Six modes of co-production for the sustainable development of ecosystems

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Abstract

The promise of co-production to address complex sustainability challenges is compelling. Yet, co-production – the collaborative weaving of research and practice – encompasses diverse aims, terminologies and practices, with poor clarity over their implications. To explore this diversity, we systematically mapped differences in how 32 initiatives from six continents co-produce diverse outcomes for the sustainable development of ecosystems at local to global scales. We found variation in their purpose for utilising co-production, understanding of power, approach to politics, and pathways to impact. A cluster analysis identified six modes of co-production: (1) researching solutions; (2) empowering voices; (3) brokering power; (4) reframing power; (5) navigating differences; (6) reframing agency. No mode is ideal – each holds unique potential to achieve particular outcomes, but also poses unique challenges and risks. Our analysis provides a heuristic tool for researchers and societal actors to critically explore this diversity and effectively navigate trade-offs when co-producing sustainability.

Introduction

Co-production is a rapidly growing endeavour, now widely applied in the fields of health, development, education, climate change, industrial production, and sustainability[1,3–5,2,6]. It broadly seeks to connect researchers with diverse societal actors to collaboratively and iteratively produce knowledge, action and societal change[1]. The promise is compelling: developing solutions through legitimate processes that draw on diverse and credible expertise with, by, and for those best placed to use them[5,7,8]. Sustainability is one important arena in which co-production has been increasingly practiced and examined[1,5,9]. Yet, both the meaning and outcomes of co-production remain ambiguous, as efforts now employ diverse terminologies – for example, collaborative governance[10], social learning[4,11], co-design[12], transdisciplinarity[13–15], and participatory action research[13] – linked to varied approaches with different goals, theories, practices, capacities, and outcomes[1,4,13,16–20]. Poor conceptual clarity of distinct approaches and the lack of systematic empirical analysis of their outcomes risks framing co-production as a panacea[1,7,9]. Amidst growing concerns over how co-production efforts may in some cases entrench social inequalities and power relations[7,17,21,22], or fail to achieve sustainability goals[1,13,15,23,24], scholarship points to the importance of exploring multiple impact pathways, trade-offs among approaches, and cross-scalar dynamics[13,23,25]. Yet, much empirical guidance to date has been limited by scope, often including relatively few case studies[15,18,26], geographical contexts[25,27], or methodological approaches[28,29].

The empirically-based analysis presented here of selected examples of co-production provides a heuristic tool for researchers and societal actors to understand the growing diversity of approaches and effectively navigate associated trade-offs when designing co-production processes. Our selected examples focus on one domain of co-production scholarship and practice in sustainability – reshaping how ecosystems can be managed for sustainability. To explore diverse co-production approaches in this domain, we analysed 32 cases that sought to advance sustainable development by co-producing sustainable interactions between people and terrestrial or marine ecosystems (hereafter, 'sustainable development of ecosystems', or in short 'sustainability'). We conducted qualitative and quantitative analyses to identify distinct choices in the design and implementation of co-production cases and

connect these choices to potential outcomes, challenges, and risks. We employed an information-oriented, maximum variation approach to sampling[30], with 32 cases selected to maximise diversity for: sectoral involvement, researcher roles, co-production practices, and geographical/scalar locations. These cases span six continents and operate across local, regional, national, transnational, and global scales (Fig. 1). They interweave knowledge and action through diverse methods that combine both descriptive and normative aspects of co-production[1,4]; for example, research-informed co-management processes[31–33], (trans)national learning networks[34,35], and global dialogues[36,37]. All cases sought to beneficially influence how ecosystems function towards sustainability; yet, aspirations ranged from more modest goals of mainstreaming knowledge within established policies, to intentions to fundamentally reshape narratives, practices, policies, and institutions.

