



Expert knowledge and institutional interplay: Exploring the epistemic linkages of the IPCC, IPBES, WCRP, and Future Earth

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ABSTRACT

This article investigates the potential of knowledge interplay between epistemically driven organizations representing diverse institutional epistemologies. The concept of epistemic linkage is proposed to describe the connections that facilitate knowledge-related ties between these kinds of organizations. Epistemic linkages were mapped through experts ($n = 2093$) appointed to two organizations coordinating global environmental assessment processes, the Intergovernmental Panel on Climate Change (IPCC) and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), as well as two international research platforms, the World Climate Research Programme and Future Earth. Epistemic linkages form networks that underpin structures of knowledge interplay between and within the climate change and biodiversity regimes. Structural attributes of these networks, such as polycentricity, fragmentation, and complexity, were determined through the application of social network analysis (SNA). This study evaluates the network structures' potential implications for knowledge interplay. It further illustrates the value of deliberated epistemic linkages and knowledge interplay in fostering epistemic alignment and mutual awareness. The findings reveal that epistemic linkages between IPCC and IPBES are limited, and the network is structurally constrained. The article concludes with a discussion of how the epistemic linkages have significance for coordination efforts across institutions that aim to address interconnected environmental challenges such as climate change and biodiversity loss across regimes.

1. Introduction

The dual crises of climate change and biodiversity loss demand urgent, coordinated action (Chen et al., 2021; IUCN World Conservation Congress, 2021; Pörtner et al., 2021). Scientists increasingly emphasize that addressing these complex and interconnected challenges requires not only coordinated policy responses but more collaboration across knowledge systems and disciplinary views (Pörtner et al., 2021). A growing body of International Relations (IR) literature points out that the fragmentation of governance across issue areas, such as climate change and biodiversity loss, hinders such coordination (van Asselt, 2012; van Asselt and Zelli, 2014; Oberthür, 2009, 2011; Oberthür and Stokke, 2011; Rosendal, 2001). A potential solution lies in strengthening knowledge interplay: the flow of knowledge and the pursuit of epistemic common ground across institutional boundaries (Morin et al., 2017). Yet, the climate and biodiversity regimes continue to operate largely in

parallel, with limited epistemic coordination.

The Intergovernmental Panel on Climate Change (IPCC) and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) are central sources of science-based knowledge in their respective regimes. As epistemically driven organizations, they shape policy options by framing and synthesizing knowledge (Oppenheimer et al., 2019). At first glance, they are well-positioned to strengthen their knowledge interplay and, in this way, to foster greater epistemic alignment across the climate and biodiversity domains.

However, IPCC and IPBES are ingrained in distinct institutional epistemologies – that is, differing ways of creating, validating, and using knowledge (Borie et al., 2021; Maas et al., 2021). In addition to institutional logics, their knowledge interplay is outlined by epistemic diversity: the varied worldviews that experts bring to assessment processes (Hakkarainen et al., 2020; Mäkinen-Rostedt et al., 2023). Further,

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bridging diverse knowledge systems can be hindered by asymmetries in information access and the distribution of power among stakeholders (see e.g., Borie et al., 2021; King, 2004; White and Lidskog, 2023). Far from being uniform, each institution reflects its societal objectives and disciplinary priorities, empowering certain norms and validation practices over others (Gustafsson, 2021; van der Hel, 2016; van der Hel and Biermann, 2017; Lahsen and Turnhout, 2021; Montana, 2021; Turnhout et al., 2016).

Building on both IR's focus on institutional interplay and Science and Technology Studies' (STS) observations on the performative power of knowledge (De Donà 2022; Jasanoff, 2004; Turnhout et al., 2016), this study argues that institutional fragmentation can be reduced if interplay extends from information sharing to how knowledge itself is created and validated. Research from both IR and STS suggests that coordination across knowledge systems is essential for managing complex global challenges. While IR scholarship has long highlighted information exchange as one of the key connectors between institutions (Gehring and Oberthür, 2009; Sanderink and Nasiritousi, 2020), STS research has presented that the framing and validation of knowledge fundamentally shape what is seen as viable governance solutions (Jasanoff, 2004; Turnhout et al., 2016). Yet, the interactions between IPCC and IPBES within the climate and biodiversity regimes remains unexplored, and the potential for their epistemic alignment as a source of coherence has received limited attention.

To address this, we propose the concept of 'epistemic linkage', which extends Young et al.'s (1999/2005) framework of political and functional linkages between institutions. We define epistemic linkage as encompassing both the cognitive dimension of knowledge and the processes by which knowledge is created and validated. To map epistemic linkages, we apply social network analysis (SNA) to a dataset of over 2000 experts appointed to global environmental assessment processes. In this context, epistemic linkage refers to an interinstitutional connection formed through expert's membership in assessment processes. Because institutional epistemologies establish the kind of expert communities organizations cultivate (Gustafsson, 2021), experts participating in the work of various organizations may serve as bridges, allowing knowledge, norms, and practices to flow between regimes (Böhmeit and Spilker, 2016). The connections experts form between organizations and the network structure these "co-memberships" (as in e.g., Beckfield, 2008; Greenhill and Lupu, 2017; Gomez and Parigi, 2015) make, may, according to SNA theory, foster convergence between organizations (Pattberg et al., 2018). The varying network structures have different implications for how knowledge flows within the network (Böhmeit and Spilker, 2016).

We pose two research questions:

1. Do IPCC and IPBES have epistemic linkages?
2. What structural characteristics – fragmented, polycentric, or complex – define the epistemic networks of these organizations, and how might these structures enable knowledge interplay?

The paper is organized as follows: first, by combining IR and SNA literatures, we introduce the concept of epistemic linkage and explain our analytical framework to compare structural characteristics of epistemic networks. Then, we summarize the data collection process and methods and present the results on the types of structures formed by epistemic linkages within and between the climate change and biodiversity regimes. After that, the findings are interpreted in relation to their implications for knowledge interplay between IPCC and IPBES. Finally, conclusions are drawn. It is claimed that the concept of epistemic linkage provides novel empirical insight into how epistemically driven organizations are structurally equipped to bridge knowledge gaps and may foster epistemic alignment across knowledge systems and regimes, thereby contributing to both IR and STS literatures.

2. Literature review: knowledge and institutional interplay

Institutional interplay refers to how the performance, effectiveness, or development of one institution is influenced by its interactions with another (Jinnah, 2011; Oberthür and Stokke, 2011). Scholars studying 'interlinkages', 'overlap', or 'complexity' in global governance emphasize that organizations do not function in isolation but within broader networks of relationships (Abbott et al., 2016; Elsässer et al., 2022). These connections can shape governance outcomes and influence the ability to address shared challenges (Gehring and Oberthür, 2009; van Asselt and Zelli, 2014). As Kim (2020, 914) notes, "whether a new institution contributes to fragmentation or defragmentation of global governance largely depends on the connections it makes".

