. He was involved in AR1 as author, 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 (University of Toronto) has contributed during AR4 to both WG3 (as LA of Chapter 6 on *Residential and commercial buildings*) and WG1 (as CA of Chapter 9 on *Understanding and Attributing Climate Change*). Harvey holds a PhD in climate modelling and publishes extensively on energy and climate change. Detlef Van Vuuren (Netherlands Environmental Assessment Agency), Michael Grubb (University College London), Joanna I. House (University of Bristol), Jan Fuglestad (CICERO) and Haroon Kheshgi (ExxonMobile) were also all at some point cross-WG bridges between WG3 and WG1, and sometimes also WG2. As an economist with experience in policy advice, Michael Grubb, professor at the University College London (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 to the Bureau, candidates need to have both credible scientific credentials and close ties with the government that nominates them. They play an important role in translating the expectations of the IPCC member states and in defending 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. While affiliated to the Potsdam Institute for Climate Impact Research (PIK) in AR3 and AR5, he was also scientific advisor of the German delegation.

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 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, 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 government representative in all five assessment cycles.

Top AR5 bridges

We identified 75 thematic and 97 functional bridges in AR5 (Table 3). 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 the AR6 cycle as author, delegate or member of the secretariat are marked with an asterisk.

Top-20 thematic bridges	Main and secondary WG	Top-20 functional bridges	Role	Top-20 temporal bridges	Previous involvement
* Van Vuuren, D. (NL)	WG3 → WG1/II	* Sokona, Y. (CH)	Bureau	Zillman, J. W. (AU)	AR1-5
* House, J.I. (UK)	WG3 → WG1/II	* Pichs Madruga, R. (CU)	Bureau	* Abuleif, K.M. (SA)	AR2-5
* Fuglestad, J. (NO)	WG1 → WG3	* El Gizouli, I.A. (SD)	Bureau	Clini, C. (IT)	AR1-5
Houghton, R.A. (UK)	WG1 → WG3	Edenhofer, O. (DE)	Bureau	<i>Jorgensen, A.M.</i> (DK)	AR1-5
Rasch, P. (US)	WG1 → WG3	Qin, Dahe (CN)	Bureau	Penman, J.M. (US)	AR1-5
Smith, Steven J. (US)	WG3 → WG1	Stocker, T. (CH)	Bureau	Izrael, J.A. (RU)	AR1-5
* Minx, J.C. (DE)	WG3 → WG1	Friedlingstein, P. (UK)	WG1	* Majeed, A. (MV)	AR1-5
<i>Seyboth, K.</i> (US)	WG3 → WG2	* Cramer, W. (DE)	WG2/I	* Zatari, T.M. (SA)	AR1-5
Kheshgi, H.S. (US)	WG3 → WG2	Field, C. (US)	Bureau	Bodin, S. (SE)	AR1-5
* 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	* <i>Pereira, J.J</i> (MY)	WG2	* Lee, Hoesung (KR)	AR2-5
Zylicz, T. (PL)	WG3 → WG2	Pachauri, R. (IN)	Bureau	Ding, Yihui (CN)	AR1-5
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)	AR1-5
(18 ex aequo)		* Kwon, Won Tae (KR)	WG1	* Anisimov, O.A. (RU)	AR1-5
		Nojiri, Y. (JP)	WG2/I	* Semenov, S. (RU)	AR1/3/4/5
		* Kopp, R. (US)	WG2/I	Petit, M. (FR)	AR2-5
		* Shongwe, M. (ZA)	WG1/II	Metz, Bert (NL)	AR2-5
		(20 ex aequo)		Sutamihardja, R.T. (ID)	AR2-5

Table 6 shows that 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 climate science in general) is known to be dominated by male experts (Gay-Antaki and Liverman, 2018) from the Global North (Ho-Lem et al. 2011).