Our analysis emerged from a desire to examine the choices we knowingly or unknowingly make when studying and participating in co-production efforts for the sustainable development of ecosystems – both in the aims that are set, and the design choices and practices that shape resulting outcomes. The iterative analyses identified six modes of co-production defined by how they frame the *purpose* of co-production, conceptualise *power*, approach *politics*, and theorise impact *pathways*. Below we describe the diversity of cases, and then explore these four themes. We then introduce the six modes of co-production and their unique potential to produce particular outcomes and risks, thereby elucidating when and how particular co-production approaches may be effective and constructive. We conclude by highlighting some critical trade-offs that arise between different modes of co-production, and some common features that enhance likelihood of achieving outcomes. We encourage the use of our analysis, particularly as distilled in our graphical visualisations, as a useful heuristic tool to guide researchers and societal actors towards more reflexive co-production design and practice in pursuit of sustainability. The analysis and heuristic presented here are not intended to serve as a generalisable checklist of 'how to co-produce'; rather, our approach seeks to cultivate flexibility and reflexivity that enable researchers and practitioners to plan as well as improvise what action is required in their situation.

Diversity of co-production cases

The 32 cases engaged with diverse sustainability issues related to habitat degradation, climate change, wildfire, and supply chains. All cases were implemented by and/or extensively researched by the 42 co-authors of this paper (case selection process detailed in Methods). Some cases worked either at local or global scales, but the majority spanned multiple scales in locations around the world (Fig. 1). All cases fostered collaboration across at least three sectors, with research, government, NGO and community actors involved in most cases. Societal actors ranged from business CEOs[36] and urban planners[38,39], to indigenous leaders[40,37] and artists[32]. The cases employed diverse approaches to co-producing knowledge and action, such as participatory modelling to inform resource management[33,41]; research-informed co-management institutions[31,38,42,43]; learning networks or think tanks to guide practice[34,37]; and 'labs' to collectively rethink problems[39,44]. Half the cases engaged people with similar values and goals, while the other half navigated conflicting agendas, and in some cases, bitter disputes.

The combined budget of the cases reached 120 million (median 500,000) USD, ranging from short 18-month projects to ongoing initiatives of 20+ years (Fig. 1). Leadership teams were typically dominated by citizens of project localities, except when working in less developed countries. In addition, two-thirds of all cases were led by at least 50% women. In some cases, research played a minor role; however, in two-thirds of cases, researchers held relatively greater power over decisions. The majority of cases spanned at least four disciplines such as ecology, social science, art, and engineering. Some applied more 'realist' research methods (i.e. methods used to describe reality, such as hydrological modelling), while others emphasised 'relativist' methods (i.e. methods that study 'reality' as, in part, socially constructed, like discourse analysis)[45].

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Key differences across co-production cases

We conducted iterative qualitative analyses to identify key differences in how cases frame and practice co-production, and pursue and achieve distinct outcomes. The analyses spanned 2017 – 2019 and entailed multiple steps (see Methods for details): a) collaboratively producing a common inquiry framework based on exploratory workshops of co-production cases and literature review; b) systematically selecting diverse cases; c) applying the inquiry framework to gather data on each case study in collaboration with a case expert; d) conducting a preliminary analysis to identify dimensions of difference across cases, and then testing and refining a list of 72 dimensions in two participatory workshops; e) systematically assigning numerical scores and qualitative justifications for each dimension of difference for the 32 cases; f) conducting statistical and qualitative analyses to identify and understand patterns. Four key themes emerged from the analyses; cases varied in their (1) purpose for utilising co-production, (2) understanding of power, (3) approach to politics, and (4) intended impact pathways. For each theme (below), cases typically followed one of two approaches, which can be viewed as opposite ends of a spectrum that sit in tension (Fig. 2). However, some cases demonstrated that these tensions are not inevitable and may be spanned in productive ways.

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Purpose

Why do actors co-produce? The motivations driving co-production efforts heavily shape them[18,19,46]. We identified two main motivations underlying co-production: to more effectively solve predefined problems and to reframe problems. Examples of solving predefined problems include initiatives to fill knowledge gaps, such as land use impacts on ecosystem services[41], or collectively manage problems, such as river pollution[38]. Examples of reframing problems include shifting people's focus on ensuring sustainable production of a commodity, to becoming an active steward of the ecosystem on which that product depends – whether farmers/fishers in a local resource context[44,33,31] or corporate actors with global influence[36]. Earlier problem definition facilitated quicker solutions, but also inhibited participants from questioning their assumptions. For example, partnerships between researchers and policymakers explored more topics over time, but rarely questioned their assumption that a lack of knowledge was the primary barrier to change. Cases seeking to reframe problems engaged actors with divergent views to either negotiate compromise, or facilitate reframing. Reframing was sometimes

pursued unidirectionally (i.e. using knowledge to convince actors), but others created spaces to collectively question multiple perspectives in ways that placed them on equal ground. Projects that emphasised reframing often struggled to engage solutions-oriented actors and produce concrete actions. Cases were therefore often challenged by an *apparent* paradox: they needed to stabilise problem framings to align actors and empower action, while also questioning problem framings to spark more diverse and innovative possibilities.