In functionally and politically fragmented contexts, knowledge becomes more significant for fostering alignment between organizations (Stone, 2013). New knowledge can prompt organizations to reassess their understandings (Jungcurt, 2011; Litfin, 1994; Stokke, 2020; Young et al., 1999/2005), while sharing existing knowledge can drive mutual learning and interactions (van Asselt and Zelli, 2014; Hackmann, 2016; Morin et al., 2017; Oberthür, 2009). However, in the previous studies on institutional interplay, knowledge is often conceptualized narrowly as a homogenous resource used by organizations to manage their legitimacy or influence (e.g., Andresen and Skjaereth, 2007; Alter and Meunier, 2009; Stokke, 2020).

2.1. Typologies of institutional interaction and their limitations

According to Young et al.'s (1999/2005) classical typology, institutional interactions fall into political or functional linkages. Functional linkages occur when "the operation of one institution directly influences the effectiveness of another through some substantive connection of the activities involved" (Young et al., 1999/2005, 50). Political linkages are intentional efforts to enhance cooperation. Through inter-secretariat joint communication, the Convention on Biological Diversity (CBD) and the United Nations Framework Convention on Climate Change (UNFCCC) Secretariats have raised awareness of the functional linkages between biodiversity loss and climate change (Kim and Bosselmann, 2013; Hickmann and Elsässer, 2020). The Secretariats have also advised on the tensions between climate change and biodiversity actions (Jinnah, 2011), while some studies have identified functional predominance of climate governance over CBD in forest plantation policies (Jacquemont and Caparrós, 2002).

The UNFCCC and CBD exhibit strong functional connections in forest and land-use policies (van Asselt, 2012; Kim, 2004). The secretariats have also attempted to strengthen political linkages through joint initiatives such as the Joint Liaison Group (JLG), established in 2001. However, these efforts have often fallen short of achieving suggested policy coherence, such as aligning Kyoto protocol and REDD+ mechanism, or developing joint rules with forest carbon sinks (Kim, 2004). Despite early joint reports, sustained JLG collaboration has subsided since 2016, too (GIZ, 2025).

Young et al.'s typology has been criticized as too simplistic, as it overlooks some forms of interactions, such as those driven by shared geographical memberships (e.g., the EU) (Stokke, 2001) or by epistemic factors. Gehring and Oberthür (2009) proposed a more nuanced typology: 1) cognitive interplay – knowledge produced in one institution influences the other, 2) normative interplay – involving overlapping or conflicting norms and principles, 3) behavioral interplay – when one institution's behavior affect another, and 4) functional interplay – when one institution's action influences another's actions. Sanderink and Nasiritousi (2020) further refined the classifications by introducing "impact-level interaction", describing unintended effects of one institution on the goals of another.

Even the more nuanced typology still considers the interplay of institutions with jurisdictional or political power. The typology underplays epistemically driven institutions, which shape knowledge

systems and validate ideas in governance processes (e.g. Borie et al., 2021; van der Hel and Biermann, 2017; Lahsen and Turnhout, 2021; Oppenheimer et al., 2019). Rather than viewing knowledge solely as cognitive, STS scholars stress knowledge's performative role in shaping how global issues are framed and acted upon (Allen, 2017; Hysing and Lidskog, 2021; Jasanoff, 2004; Miller, 2001, 2004; Maas et al., 2021). Moreover, epistemically diverse and inclusive knowledge processes – rather than epistemic consensus or new information alone – are increasingly seen as drivers of reflexive and transformative governance (Díaz et al., 2015; Lahsen and Turnhout, 2021; Montana, 2019, 2021; Tengö et al., 2014).

2.2. Epistemic linkages

In fragmented contexts, knowledge can be a mechanism through which governance is made more aligned, and thus, more responsive to complex challenges. Knowledge interplay between epistemically driven organizations such as IPCC and IPBES extends beyond information-sharing. These institutions operate within distinct institutional epistemologies – normative systems that shape how knowledge is created, validated, and framed (Borie et al., 2021). Hence, grasping knowledge movement solely as a linear transfer of ideas between institutions is insufficient. In addition to cognitive dimension, knowledge interplay between epistemically driven organizations encompasses:

- Political dimensions, where knowledge drives the alignment of institutional goals
- Normative dimensions, where institutions either converge or diverge on norms for validating and disseminating knowledge
- Behavioral dimensions, where methods of knowledge production influence practices across organizations.

To capture this complexity, we propose the concept of **epistemic linkage**: connections between institutions with different epistemologies that facilitate the flow of knowledge and the mutual awareness on how knowledge is evaluated and validated. This concept reflects two dimensions of knowledge: (1) **epistemic**, referring to the nature and diversity of knowledge itself, and (2) **epistemological**, concerning distinct, institutionalized perceptions of how knowledge is produced, assessed and applied. **Institutional epistemologies** refer to the ways in which institutions conceptualize and validate knowledge (Borie et al., 2021). Epistemic linkages foster not just information sharing, but mutual understanding of knowledge practices, making institutional interplay more feasible. We study epistemic linkage as interinstitutional ties where expert co-membership enables knowledge flow across organizations (Böhmelt and Spilker, 2016).

2.3. Interactions between the IPCC and IPBES

There is an extensive literature on the interactions between the secretariats of UNFCCC and CBD conventions (e.g. Bauer, 2006; Bauer and Ege, 2016; Biermann and Siebenhuener, 2009; Hickmann and Elsässer, 2020; Jinnah, 2011). Much of the most recent literature on climate governance has expanded their focus from intergovernmental views to transnational interactions and linkages between actors such as cities, non-governmental organizations, and private sector (Betsill et al., 2015; Gordon and Johnson, 2017). This opens the governance landscape to “alternative forms of climate governance and how these activities might collectively result in climate governance from the ‘bottom up’” (Betsill, et al., 2015, 1). However, the interaction potential between epistemically driven organizations is not scrutinized.

Meanwhile, IPCC and IPBES are increasingly called upon to progress their epistemic alignment across climate and biodiversity regimes. In response to this, IPBES prioritized collaboration with IPCC in its 2019–2030 work programme to address overlaps between biodiversity and climate change (IPBES, 2021). The collaboration culminated in a

co-sponsored workshop and joint report (Pörtner et al., 2021; IPCC, 2020). After this collaborative effort, IPBES compiled several suggestions from its member governments for thematic or methodological cooperation between the IPCC and IPBES (IPBES, 2024). However, some IPCC member governments and the IPCC bureau have raised concerns that such collaboration might result in the IPCC losing its control over its knowledge production and jeopardizing its “integrity and reputation” (IPCC, 2024). As a result, the formal deepening of inter-institutional linkages and the pursuit of joint assessments have not progressed. Nevertheless, there have been continuing calls for informal collaboration, including joint webinars (ibid.) and the participation of appointed experts in the work of both bodies (McElwee, 2025).