The top thematic bridges of AR5 create important connections between WG3 and WG1 and between WG3 and WG2. Detlef van Vuuren and Joanna I. House stand out as bridges between the three WGs. Van Vuuren is a senior researcher at the Netherlands Environmental Assessment Agency (PBL) 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 (Chapter 6 on *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). In Hughes and Paterson's analysis (2017), Van Vuuren is among the WG III authors whose careers are organised around producing knowledge for IPCC reports. Joanna I. House, one of the very few female bridges in our study, 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 observed previously, most of the top functional bridges are members of the AR5 Bureau – the WG3 co-chairs (Youba Sokona, Ramon Pichs Madruga, Ottmar 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 was LA in WG1 and in the 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 (IPSL). 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, with some having participated in all five assessment cycles. It is interesting to note that many of those bridges (e.g., Zillman, Jorgensen, James M. Penman, Yuri Izrael) are not involved in the new AR6 cycle, most probably due to their age (many left the IPCC after the election of the AR5 Bureau in 2008). This may suggest that, after more than 30 years of existence, a new generation of scientists and diplomats is taking over the IPCC.

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 & Wanneau, 2017). In running for the chairmanship Jean-Pascal van Ypersele, 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-people¹⁴”. The integration between WGs took also centre 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’ between 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 science and politics of climate change, 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 after every assessment cycle.

Besides its work practices and bureaucratic procedures, the IPCC owes, we argued, its persistence and coordination to the individuals that remained in the organisation for several assessments, or that served in more than one of its WGs, or who contributed to its activities as author and as delegate. These bridging individuals play a crucial role in the IPCC, stabilising its complex architecture and gluing together its different (and otherwise quite independent) components. **If the IPCC is an extreme example in this respect, all complex organisations, whose activities are divided in separated departments, divisions or groups face similar coordination challenges, and often solve them by asking some members to occupy different roles at the same time. “Multipositionality”, i.e., the capacity to cumulate and combine different positions, has long been studied in sociology as a source of power (Boltanski, 1973; Bourdieu & Boltanski, 1973; Robert, 2010) and has recently been investigated with the tools of social network analysis (see the contributions in Argibay & Lemercier eds., 2013).**

¹⁴ Available here: https://vanyp.elic.ucl.ac.be/assets/teclim/vanyp/docs/platform/JPvY_platform_EN.pdf

In line with such relational approach to multipositionality, this paper compared various metrics of betweenness (including both classic metrics and a new measure of Jaccard bridgeness which allows for a decomposition of bridging type), computing them on an affiliation network extracted from a database of the eight thousand individuals who contributed to the IPCC since its foundation. This approach allowed us to reveal various types of bridges and confirmed the connection between multipositionality and power, showing how most IPCC leaders have held multiple roles in the organisation. Our objective, however, was less to investigate multipositionality as a source of sway than as the relational glue that allows network organisations like the IPCC to act in a (more or less) coordinated way.

Our analysis allowed us to single out the scientists who have facilitated the exchange of information between the three WGs of the IPCC, thus mitigating some of the shortcomings of their disciplinary division, which have been recognised as a potential source of errors and inconsistencies. Besides this thematic bridging, which is explicitly acknowledged and actively promoted by the IPCC, our analysis highlighted the existence of two other forms of bridging, functional and temporal. Functional bridging – the act of contributing to the IPCC simultaneously as author and delegate – is generally discouraged by the organisation but remains nonetheless crucial to assure the smooth and discerning coproduction of the assessment work. Finally, temporal bridging – the act 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 also 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. The fact that temporal bridges are, by far, the most common type of bridges in the IPCC (four time more numerous than functional bridges and almost six times more numerous than thematic bridges) supports our argument that, in contrast with structuralist social theories, social persistence may rely on repetition and temporal bonding rather than on a stable bureaucratic apparatus.

This conclusion, of course, cannot be validated using only the case of the IPCC. The method that we employed to investigate bipartite bridges in the IPCC, however, can be easily applied to other complex organisations that can be represented as bipartite networks of participants and workstreams and we hope that further investigations will confirm our intuition.