Power

How is human agency conceptualised? Power and agency are inherent to sustainability scholarship, yet these concepts are interpreted in diverse ways[47–49]. We identified two predominant approaches to understanding human agency: focusing on the behaviour of actors directly linked to sustainability problems (e.g. encouraging resource users to extract less or recuperate habitats[41,50]), versus targeting more systemic aspects (e.g. addressing broader paradigms and systems that influence resource users' agency[37,51]). This echoes different definitions of 'power' in the literature, ranging from more direct interactional forms (i.e. exercising 'power over' others), to diffuse, structural, and preconstituted forms[47]. While the direct approach was typically seen in cases focused on solving problems, the more systemic approach often emerged from processes that used iterative dialogue and creative methods to reframe participants' perceptions of agency[32,44]. Some cases realised contradictions over time between their direct actions (e.g. supporting local communities to adapt to climate change) and failure to address systemic issues that constrained those actions (e.g. policies and actors causing climate change)[40]. Projects therefore struggled to navigate tensions between promoting a limited view of agency to empower direct action, and expanding views to consider systemic issues that could leverage wider impact. While the former risked failing to address the roots of sustainability problems, the latter risked disempowering individual agency if people felt overwhelmed by 'big' systemic challenges.

Politics

How are power relations changed? Co-production literature increasingly explores the politics inherent to reshaping relations of power among actors[16,21,52]. Here we refer to politics as the work of deciding who gets what, when and how, which refers to a broader sphere of engagement than the deliberation of official government processes[53]. We identified two distinct ways that cases engage with politics to reshape power relations: by empowering marginalised actors, such as grassroots groups or local officials, or by influencing powerful actors, such as international policy makers or corporate executives, to yield power. Most cases focused on local actors; for example, by empowering municipal officials through provision of science-based evidence to engage political decision-makers[54]. Some sought to persuade actors to change behaviours defined as problematic by actors external to the context (e.g. exploitation of natural resources by farmers[50]), while others began with local interpretations of problems[43]. Several cases facilitated integration of local and external views to develop new possibilities for action. Some took the further step of representing these views in decision-making arenas, or gave local actors a seat in discussions with more powerful actors. Yet, very few cases sought to reshape power relations through deep engagement with globally powerful actors, or directly connected them to iterative bottom-up processes. Indeed, cases that directly engaged powerful actors rarely questioned their control over particular actors. This dynamic played out within some project teams, where actors from the global North held greater control over co-production processes occurring in the global South, with no cases of the reverse[55]. Cases therefore

tended either to not actively attempt to influence the politics that shaped power relations, or struggled to navigate the politics of shifting power by iteratively engaging one, or occasionally both sides of power differentials.

Pathways

How are impacts catalysed? Co-production initiatives exhibit diverse possible impact pathways[23,56]. Our cases employed two main pathways: by primarily producing scientific knowledge as a product that is expected to shape policy and/or practice (i.e. 'by producing knowledge'; Fig. 2), or through more integrated forms of knowing, relating and doing (i.e. 'by relating together'). Examples of producing knowledge included developing new scientific research outputs like academic journal articles, or reports for policy-making and practice (e.g. guidelines for practitioners)[54,57]. Examples of relating together emphasised iterative dialogue to share practical experiences of actors involved[36,37,39,44], and direct action through co-managing ecosystems and creating new institutions and policies[31,32,34,38]. Many cases focused on producing knowledge, clearly linked to the dominant role of researchers in our sample of cases. These cases often quickly stabilised notions of problems, such as the need to fill particular knowledge gaps related to interventions, resource/information flows, or actors' perceptions. The actors that this knowledge sought to influence were involved in varied ways, from informing questions, to co-producing research, or engaging in social learning around the produced knowledge. In contrast, cases that focused less on producing scientific knowledge outputs typically emphasised relating together. This latter approach was associated with fewer predefined goals and more space to enact emergent ideas.