Institutions have “culturally specific, historically and politically grounded, public knowledge-ways” (Jasanoff, 2004, 249). Borie et al. (2021) coined these differences as institutional epistemologies that shape organization's cultures and knowledge practices, which influence how knowledge is created, used, and disseminated in a certain institutional framework (see also Lahsen and Turnhout, 2021). IPCC's and IPBES' institutional epistemologies differ in their (1) conceptual frameworks, which shape problem-framing, (2) modes of futuring, such as scenarios and modeling, and (3) consensus management and disagreement resolving among experts. Further, while IPCC focuses primarily on natural sciences, IPBES aims to include a wider range of disciplines, knowledges, and stakeholders in its work (Borie et al., 2021).

Research shows that epistemic diversity – entailing varied epistemic worldviews, not just disciplines – can influence both the content and the dissemination of knowledge (Hakkarainen et al., 2020; Mäkinen-Rostedt et al., 2023). Prior studies have demonstrated that experts' epistemic viewpoints may shift over time, aligning with institutional norms (Gustafsson, 2021; Mäkinen-Rostedt et al., 2023). Thus, inclusive practices are essential for overcoming structural biases, such as the dominance of Western scientific paradigms (Morin et al., 2017; Tengö et al., 2014). Various epistemic and epistemological differences can hinder the interactions as well as knowledge flow in and between the organizations (Borie et al., 2021; Montana, 2021; Morin et al., 2017; Obermeister, 2017).

In IR, mechanisms for knowledge exchange are seen to hold significant potential for promoting institutional cooperation and alignment, enabling social learning and reducing knowledge gaps in interlinked issue-areas (Hackmann, 2016; Olsson et al., 2004; Oberthür, 2009). Through strategic interplay and collective agency, institutions can enhance governance across overlapping issue areas (Oberthür, 2009; Stokke, 2001, 2011, 2020). The operational activities that represent epistemic interplay include creation of shared knowledge pools (Underdal, 2002; Oberthür and Stokke, 2011), development of common communication structures (Siebenhuener, Suplie, 2005), and strategic knowledge co-management on the science-policy boundary (Morin et al., 2017), as well as promoting reflexive, epistemologically inclusive organizational management (Maas et al., 2021).

In addition to institutions like IPCC and IPBES, informal expert networks such as the World Climate Research Programme (WCRP) and Future Earth (FE) play significant roles in the global knowledge architecture, bridging experts across regime lines. Jungcurt (2011, 194) emphasizes that expert knowledge, and its ability to pass through and between institutions on various governance levels, is key to “the development of shared understandings, the resolution of interinstitutional disruptions, and the establishment of mechanisms for interplay management”. Including platforms like FE and WCRP in our analysis reflects that knowledge flows across both vertical (formal-informal) and horizontal (issue-area) boundaries.

WCRP and FE are independent international research platforms that facilitate research communities. Both platforms are connected to IPCC's and IPBES' knowledge assessment processes. WCRP, established in 1980 under the sponsorships of World Meteorological Organization (WMO) and International Science Council (ISC, formerly ICSU), focuses on

physical climate science. WCRP provides scenarios that IPCC uses in its reports, coordinates work between modeling and analyzing research communities and participates in the interpretation of the results (ISC et al., 2018, 42).

Similarly, Future Earth (FE), co-sponsored by ISC, was created to reshape fragmented research agendas into more transformative, trans-disciplinary, and action-oriented initiatives. It also promotes the integration of social sciences into Earth system research (Lahsen and Turnhout, 2021; van der Hel, 2016). FE seeks close collaboration with IPBES. As explained under their memorandum of understanding (UNEP and FE, 2017), FE was expected to contribute to increasing the number of experts nominated for IPBES assessments, catalyze funding for new research aligning with IPBES priorities, and assist in data collection and the non-governmental stakeholder strategy work of IPBES.

2.4. Epistemic linkages and network structures

The structures that emerge from institutional linkages have gained increasing attention in IR (e.g., Biermann and Kim, 2020; Biermann et al., 2009; Jordan et al., 2018; Kim, 2020). Rather than viewing disconnections as inherently negative, IR literature suggests that complex regime architectures which include some level of institutional fragmentation may outperform integrated, centralized governance systems (Stokke, 2017). Social Network Analysis (SNA) offers tools to compare such structures, using metrics like modularity, average path length, and centrality (Kim, 2013; Widerberg, 2016).

SNA is particularly relevant for studying epistemic linkages, as it connects structural features to knowledge-movement potential (Reagans and McEvily, 2003). For instance, cohesion of the network is a crucial factor for knowledge exchange (Turner et al., 2014; Cunningham et al., 2015). Cohesive networks tend to share similar knowledge (Crona and Bodin, 2006), while loosely connected structures enable novel ideas and innovations (Johanson, 2001; Reagans and Zuckermann, 2001). Dense connections are useful for spreading existing knowledge (Podolny and Baron, 1997). Well-integrated structures that facilitate the flow of various types of knowledge support more cooperative governance (Crona and Bodin, 2006).

Both SNA and IR scholars agree that topological network features, such as density, clustering, and distribution, influence on the abilities of the network, i.e. the movement of knowledge or governance effectiveness (e.g. Bodin and Crona, 2009; Borgatti et al., 2018; Cowan and Jonard, 2004; Reagans and McEvily, 2003). In IR, global structures are often described as complex (Orsini et al., 2019), fragmented (Biermann et al., 2009), or polycentric (Jordan et al., 2018). Connecting this to network thinking, fragmentation refers to the degree of connectivity between institutions, polycentricity describes multiple decision-making centers, and complexity refers to a system's ability to self-organize (Kim, 2020, 904). SNA provides tools to map these structures, identifying gaps or overlaps in linkages and contributing to the understanding of adaptability, resilience, and coherence of the structures (Borgatti and Halgin, 2014). There are similar perceptions on the outcomes of different structural features in SNA and IR literature and that will be used as our overall analytical framework (Table 1.).

First, in SNA, complex networks include small-world networks (high clustering, low average path length) and scale-free networks ("highly skewed degree distribution called power law") (Kim, 2020, 916). Both types influence collective dynamics, such as adaptability and robustness, but also pose vulnerabilities (Albert and Barabási, 2002). The ability of small-world networks to be slightly cohesive but still divergent is seen as beneficial for learning and innovatively combining knowledges (Cowan and Jonard, 2004; Watts, 1999) that governing the epistemic common ground of complex problems such as climate change and biodiversity loss require. In IR, complex regimes are often seen governed effective if the problem at hand is addressed, whether by differentiating roles to avoid overlap or by fostering a shared understanding (Biermann et al., 2009; Gehring and Oberthür, 2008).

Table 1
Structural features of network and their implications to governance and knowledge flow according to international relations (IR) literature and social network theory (SNA) literature.