References

- Allen, M.P., 1974. Interlocking Corporate Directorates. *Am. Sociol. Rev.* 39, 393–406.
- Argibay, C., Lemerrier, C., 2013. Network Analysis: A Method for Political Science., in: 12th Congrès de l’Association Française de Science Politique. AFSP, Paris.
- Arpin, I., Barbier, M., Ollivier, G., Granjou, C., 2016. Institutional entrepreneurship and techniques of inclusiveness in the creation of the Intergovernmental Platform on Biodiversity and Ecosystem Services. *Ecol. Soc.* 21, art11. <https://doi.org/10.5751/ES-08644-210411>
- Beck, S., 2012. Between Tribalism and Trust: The IPCC Under the “Public Microscope.” *Nat. Cult.* 7, 151–173. <https://doi.org/10.3167/nc.2012.070203>
- Bjurström, A., Polk, M., 2011. Physical and economic bias in climate change research: a scientometric study of IPCC Third Assessment Report. *Clim. Change* 108, 1–22. <https://doi.org/10.1007/s10584-011-0018-8>
- Boltanski, L., 1973. L’espace positionnel : multiplicité des positions institutionnelles et habitus de classe. *Rev. française Sociol.* 14, 3–26. <https://doi.org/10.2307/3320321>
- Borgatti, S.P., Everett, M.G., 1997. Network Analysis of 2-Mode Data. *Soc. Networks* 19, 243–269. https://doi.org/10.1007/978-3-658-21742-6_16
- Borgatti, S.P., Everett, M.G., 2005. A Graph-Theoretic Perspective on Centrality. *Soc. Networks* 28, 466–484.

- Borgatti, S.P., Halgin, D.S., 2011. Analyzing Affiliation Networks, in: Scott, J., Carrington, P. (Eds.), *The SAGE Handbook of Social Network Analysis*. Sage, London, pp. 417–433.
<https://doi.org/10.4135/9781446294413.n28>
- Bourdieu, P., Boltanski, L., 1976. La production de l'idéologie dominante. *Actes la Rech. en Sci. Soc. Année 2*, 3–73.
- Brandes, U., 2008. On variants of shortest-path betweenness centrality and their generic computation. *Soc. Networks* 30, 136–145. <https://doi.org/10.1016/j.socnet.2007.11.001>
- Brandes, U., 2001. A faster algorithm for betweenness centrality. *J. Math. Sociol.* 25, 163–177.
<https://doi.org/10.1080/0022250X.2001.9990249>
- Burt, R.S., 2005. *Brokerage & Closure: An Introduction to Social Capital*. University Press, Oxford.
- Burt, R.S., Kilduff, M., Tasselli, S., 2013. Social Network Analysis: Foundations and Frontiers on Advantage. *Annu. Rev. Psychol.* 64, 527–547. <https://doi.org/10.1146/annurev-psych-113011-143828>
- Collins, H., Evans, R., Gorman, M., 2007. Trading zones and interactional expertise. *Stud. Hist. Philos. Sci. Part A* 38, 657–666. <https://doi.org/10.1016/j.shpsa.2007.09.003>
- Corbera, E., Calvet-Mir, L., Hughes, H., Paterson, M., 2015. Patterns of authorship in the IPCC Working Group III report. *Nat. Clim. Chang.* 6, 1–7. <https://doi.org/10.1038/nclimate2782>
- De Pryck, K., 2021. Intergovernmental Expert Consensus in the Making. The case of the Summary for Policymakers of the IPCC 2014 Synthesis Report. *Glob. Environ. Polit.*