Modes of co-production

The hierarchical clustering[58] analysis grouped cases that similarly approached purpose, power, politics, and pathways into six clusters (Fig. 3). Clusters represent distinct modes of co-production that employed particular designs and practices to pursue up to 14 types of identified outcomes. These modes varied in their aims (Fig. 4); for example, some particularly sought to produce scientific knowledge outputs (1, 2, & 4), reframe pre-existing beliefs and values (2-6), enhance policy uptake (1, 2, 4, 5), or build institutions (3 & 5). For each mode, we discuss their main features and key strengths and weaknesses in relation to the extent that cases pursued and achieved particular outcomes (Fig. 4). We connect this discussion to the unique opportunities and critical risks associated with different approaches to navigating purpose, power, politics, and pathways (Fig. 5).

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Mode 1

Researching solutions. Here, scientists and decision-makers employing more 'realist' investigative methods[45] like ecosystem modelling, produced practical scientific knowledge, with the goal to influence policies and interventions. Cases varied in the relative power of scientists or decision-makers to define topics, but spanned relatively low social diversity of actors. These projects generated evidence that could inform or justify the approach of environmentally motivated decision-makers.

This was most effective within institutional contexts that supported actors to iteratively evolve relationships, questions, and methods over time, and adapt to shifting policy contexts[54]. However, this approach was less effective at shifting the strategies and priorities of decision-makers, who were more receptive to knowledge that helped rather than opposed their plans. The emphasis of these projects on lack of knowledge as the principal barrier to change therefore often limited their capacity to realise broader recommended shifts in management and policy. Cases also struggled to support emergent goals, such as addressing capacity needs. Effort to empower scientific knowledge risked marginalising the voices of other actors (and knowledge systems) who were excluded from the process but affected by resulting recommendations[21].

Mode 2

Empowering voices. These cases also co-produced knowledge to address ecosystem management and policy challenges, led by interdisciplinary scientists alongside community and/or government actors. However, they differ from mode 1 through their explicit intention to empower relatively marginalised actors and include greater social diversity, such as by supporting initiatives of local and indigenous communities. Cases created meaningful solutions for local actors and produced science to confront broader narratives that furthered ecosystem degradation and social inequalities[43,59]. Several cases navigated a careful balance between neither suppressing nor romanticising local views by developing respectful ways to integrate external expertise and expand problem definitions[40,43]. Compared with mode 1, cases emphasised process and more actively engaged with/in policy and management contexts, producing greater impacts[57]. Outcomes were enhanced for cases that prioritised process learning and quality, fulfilled capacity needs, and built institutions to evolve multi-scalar partnerships and activities over time. However, the strong emphasis on producing and empowering particular knowledge forms constrained possibilities for reframing. This knowledge could also be ignored by higher level decision-makers who were often not deeply involved, hindering initiatives' broader desired social equitability outcomes.

Mode 3

Brokering power. This mode was the smallest, and highly unique. Both cases engaged relatively powerful actors to develop long-term innovative institutions to address sustainability challenges. In contrast to modes 1 and 2, these cases fostered *dialogue around synthesised knowledge* and took direct policy and management actions, instead of mainly *producing scientific knowledge*. Both cases also equally focused on reframing problems *and* pursuing solutions, yet did so in distinct ways. One case created a safe space for international CEOs and scientists to reframe views of ocean sustainability problems to develop governance solutions[36]. The other case took collective action to restore a polluted river, using a shared concern as a pathway to build trust and reframe polarised relations in a cross-border conflict[38]. These cases used third party brokers and carefully controlled participation to facilitate safe spaces for dialogue, given the high potential for conflicts among identities and interests. Tracking process results was critical to fostering ongoing engagement and navigating a balance between speaking the language of powerful actors while trying to reframe thinking. Due to the stronger emphasis on scientific/technical expertise (over local knowledge and concerns), these cases risked legitimising existing power relations.