	Complexity	Fragmentation	Polycentricity
IR literature	Positive: can influence system's ability to self-organization. Negative: can be overly complicated system with "many parts". (Stokke, 2017)	Positive: interlocking governance structures that prevent conflicts (van Asselt and Zelli, 2014). Negative: conflicts and poor international compliance (Biermann et al., 2009).	Positive: decentralized but effective decision-making (Östrom, 2000; 2010; van Asselt and Zelli, 2014). Negative: coordination gaps and lack of coherence (Gupta et al., 2016).
SNA literature	Positive: might foster robustness and adaptivity, i.e. self-organization and multiple, possible connections. Negative: vulnerability (Albert and Barabási, 2002.)	Positive: certain level and type of fragmentation might foster new knowledge and innovations (Johanson, 2001; Reagans and Zuckermann, 2001). Negative: too fragmented structure is a barrier to seamless knowledge exchange (Beckfeld, 2008).	Positive: might support coherence in decentralized systems, (Jarman et al., 2017), i.e., multiple types of knowledge centers co-exist which leads to better cooperation and resilience.

Second, fragmentation in IR refers to “collections of institutions with no identifiable core and weak or nonexistent linkages between regime elements” (Keohane and Victor, 2011, 8). While fragmentation can lead to inefficient systems (Biermann et al., 2009, 2020), moderate fragmentation may prevent conflicts (van Asselt and Zelli, 2014). In SNA, fragmentation can be positive for innovations, but too fragmented system is considered inefficient (Johanson, 2001; Reagans and Zuckermann, 2001).

Third, polycentricity, which involves multiple decision-making centers, facilitates decentralized order in international relations (Ostrom, 2000; Ostrom, 2010). In SNA, a decentralized structure is not interdependent, which is why it is considered robust against shocks and capable of reorganizing itself after an attack (Jarman et al., 2017). The climate change regime, for example, is thought to exhibit characteristics of synergistic fragmentation (Biermann et al., 2012) but also features of conflictive fragmentation and polycentricity (van Asselt and Zelli, 2014).

To assess the epistemic linkages and the potential for knowledge interplay between IPCC, IPBES, WCRP, and FE, we adapt Kim’s (2020) typology of global governance networks and their metrics: fragmentation (how disconnected the network is), polycentricity (multiple centers in the system), and complexity (potentially adaptive features and a clustered structure). The epistemic linkages are defined through expert membership in the knowledge assessment processes. These experts can act as brokers, i.e. individuals who enable knowledge flow (Gupta et al., 2016; Stovel and Shaw, 2012) and epistemic alignment across institutional boundaries (Berkes, 2009; Fotouhi et al., 2018). Particularly valuable are heterogenous brokers, who connect dissimilar institutions (Hamilton et al., 2020). Such connections help circulate diverse knowledge types and promote innovation (Tortoriello et al., 2011).

3. Material and method

Our network analysis is based on data collected from the official web pages of each organization during 2020–2021. The data is openly available at the Finnish Social Data Archive (Mäkinen-Rostedt, 2024). We constructed a network between IPCC, IPBES, WCRP, and FE by choosing experts’ membership in individual assessment processes or programs as a linkage. We recorded the membership of everyone appointed as authors in the assessments for IPCC and IPBES, as well as the details of experts appointed to the steering or advisory committees of various WCRP and FE programs between 2015 and 2021 (N = 2093). The final dataset includes 101 distinct assessment processes or programs, i.e., nodes with appointed expert participation. Membership in IPCC’s assessments was recorded by each of the three IPCC working groups’ chapters because the IPCC authors are appointed in this way. For example, the IPCC working group 1 of the 6th Assessment Report has 17 chapters and a group for synthesis report which amounts to 18 IPCC processes, i.e., nodes. IPBES, on the other hand, recorded authors’ memberships at the level of entire assessment reports, rather than by individual chapters, at the time the data were collected.

We used the co-membership or shared membership (as e.g., in Beckfield, 2008; Greenhill and Lupu, 2017; Gomez and Parigi, 2015) of selected experts as a linkage (i.e., a connection or tie) between the nodes. In this study, assessment processes serve as nodes in the network, and experts’ participation in these processes form the linkages between them. These linkages represent potential pathways for knowledge flow, and their structure defines the network of institutional epistemic interplay. In addition to the co-membership attribute, other background variables available on the expert organization’s official websites – such as assumed gender, organizational affiliation, and citizenship – were coded for each expert (see Appendix A for detailed sample characteristics). Unfortunately, information about the discipline was not accessible for all experts. However, we do not consider this a major drawback as previous studies have shown that epistemic worldviews are not always grounded on the discipline (Hakkarainen et al., 2020; Mäkinen-Rostedt

et al., 2023). Calculations were performed with the UCINET network analysis program and with SPSS, while graphics were produced with Netdraw.

4. Results

4.1. Epistemic diversity across the IPCC, IPBES, Future Earth, and WCRP

According to the sample characteristics (Appendix A: Table 1.b.–2. b.), whole global network of IPCC, IPBES, Future Earth, and WCRP is dominated by Western male experts, reflecting the still prevailing epistemic views of the global environmental knowledge production. Appointed experts are predominantly male (62 %) and represent universities (54 %) from UNFCCC Annex II countries (54 %). Of the four organizations, IPBES appears to be the most diverse one: 40 % of all its 1050 experts are female, and 47 % represent a UNFCCC Non-Annex country, while 7 % are from LDC-countries. In all four organizations, the USA is the most dominant country of representation for experts (Appendix A: Table 2.b.), but the proportions vary from 33 % (WCRP) to 18 % (IPBES). The countries of representation for IPCC, Future Earth and WCRP experts are typically industrialized countries such as the USA (12–33 %), the UK (8–12 %), Australia (5–7 %), China (5–8 %), Germany (5–6 %), Japan (5–6 %), and France (4–7 %). IPBES, however, stands out by including countries like Turkey (1,5 %), Mexico (3 %), India (4 %), and Kenya (2 %) among its top-represented nations.

4.2. Epistemic linkages within and between the climate and biodiversity regimes

We transformed the bipartite matrix (Borgatti and Halgin, 2014; Faust, 1997), where x represented individual experts and y represented a specific process of the four organizations (Appendix A: Fig. 1.b.), into a weighted unipartite network of IPCC, IPBES, WCRP, and FE assessment processes (Fig. 1.). This network comprises 101 nodes and 528 epistemic linkages (‘co-memberships’) between these nodes. Altogether, 17 % (17) of the 101 nodes have at least one connection, while 10 % (10) are isolated nodes, meaning they represent processes that do not share any members with other processes. Fig. 1 visualizes the linkages between processes of IPCC, IPBES, WCRP, and FE.