- De Pryck, K., Wanneau, K., 2017. (Anti)-boundary work in global environmental change research and assessment. *Environ. Sci. Policy*. <https://doi.org/10.1016/j.envsci.2017.03.012>
- Devès, M.H., Lang, M., Bourrelie, P.-H., Valérian, F., 2017. Why the IPCC should evolve in response to the UNFCCC bottom-up strategy adopted in Paris? An opinion from the French Association for Disaster Risk Reduction. *Environ. Sci. Policy* 78, 142–148. <https://doi.org/10.1016/j.envsci.2017.10.001>
- Durkheim, E., 1982. *The Rules of Sociological Method* (Translation by W.D. Hall, edited by Steven Lukes). The Free Press, New York.
- Durkheim, E., 1884. *Règles de la méthode sociologique*.
- Emirbayer, M., 1997. Manifesto for a Relational Sociology. *Am. J. Sociol.* 103, 281–317.
<https://doi.org/10.1086/231209>
- Euler, L., 1736. *Solutio problematis ad geometriam situs pertinentis*. *Comment. Acad. Sci. petropolitanae* 128–140.
- Faust, K., 1997. Centrality in affiliation networks. *Soc. Networks* 19, 157–191. [https://doi.org/10.1016/S0378-8733\(96\)00300-0](https://doi.org/10.1016/S0378-8733(96)00300-0)
- Fogel, C., 2005. Biotic Carbon Sequestration and the Kyoto Protocol: The Construction of Global Knowledge by the Intergovernmental Panel on Climate Change. *Int. Environ. Agreements Polit. Law Econ.* 5, 191–210.
<https://doi.org/10.1007/s10784-005-1749-7>
- Freeman, L.C., 1979. Centrality in social networks. *Soc. Networks* 1, 215–239. [https://doi.org/10.1016/0378-8733\(78\)90021-7](https://doi.org/10.1016/0378-8733(78)90021-7)
- Freeman, L., 1977. A Set of Measures of Centrality Based on Betweenness. *Sociometry* 40, 35–41.
- Freeman, L.C., 2004. *The Development of Social Network Analysis*. Empirical Press, Vancouver.
- Gay-Antaki, M., Liverman, D., 2018. Climate for women in climate science: Women scientists and the Intergovernmental Panel on Climate Change. *Proc. Natl. Acad. Sci.* 115, 2060–2065.
<https://doi.org/10.1073/pnas.1710271115>
- Gleditsch, N.P., Nordås, R., 2014. Conflicting messages? The IPCC on conflict and human security. *Polit. Geogr.* 43, 82–90. <https://doi.org/10.1016/j.polgeo.2014.08.007>
- Granovetter, M., 1973. The Strength of Weak Ties. *Am. J. Sociol.* 78, 1360–1380.
- Guillaume, J.-L., Latapy, M., 2004. Bipartite structure of all complex networks. *Inf. Process. Lett.* 90, 215–221.
<https://doi.org/10.1016/j.ipl.2004.03.007>
- Hafner-Burton, E.M., Kahler, M., Montgomery, A.H., 2009. Network Analysis for International Relations. *Int. Organ.* 63, 559–592. <https://doi.org/10.1017/S0020818309090195>
- Hecht, A.D., Tirpak, D., 1995. Framework agreement on climate change: a scientific and policy history. *Clim. Change* 29, 371–402. <https://doi.org/10.1007/BF01092424>