Mode 4

Reframing power. These cases engaged both relatively marginalised *and* powerful actors (e.g. local communities, and national NGO and government actors) to reframe technocratic narratives and shift practices and policies that marginalise social concerns[37,51,60]. Like mode 3, they were led by researchers alongside relatively powerful practitioners. However, in contrast, researchers explicitly sought to shift power away from powerful actors and towards marginalised actors whose perspectives they explored using 'relativist' critical social science methods. As a result, some reframing of dominant perspectives occurred; however, cases struggled to create 'safe enough spaces'[29] to do so. This was partly due to spanning multiple cultures, sectors, and identities during relatively short timelines[37], and partly related to their emphasis on producing knowledge (like modes 1 and 2) and little focus on institution building (unlike mode 3). This shifted the balance of power towards researchers, who faced the challenge of keeping work critical of power relations, while also trying to relinquish power to solutions-oriented actors to foster practical relevance[51,60]. Only cases with strong existing institutional roots or multi-scalar networks managed to somewhat shift policy and practice[37,60].

Mode 5

Navigating differences. This mode is distinguished from modes 1-4 through a stronger emphasis on managing processes of relating together, learning, and empowerment over producing and transferring scientific knowledge about human-ecosystem interactions. Researchers employed more 'relativist' methods[45], but in contrast to mode 4, they held less power. Facilitation techniques and boundary objects[61] were used to connect stakeholder groups to explore conflicts and reframe perspectives, while allowing new institutions, regulations, and practices to emerge. These processes valued all forms of expertise, and effectively minimised hierarchies to directly engage with actors across power differentials[31]. This model showed promising evidence of reframing, for example, by changing fixed notions of 'stakes' to more dynamic 'stakeholding'[34] and shifting scientific knowledge from a dominant position to a more democratic one[32]. The early focus on reframing (instead of generating solutions) allowed actors to navigate conflicting identities to build long-term (mean of 8 years) complementary bottom-up and top-down processes[32,42]. This resulted in higher attainment of policy and management outcomes. Some cases additionally linked diverse local co-production efforts through learning networks[34,35]. A few cases were blocked by unsupportive high-level actors, underscoring the importance of managing those risks and building trust across power differentials.

Mode 6

Reframing agency. These cases focused the least on using co-production to solve pre-defined problems. Led mostly by researchers with both highly relativist design and systems thinking backgrounds, they created safe spaces to identify collective forms of agency capable of addressing systemic governance issues, such as through urban/transformation labs[39,44]. These cases did not seek to empower particular knowledge, but instead allowed diverse knowledge forms to be expressed. To create safe spaces, they engaged environmentally-motivated change agents in local contexts, thereby spanning fewer conflicting identities and cultures. They also explored emotional and psychological anxieties related to questioning power and beliefs[39]. Despite their relatively short duration, these cases most effectively triggered reframing, illustrating the value of creating spaces without explicit solution agendas. For example, in one case participants realised an incongruence between their own narratives and practices, leading them to shift focus from agro-technologies to fostering social solidarity[44]. These

cases also trained participants to employ co-production approaches in their own work. Few shifts in policy and practice have been documented; however, these projects did not explicitly seek these outcomes and also were among the most recently completed. These cases struggled most to engage powerful impact-motivated actors and risked creating echo chambers (i.e. spaces where people encounter views that mainly coincide with their own).

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The outcomes and future of co-production for sustainability

This analysis unpacks the diverse design and implementation choices that fall within the growing field of co-production scholarship and practice for the sustainable development of ecosystems. The six co-production modes we identify show how distinct approaches to engaging with purpose, power, politics, and pathways are suited to achieving different types of outcomes. Yet, approaches also differ in their potential risks, such as creating echo chambers, reinforcing the status quo, and being co-opted by powerful vested interests (Fig. 5). By clarifying the connections between co-production choices and differential benefits and risks, we provide a heuristic tool to enhance understanding and design considerations where researchers and societal actors interweave knowledge and action for sustainability. For example, among our cases, design choices that prioritised relating together and systemic interpretations of agency were crucial to reframing perspectives, while knowledge-focused and solution-oriented approaches were better suited to influencing policy. Particular approaches may also be appropriate in different stages of a change process, and further research may explore the role of certain approaches in varying contexts[62]. We therefore argue that this diversity is a strength – different approaches contribute to change in distinct ways, if the associated risks are proactively managed (Fig. 5).