We analyzed the position of each node within its respective organizational network and compared the structures of the individual networks. The structure of the IPBES network differs from the other three (Figs. 1–2, Table 2). IPBES is the only network without isolated components, and its nodes have 19–130 direct, ‘one-hop’ connections (Borgatti et al., 2009; Newman, 2010; Granovetter, 1973) to other nodes. In contrast, the nodes of the other three organizations have fewer direct connections, ranging from 1 to 45.

There are disconnections in other networks: IPCC has nine isolated nodes, WCRP has nine, and FE 15. However, when examining the global network encompassing all four organizations (as illustrated in Fig. 1), the total number of isolated nodes drops to 10. This reduction occurs because nodes share members across organizational boundaries. Fragmentation scores, representing the proportion of nodes that cannot reach each other, are lower in the global network than in the individual networks of IPCC, WCRP, and Future Earth. In other words, if the peripheral nodes become disconnected from the global network, some nodes may shift to the margins. Consequently, the central nodes gain even more prominence, leading to a more centralized global network structure. This highlights the benefits of epistemic linkages across organizational and regime boundaries in enhancing overall connectivity.

The IPCC Synthesis Report node (degree centrality 45) and the IPBES Global Assessment node (degree centrality 130) have the most direct connections to other nodes, indicating their pivotal roles in integrating knowledge within their respective organizational networks. The IPCC Synthesis report synthesizes the work of the three working groups.

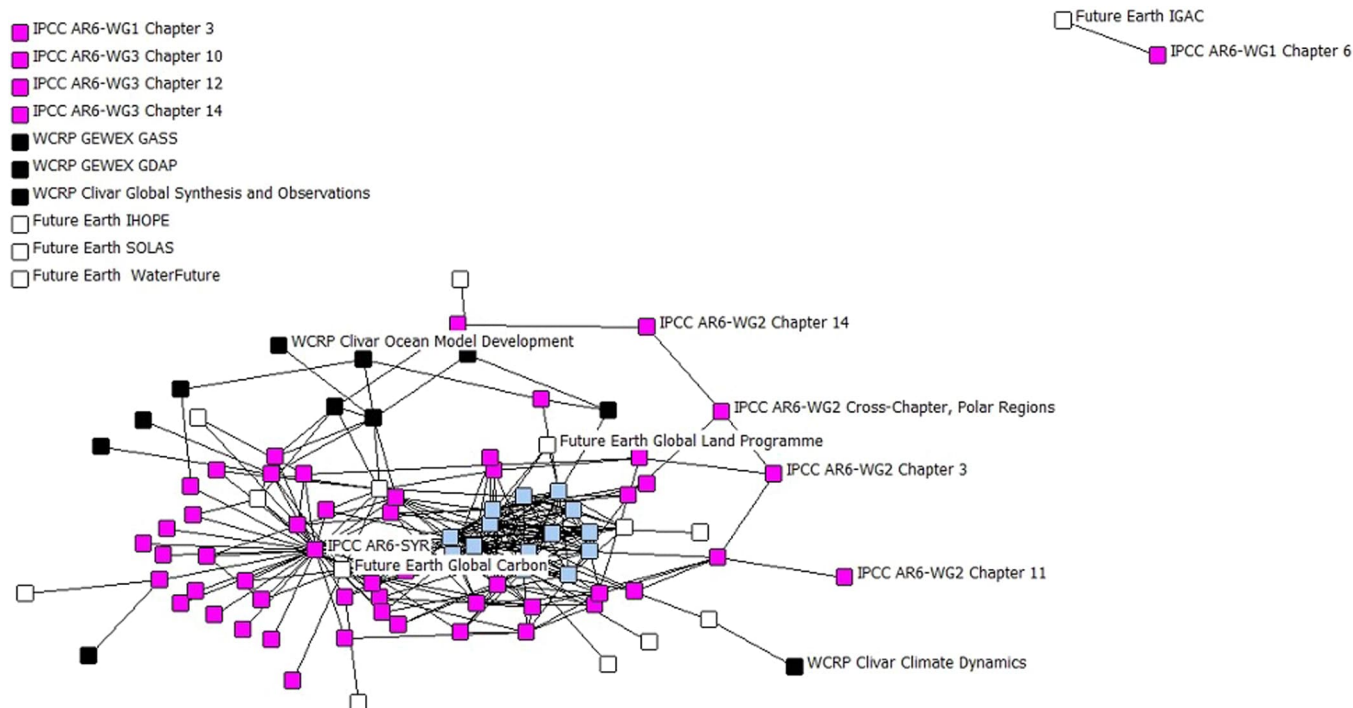


Fig. 1. Visualization of the unipartite matrix of IPCC, IPBES, WCRP, FE and their connectivity. The blue nodes represent IPBES, the pink nodes represent IPCC, the black nodes represent WCRP, and the white nodes represent FE. As we focus on structures rather than individual nodes, only the labels of the most central nodes (e.g., IPCC AR6-SYR and Future Earth Global Carbon Project) or the labels of the most isolated ones are included to enhance the readability of the visualization.

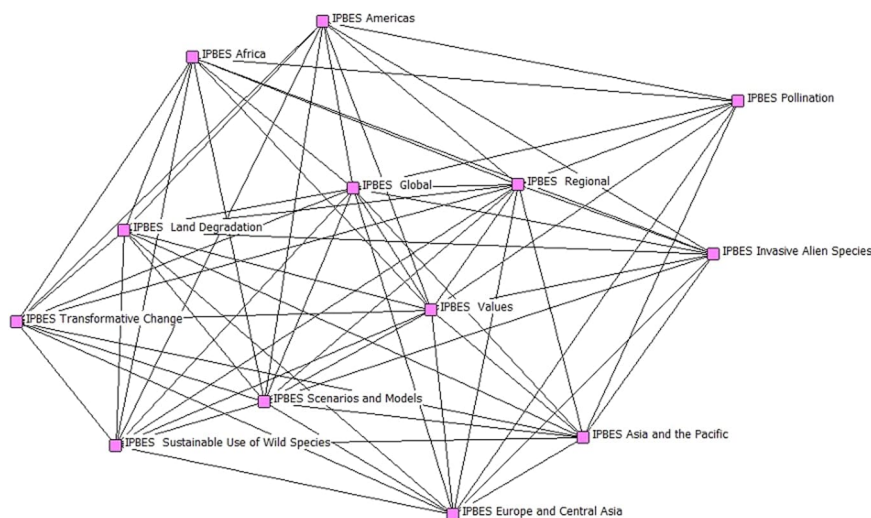


Fig. 2. The visualization of IPBES assessment report processes ('nodes') connected by appointed expert's membership.

Table 2
Basic measures of the aggregate network of IPCC, IPBES, WCRP, and FE.