- Ho-Lem, C., Zerrieffi, H., Kandlikar, M., 2011. Who participates in the Intergovernmental Panel on Climate Change and why: A quantitative assessment of the national representation of authors in the Intergovernmental Panel on Climate Change. *Glob. Environ. Chang.* 21, 1308–1317. <https://doi.org/10.1016/j.gloenvcha.2011.05.007>
- Hughes, H.R., Paterson, M., 2017. Narrowing the Climate Field: The Symbolic Power of Authors in the IPCC's Assessment of Mitigation. *Rev. Policy Res.* 34, 744–766. <https://doi.org/10.1111/ropr.12255>
- IAC, 2010. Responses to the IAC Questionnaire.
- IPCC, 2010. Conflict of Interest Policy.
- IPCC, 2013. Procedures for the Preparation, Review, Acceptance, Adoption, Approval and Publication of IPCC Reports. Geneva.
- Jacomy, M., Venturini, T., Heymann, S., Bastian, M., 2014. ForceAtlas2, a Continuous Graph Layout Algorithm for Handy Network Visualization Designed for the Gephi Software. *PLoS One* 9, e98679. <https://doi.org/10.1371/journal.pone.0098679>
- Jasanoff, S., 2004. *States of Knowledge*. London.
- Klenk, N., Meehan, K., 2015. Climate change and transdisciplinary science: Problematizing the integration imperative. *Environ. Sci. Policy* 54, 160–167. <https://doi.org/10.1016/j.envsci.2015.05.017>
- Lahn, B., Sundqvist, G., 2017. Science as a “fixed point”? Quantification and boundary objects in international climate politics. *Environ. Sci. Policy* 67, 8–15. <https://doi.org/10.1016/j.envsci.2016.11.001>
- Latour, B., 2005. *Reassembling the social. An introduction to actor-network-theory*. Oxford University Press. <https://doi.org/10.1163/156913308X336453>
- Lidskog, R., Sundqvist, G., 2015. When Does Science Matter? International Relations Meets Science and Technology Studies. *Glob. Environ. Polit.* 15, 1–20. https://doi.org/10.1162/GLEP_a_00269
- Littoz-Monnet, A., 2017. *The Politics of Expertise in International Organizations*. Routledge, London.
- Mandrekar, J.N., 2010. Receiver operating characteristic curve in diagnostic test assessment. *J. Thorac. Oncol.* 5, 1315–1316. <https://doi.org/10.1097/JTO.0b013e3181ec173d>
- Moreno, J., 1934. *Who Shall Survive? Nervous and Mental Disease Publishing*, Washington, DC.
- Morin, J.-F., Louafi, S., Orsini, A., Oubenal, M., 2017. Boundary organizations in regime complexes: a social network profile of IPBES. *J. Int. Relations Dev.* 20, 543–577. <https://doi.org/10.1057/s41268-016-0006-8>
- Noack, A., 2007. Unified quality measures for clusterings, layouts, and orderings of graphs, and their application as software design criteria. Brandenburg University of Technology.
- Noack, A., 2009. Modularity clustering is force-directed layout. *Phys. Rev. E* 79, 026102. <https://doi.org/10.1103/PhysRevE.79.026102>
- O'Reilly, J., Oreskes, N., Oppenheimer, M., 2012. The rapid disintegration of projections: The West Antarctic Ice Sheet and the Intergovernmental Panel on Climate Change. *Soc. Stud. Sci.* 42, 709–731. <https://doi.org/10.1177/0306312712448130>
- Oestreich, J.E., 2011. Intergovernmental Organizations in International Relations and as Actors in World Politics, in: Reinalda, B. (Ed.), *The Ashgate Research Companion to Non-State Actors*, Farnham And Burlington. Ashgate, VT, pp. 61–172.
- Pachauri, R., Taniguchi, T., Tanaka, K., 2000. Guidance Papers on the Cross Cutting Issues of the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC).
- Robert, C., 2010. Who are the European experts? Profiles, trajectories and expert ‘careers’ of the European Commission. *French Polit.* 8, 248–274. <https://doi.org/10.1057/fp.2010.13>
- Ruffini, P.-B., 2017. *Science and Diplomacy*. Springer, New York.
- Scott, J., 1991. *Social Network Analysis*. Sage, Los Angeles.
- Skodvin, T., 2000. Structure and Agent in the Scientific Diplomacy of Climate Change. An Empirical Case Study of Science-Policy Interaction in the Intergovernmental Panel on Climate Change. Kluwer Academic Publishers, Dordrecht.
- Tarde, G., 1893. *Monadologie et sociologie. Les empêcheurs de penser en rond*, Paris.
- Venturini, T., Jacomy, M., Baneyx, A., Girard, P., 2016. Hors champs: la multipositionnalité par l'analyse des réseaux. *Réseaux* 199, 11–42. <https://doi.org/10.3917/res.199.0011>

- Venturini, T., Jacomy, M., Jensen, P., 2021. What do we see when we look at networks: Visual network analysis, relational ambiguity, and force-directed layouts. *Big Data Soc.* 8, 205395172110184. <https://doi.org/10.1177/20539517211018488>
- White, H.C., 1992. *Identity and Control. A Structural Theory of Social Action.*
- Zillman, J.W., 2007. Some Observations on the IPCC Assessment Process 1988–2007. *Energy Environ.* 18, 869–891. <https://doi.org/10.1260/095830507782616896>
- Zillman, J.W., 2008. Australian Participation in the Intergovernmental Panel on Climate Change. *Energy Environ.* 19, 21–42. <https://doi.org/10.1260/095830508783563145>