In accordance with other studies[13,16,63], our analysis shows that co-production requires careful facilitation to bridge diverse perspectives, values, and identities, and that multi-scalar and long-term engagement is essential for achieving outcomes (Fig. 6). Our cases collectively highlight just how varied the possible outcomes of co-production are, from informed policies and shifted narratives, to reshaped relations and institutions. Yet, particular synergies and trade-offs emerged among these outcomes (Fig. 6). For example, cases that fostered the most substantial reframing of perspectives and feelings of empowerment (e.g. in Reframing Agency) did not demonstrate shifts in policies or practices. Another notable trade-off is that the successful production of scientific knowledge was consistently negatively associated with attaining most other outcomes (Fig. 6). Similar to recent studies[13,15,64,65], our analysis suggests that the tendency of researchers to direct co-production resources to filling knowledge gaps – whether led by natural scientists (e.g. in Researching Solutions) or critical social scientists (e.g. in Reframing Power) – may actually hinder the attainment of other types of outcomes that inspire collective action, such as reframing narratives and building institutions.

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Our study suggests that co-produced scientific knowledge can further *existing* policy goals; however, when the goal is to fundamentally *reframe* policies, we found that cultivating dialogue and relations

that question problem definitions and explore systemic forms of agency are critical (e.g. Navigating Differences & Reframing Agency; Fig. 4). Co-production efforts that demonstrated the largest shifts in institutions and management practices directly supported researchers and diverse societal actors to iteratively balance critically reflexive and solutions-oriented spaces (e.g. Brokering Power & Navigating Differences; Fig. 4). This allowed actors to navigate different agendas for change to grow ideas and actions which were unforeseen from the outset. While several local cases spanned these dual reflexive and action-oriented purposes of co-production, we call for greater exploration of how to do so across scales, and in particular with globally powerful actors.

Despite the promising outcomes of diverse co-production practices, their ultimate sustainability impacts remain unclear since few cases monitored social (13%) and ecological (22%) aspects of sustainability, such as improved human well-being amidst more sustainable resource levels. Attributing such impacts to co-production processes is challenged by their often spatially and temporally dispersed and unanticipated effects. We therefore support others' calls for approaches that iteratively monitor impacts occurring within (and not just after) co-production processes to support adaptive learning while acknowledging complex and unpredictable impact pathways[1,9,12,19,66]. Indeed, such monitoring was linked to enhanced achievement of outcomes across our cases (Fig. 6). For example, one case examined people's cognitive maps, perception of agency, and social networks at multiple stages during the process to facilitate *and* document the changes occurring[44] (see Supplementary Table 4 for more approaches). We therefore echo existing concerns that funding paradigms and policy orientations requiring predefined problem definitions and impact pathways may constrain the full range of possible outcomes of co-production[5,66].

Undertaking this analysis enabled us to collectively and critically interrogate the diverse assumptions behind the purpose of our co-production practices, ways of navigating power and politics, and presumed pathways to sustainability. We have produced a heuristic that can be used to support researchers and practitioners to navigate the trade-offs and risks associated with different approaches to weaving knowledge, action, and change. Given similar co-production challenges around power, impact, and scale experienced across diverse fields[1,4,13,21,63], this tool may help facilitate critical reflection in other contexts, or otherwise inform the design of additional analyses that go even further in depth and wider in scope. We encourage the application of our heuristic as a reflexive tool to open up dialogue and strengthen transparency in design choices in co-production processes for sustainability, and welcome future evaluations of its effectiveness for guiding scholarship and practice.

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Author Contributions

J.M.C., C.W. and M.R. conceived the project and co-led the design of methods, with contributions from R.S.R., M.R., A.S., N.B., C.C., M.E.F.G., K.G., B.G., N.K., M.T., A.T.B., K.C., R.G., T.P. Authors J.M.C., M.R., C.W., R.S.R., and A.T.B organised and designed all workshops. J.M.C. coordinated the study, gathered all data, and led the data analysis in collaboration with all authors. J.M.C. and C.W. drafted the manuscript and all authors contributed and commented on drafts and the final version.

Competing Interests

The authors declare no competing interests.

Figure Captions

Figure 1. Overview of the 32 cases. Cases are grouped by the scale(s) at which the co-production work took place, while the map shows the geographical locations. Colors indicate the mode identities in Fig. 3. Listed contributors provided case materials and interviews, and held a senior leadership position in the case and/or extensively researched it. Additional case details are available in Supplementary Table 1. See Methods for details on the case selection process.