Aggregate network measures	Density	Diameter	Fragmentation
All four networks as one network (101 nodes, 528 ties)	0.052	7	0.224
IPCC 'subnetwork' (56 nodes, 134 ties)	0.044	6	0.328
IPBES 'subnetwork' (14 nodes, 156 ties)	0.857	2	0
WCRP 'subnetwork' (14 nodes, 12 ties)	0.066	4	0.769
FE 'subnetwork' (17 nodes, 2 ties)	0.007	1	0.993

Similarly, the IPBES Global Assessment Report builds on the contributions of experts who were also appointed to IPBES' regional, thematic and national assessments. The high connectivity of the Synthesis report and the IPBES Global Assessment Report likely stems from their broad scopes, both in terms of disciplines and geographical regions, and because many experts involved in these processes have experience with other, more specific or regional assessment processes.

We also calculated the betweenness centrality measures to assess global centrality within the network (Fig. 3). The betweenness centrality identifies the 'bridge' nodes that lie on the shortest paths between other nodes (Freemann, 1977). Such nodes facilitate the exchange of heterogeneous information and control its flow. For the overall network of 101 nodes, the three highest betweenness centrality scores were found in the

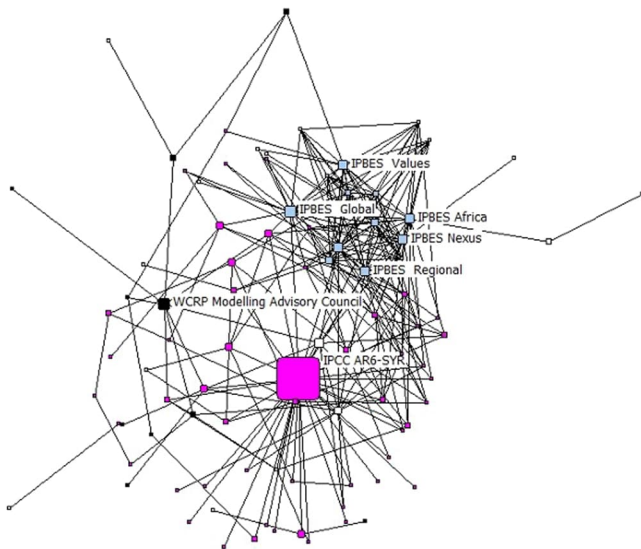


Fig. 3. Visualisation of the betweenness measures of IPCC, IPBES, WCRP, and FE assessment processes. The size of the node represents the betweenness measure. For readability, only the labels of those nodes that have the highest betweenness scores are left visible and isolates are deleted. The blue nodes represent IPBES, the pink nodes represent IPCC, the black nodes represent WCRP, and the white nodes represent FE.

IPCC Synthesis Report (1743), IPBES Global Assessment (383), and WCRP Modelling Advisory Council (310). While the WCRP Modelling Advisory Council ceased operations in 2020, its activities temporarily overlapped with many of IPBES’ and IPCC’s processes, warranting its inclusion in our analysis.

Table 2 summarizes basic aggregate network measures for the overall network and the individual networks of the four organizations. One key measure, the density of a network, indicates how many of the ties between the nodes exist compared to how many ties would be possible, reflecting the tendency of the nodes to form connections. Density scores vary between subnetworks, ranging from 0.007 to 0.857. As illustrated in Fig. 2, the IPBES network represents a structure in which all its parts reach each other. This is also evident in the fragmentation scores (Table 2) of IPBES, which show that all nodes in IPBES are connected. The density score of IPBES confirms that 86 % of all possible ties are realized.

Another measure, diameter - the longest path length of all linkages – provides insights into the speed at which knowledge or information spreads across the network. A shorter diameter reflects greater integration and faster information flow. The diameter of the IPBES network is small, whereas the diameter of the global network (7) and the IPCC network (6) is larger (Table 2.). The average path length is low across all networks, ranging from 1 to 2.915 (Table 4.). The density of IPCC network is also relatively low (0.044), like the overall network (0.052), meaning that only 5 % of the potential ties between the nodes are realized.

4.3. Structural characteristics of the networks

In Table 3, we present the topological measure scores suggested in Kim’s (2020) framework and compare them to the scores we calculated for the global network of 101 nodes of IPCC, IPBES, WCRP, and FE. Before calculating, we dichotomized the valued affiliation matrix.

In Table 3, the comparable high–low scores for structural measures are based on Kim’s framework logic (2020, 919). In the second column, we have categorized our own scores as either ‘high’ or ‘low.’ Since network measures are not absolute, “one can only define a system structure in comparison to another or to itself at a different point of

Table 3

Network-based framework measures for fragmentation, polycentricity and complexity compared with the scores of 101node global network of IPCC, IPBES, WCRP, and FE.

Measures by Structure	Score	Fragmented	Polycentric	Complex
Clustering coefficient	0.391 (medium-high)	-	High	High
Density	0.052 (low)	Low	-	-
Modularity	0.0204 (low)	High	High	-
Average path length	2.843 (low)	High	-	Low
Centralization	0.304 (deg) (low)	Low	Low	-
Skewness in Degree Distribution	2.745 (high)	-	-	High
Fraction of the giant component	88 % (high)	Low	-	High

time” (ibid., 918). Therefore, we also calculated same scores for individual networks, which are presented in Table 4.

The overall graph clustering coefficient (Tables 3–4) quantifies the average density of the neighborhoods of all nodes (Watts and Strogatz, 1998). It measures the extent to which assessment processes tend to form clusters, tight groups, or cliques. It also estimates the probability whether an assessment process l , which is connected to an assessment process j , is also connected to an assessment process k . The global clustering coefficient of the global network is relatively low (0.391), suggesting that it is neither cohesive nor redundant (Kim, 2013, 985). However, the global network density score (Table 3.), at 0.052, informs that the density of these local neighborhoods (i.e., clustering coefficient), is rather high. This combination indicates a moderate degree of clustering, which is why the clustering coefficient has been categorized as medium-high.

In the global network, 22 % of all 101 nodes have clustering coefficient value of 0.5 or higher. A closer examination reveals that, of all IPCC nodes, 11 % have a clustering coefficient of 0.5 or higher as part of the global network. The respective figures are 7 % for IPBES, 3 % for FE, and none for WCRP. Consistent with patterns observed in real-world networks, the average distance between nodes (average path length) is short. Short path length combined with the tendency of clustering to local neighborhoods are typically divergent traits but, appearing together, might suggest a socially narrow but creative small-world structure (Uzzi and Spiro, 2005). Small-world structure signals complexity (Kim, 2020) but looking at the combination of all scores (Table 3.), the degree of complexity in the global network is low.

There is a difference in whether clustering is taking place within or between cliques (Uzzi and Spiro, 2005). A more detailed analysis of

Table 4

Network-based framework measures for fragmentation, polycentricity and complexity as compared with the scores of IPCC, IPBES, WCRP, FE as subnetworks.

Measures by Structure	IPCC	IPBES	WCRP	FE
Clustering coefficient	0.106 (low)	0.854 (high)	0	-
Density	0.044 (low)	0.857 (high)	0.066 (low)	0.007 (low)
Modularity	0.363 (low)	0.016 (low)	0.292 (low)	-
Average path length	2.915 (low)	1.143 (low)	2.095 (low)	1 (low)
Centralization	0.483 (deg) (moderate)	0.167 (deg) (low)	0.282 (deg) (low)	0.063 (deg) (low)
Skewness in Degree Distribution	4.198 (high)	0.677 (low)	1.672 (moderate)	2.610 (moderate)
Fraction of the giant component	82 % (high)	100 % (high)	50 % (high)	12 % (low)

node-specific clustering coefficient scores tells that among IPBES nodes, the highest clustering coefficients are associated with the Invasive Species Assessment (0.889) and the Sustainable Use of Wild Species Assessment (0.836). These nodes do not share experts with nodes outside of the IPBES network, indicating that their clustering is localized within the IPBES rather than spanning the global network. Similarly, most high-scoring IPCC and FE nodes exhibit clustering within their own cliques. However, FE's Global Land Programme node is an exception: it shares members with both IPCC and IPBES, indicating connections between cliques and network-wide connectivity. This node represents a rare heterogenous brokerage connection in the global network, linking otherwise unconnected nodes (Hamilton et al., 2020).

Communities can be loosely defined as sets of nodes that are not organized into densely connected clusters but to less connected subgroups (Yang and Leskovec, 2014). These 'modules' connections in their subgroup are denser than the connections of the subgroup with the rest of the network. Modularity calculations can detect such modules, and low modularity scores indicate a low level of fragmentation (Kim, 2020). We used a community detection tool called the Louvain method (Blondel et al., 2008) to calculate modularity. The results show no strong modularity, implying a more integrated network structure: the algorithm calculated a modularity score of 0.024 (with a maximum of 1) and identified two potential module partitions containing 28 and 17 modules, respectively.

Additionally, the fraction of the global network's giant component included all nodes, highlighting that 88 % of the main nodes (IPCC, IPBES, WCRP, and FE) form a single large group (i.e., the giant component). This suggests that while the organizations do not create discipline-specific or discipline-crossing communities together, their common network exhibits 'emergent order', a typical feature of complex systems (Kim, 2020; sensu Janson et al., 1993).

Finally, we calculated the degree distributions of the main network and subnetworks (Tables 3–4). The degree of a node reflects the number of connections it has, and the degree distribution illustrates the probability distribution of these values across the network. The degree distributions of the four individual networks are generally positively skewed. For instance, the histogram of the degree distribution for IPCC nodes shows a long tail, with over half of the nodes having between zero and two connections. The positive skewness of these degree distributions suggests that except for IPBES, the subnetworks tend to have only few highly connected nodes, while most nodes have limited connectivity.

5. Discussion

This study examined 1) whether epistemic linkages exist between IPCC and IPBES, and 2) how the observed network structures of these linkages shape the potential for interinstitutional knowledge flow and interplay. To answer these questions, we conceptualized epistemic linkage as the connection between institutions formed through expert co-membership, reflecting the potential for knowledge flow and epistemic alignment across distinct institutional epistemologies, as coined by Borie et al. (2021). Drawing from both IR and SNA literatures, we interpreted network features such as complexity, fragmentation, and polycentricity enabling differing knowledge flow structures between climate and biodiversity regimes (Table 1).

Previous research on institutional interplay has examined cognitive, functional, behavioral, or political linkages between institutions (see e.g., Young et al., 1999/2005; Stokke, 2001; Gehring and Oberthür, 2009; Sanderink and Nasiritousi, 2020). The suggested concept of epistemic linkage foregrounds how overlap and the structure such linkages produce can facilitate or constrain knowledge interplay between epistemically driven organizations. Using SNA, we focused on structural fragmentation and the quantity of relations (see e.g., Kim, 2013), identifying cross-organizational gaps and connections.

Our main finding is that epistemic linkages across the central

epistemically driven organizations of the climate and biodiversity regimes remain limited: both IPBES and IPCC share experts mainly within their own assessment processes. FE's and WCRP's linkages were few and did not significantly increase connectivity between IPCC and IPBES in the global network (Fig. 1, Fig. 3). We also found evidence that the identified complex global network structure constrains the system's ability to diffuse and integrate knowledge. The findings further suggest that the identified structures match the institutional epistemologies of IPCC and IPBES, as theorized by Borie et al. (2021). While we do not directly assess the effectiveness of institutional interplay or regimes, our analysis brings to light important structural factors that enable or limit knowledge flow and, thus, potentially influence knowledge interplay across distinct institutional epistemologies and the climate and biodiversity regimes.

5.1. Epistemic linkages within and across institutional epistemologies

Our data show that IPBES exhibits greater representation of female experts and experts from non-Annex countries and LDCs (4.1.). This finding supports IPBES' deliberate efforts to diversify epistemic perspectives (Tengö et al., 2014). Such epistemic diversity, like diverse institutional epistemologies, enriches network dissimilarities. Dissimilarities, in turn, enhance the likelihood of connecting diverse knowledges (Xie, 2022). However, similar nodes tend to attract each other (McPherson et al., 2001), which is why intentional efforts are needed to form connections with distinct actors.

The differences in subnetwork structures of IPCC and IPBES (Tables 2 and 4) further reflect their distinct institutional epistemologies. The dense and highly connected structure of IPBES (Tables 2 and 4) corresponds to an epistemology that values inclusivity and broad participation (Montana, 2019). This structure, which shows epistemic linkages across all its assessment processes, enhances IPBES' ability to integrate diverse knowledge sources (Crona and Bodin, 2006). In contrast, IPCC's higher centralization and fragmentation of linkages (Table 2) reflect a more hierarchical structure. This is consistent with IPCC's institutional epistemology, which Borie et al. (2021) describe representing more specialized expertise.

IPBES's lower centralization score (0.167) compared to IPCC (0.483) indicates polycentricity (Ostrom, 2010). In SNA theories, a polycentric structure is suggested to more easily incorporate the complexity of various types of knowledge (Bodin and Crona, 2009). This makes IPBES' epistemic structure resilient – it is a benefit when addressing complex environmental issues that require multifaceted perspectives (Hysing and Lidskog, 2021; Montana, 2021). These structural traits are further allied with arguments that see that the functionality of regimes benefits from multiple, interconnected centers (Ostrom, 2000; Ostrom, 2010).

We also find signs of structural complexity in both IPCC and IPBES, with IPCC reflecting scale-free and IPBES small-world complexity (Table 4). A small-world structure is more than a random system "with many parts" (Stokke, 2017; Table 1). Knowledge nurtured in the nodes of the subnetwork of IPBES is getting more varied when short paths of the structure allow it to infuse with knowledge of all nodes quickly (Fleming and Marx, 2006; Uzzi and Spiro, 2005). IPCC's scale-free structure is, in turn, more vulnerable to disconnections and is better suited for disseminating information rather than supporting innovations (Albert and Barabási, 2002).

There are a few key assessment processes that act as brokers, such as the Future Earth Global Land Programme, which share members with both IPCC and IPBES assessments. Additionally, several IPCC and IPBES assessments directly share experts (Fig. 1., see also Appendix A: Fig. 1. b.). These findings indicate that epistemic linkages do exist across the climate and biodiversity regimes. The overlap is, however, selective and structurally limited. This supports our claim that expert co-membership has the potential to facilitate epistemic linkages but also highlights the current structural limitations of such overlap as a pathway to knowledge flow between climate and biodiversity regimes (Tortoriello et al., 2011;

Hamilton et al., 2020).

5.2. Constrained structural patterns: the potential of knowledge interplay

The global network score of IPCC, IPBES, WCRP, and FE suggest a weak complex structure with signs of high clustering, low density and limited network range (Table 3). The scores (Tables 3–4) indicate that the network may exhibit some characteristics of a small-world network, but as guided by Uzzi and Spiro (2005), we would avoid this categorization because the network is more connected within its respective subnetworks than between them. In other words, the network range, the linkages that cross organizational boundaries (Burt, 1992, 148–149; see also Reagans and McEvily, 2003), is low. Cross-linkages, if relocated between organizations rather than within them, could strengthen a small-world structure and allow more robust and innovative knowledge engagement. Systemic complex structural features reflect self-regulating possibilities, such as adaptiveness and reflexivity (Uzzi and Spiro, 2005). A stronger small-world structure would be resilient to disconnections between nodes due to its self-organizing ability (Jarman et al., 2017). This structural feature can be associated with "flexibility across issues and adaptability over time" which is seen as beneficial in governing disconnected regimes (Keohane and Victor, 2011, 15).

According to previous studies, low network range, i.e., few cross-boundary connections, restricts the capacity for shared learning (Burt, 1992; Reagans and McEvily, 2003; Reagans and Zuckermann, 2001). Hence, strategic expert engagement between IPCC and IPBES could increase inter-institutional epistemic alignment, as already called for in their joint report (Pörtner et al., 2021). Previous studies have noted that even if the number of global institutions increases, structural fragmentation may decrease because their linkages multiply (Kim, 2013; Greenhill and Lupu, 2017). Thus, increasing the number of co-memberships across institutional borders could potentially enhance structural coherence and reduce epistemic fragmentation, especially if polycentric or complex features are strengthened (Kim, 2013).

As discussed earlier in this paper, structural constraints suggest functional implications that both SNA and IR studies acknowledge (Table 1.). Weak interconnections across regimes limit engagement (Beckfield, 2008; Biermann et al., 2009) and make it harder for organizations to act collectively. More robust epistemic linkages could support knowledge interplay both across organizations and more broadly across climate and biodiversity regimes. More efficient knowledge flow facilitates social learning in the network and, in this way, eases joint problem solving (Hackmann, 2016; Reed et al., 2010; Morin et al., 2017). Stronger potential for integrated responses, facilitated by epistemic linkages, could prevent discrepancies when implementing the CBD's and UNFCCC's aims on various national and local scales (Jacquemont and Caparrós, 2002). Thus, knowledge interplay management might contribute to strengthening the legitimacy of existing environmental agreements.

Institutional epistemologies cannot – and to preserve epistemic diversity, arguably should not – be harmonized. A more diverse epistemic base enhances regimes' capacity to respond to complex problems (Cornell et al., 2013). However, epistemologies can be strategically bridged through the deliberate inclusion of brokers: experts who navigate multiple knowledge systems (Hamilton et al., 2020). By seeking to transcend their institutional epistemologies (Borie et al., 2021) and by co-sharing experts across organizational boundaries, particularly between IPCC and IPBES but also related organizations such as FE and WCRP, structural adaptivity can be promoted and fragmentation between knowledge systems reduced. Functionally, an integrated yet agile knowledge infrastructure (Montana, 2021), marked by diversity and reflexivity rather than normative push for consensus (Díaz-Reviriego et al., 2019; Obermeister, 2017), can foster epistemic alignment and help mitigate the tensions between the climate and biodiversity regimes (van Asselt and Zelli, 2014).

5.3. Future directions and limitations

Our analysis is bounded by decisions about network scope. We did not include, for example, government representatives in the Subsidiary Body on Scientific, Technical and Technological advice (SBSTTA) or the Subsidiary for Scientific and Technological Advice (SBSTA) in our data. SBSTTA and SBSTA are advisory bodies that provide guidance to the parties of their respective conventions: CBD and UNFCCC. According to UNEP and CBD, the IPCC is considered "the most important source of scientific, technical, and socioeconomic information on climate change for UNFCCC" (UNEP and CBP, 2012, 2). This highlights the relevance of both the IPCC and IPBES as knowledge-synthesizing bodies within their respective regimes and informed our decision to focus on them in our analysis.

Equally important, even if using expert co-membership as a proxy is considered as a strong indicator of connection between organizations in SNA, it does not guarantee information exchange (Borgatti and Halgin, 2014). Future research could add survey-based data on engagement experiences to assess how institutional epistemologies influence actual cross-institutional interaction quality.

Finally, conducting longitudinal studies could help track whether structural changes in epistemic linkages, e.g. increases in co-memberships, contribute to more cohesive or adaptive knowledge system architectures. This would advance understanding of epistemic linkage as a driver of institutional interplay over time.

6. Conclusions

This study introduced the concept of epistemic linkage to explore how expert co-membership constructs the structures of knowledge interplay between institutions. By combining IR, STS, and social network theory, we offered a novel, empirically based approach to investigating how epistemically driven organizations couple across regimes. Our findings confirm that epistemic linkages between IPCC and IPBES are limited and structurally constrained. Rather than being incidental, these identified linkages reflect differing institutional epistemologies which, in turn, may raise challenges for establishing knowledge interplay. Certain structural patterns hinder mutual learning, thereby limiting the potential for epistemic alignment between diverse institutional epistemologies. Strategically developing epistemic linkages between these organizations, particularly through intentional expert co-membership and deliberated brokerage, can uphold underlying structural conditions, such as polycentricity, that enable more adaptive and pluralistic knowledge. Future research may benefit from tracing how epistemic linkages evolve over time, and from elucidating how the linkages grow into coordinated action.

CRedit authorship contribution statement

Katri Mäkinen-Rostedt: Writing – original draft, Visualization, Software, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Aleksis Oreschnikoff:** Writing – review & editing, Investigation. **Petri Usiskylä:** Writing – review & editing, Investigation.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at [doi:10.1016/j.envsci.2025.104181](https://doi.org/10.1016/j.envsci.2025.104181).

Data availability

The data that support the findings of this study are openly available in the Finnish Social Science Data Archive at <https://urn.fi/urn:nbn:fi:fsd:T-FSD3715>.

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