Figure 2. Eight key differences in how cases approach co-production. The number of cases that exhibited each approach at varying strengths is shown (lightest shade = no emphasis; darkest shade = very strong emphasis); E.g. 4 cases heavily focused on solving predefined problems, whereas 1 case did not define any solutions at the start. The correlations diagram shows the key tensions between blue and orange approaches, meaning that cases rarely managed to strongly employ both. See Methods for the scoring process of these approaches (dimensions) and Supplementary Table 2 for detailed 7-pt likert scale definitions and illustrative quotes.

Figure 3. Six modes of co-production identified by approaches to purpose, power, politics and pathways. Spider diagrams show the value of each of the 8 approaches for all case members of each mode. Case IDs and mode colors correspond to those in Fig. 1, demonstrating the high geographic and scalar diversity within each mode. See Methods for further details on the Hierarchical Clustering process.

Figure 4. Comparison of co-production modes by main features and outcomes. The +/- symbols indicate which mode means are significantly higher/lower for each dimension, with the overall significance of comparisons denoted (Kruskal-Wallis tests; $^{+}p < 0.10$, $*p < 0.05$, $**p < 0.01$, $***p < 0.001$). For example, modes 1, 2 and 4 achieved more knowledge production, whereas modes 5 and 6 achieved more reframing. Mode 3 rarely exhibited statistically significant differences due to its small size. Outcomes are grouped into intercorrelated sets (see Fig. 6). Results are grayed out when missing >50% of data for modes with 7-8 cases, and >25% data for modes with 2-4 cases. Descriptive dimensions that did not exhibit notable differences are not shown. See Supplementary Tables 3 & 4 for definitions of all descriptive and outcome dimensions, respectively, and Supplementary Fig. 1 for correlations among all descriptive dimensions.

Figure 5. The unique opportunities and critical risks of different modes of co-production. When co-production initiatives strongly express particular combinations of approaches to purpose, power, policies and pathways, they hold unique ability to achieve certain outcomes, but each approach is also linked to critical risks. For example, mode 1 (researching solutions) and 6 (reframing agency) face the opposite transformative potentials and risks. The ability of modes 3 and 5 to achieve multiple types of outcomes (see Fig. 4; e.g. reframing, networks, management practices, institution building) is related to their unique ability to span the dichotomies: purpose (problem solving *and* problem reframing) and politics (influence powerful *and* empower marginalised), respectively. In contrast modes 1 and 6 achieved fewer types of outcomes (see Fig. 4).

Figure 6. Dimensions most strongly associated with higher attainment of sustainability outcomes. The green/pink grid shows how achieving some outcomes is positively/negatively linked to achieving other outcomes ($*p < 0.05$, $**p < 0.01$, $***p < 0.001$). Knowledge production is the only

outcome that is not correlated with achieving any other outcomes, and even shows a consistent negative trend. The descriptive dimensions that are most strongly correlated with each sub-group of intercorrelated outcomes are listed in the gray boxes. The white box contains all dimensions that are significantly linked to higher attainment of outcomes across the board. The definitions for all descriptive and outcome dimensions, and common methods that cases used to assess them are available in Supplementary Tables 3 and 4, respectively.

Methods

This study was collaboratively produced by contributors of the 32 cases through an iterative exploratory and analytical process during 2017 – 2019. We took a dialogical approach[67] in the overall study design by deliberately iterating between analysis conducted by the lead author and interrogation of those analyses by case contributors over multiple stages (further described below). This allowed the lead author to maintain independence of interpretation by individually conducting all interviews and empirical analyses, while conceptual framings and analytical interpretations of the study were iteratively improved by the in-depth practical knowledge of the diverse range of co-production experts involved. Workshops were organised at two different stages of the analysis to also foster an interactive space to co-develop the focus, scope, and methods for the analysis (further described below). This iterative multi-stage analysis resulted in a highly robust methodological approach to advance collective knowledge around diverse co-production framings, approaches, and outcomes. Our choice to collaboratively produce this research is consistent with a growing number of scholars who underscore the importance of researchers producing knowledge with those who are actually implementing the work under study in order to produce rigorous knowledge of important practical experiences[68,26].

Collaboratively produced common inquiry framework

The research began with two participatory workshops, one convened at The Pew Charitable Trusts in Washington D.C., United States (May 23-25, 2017) and the other at the 2nd Programme on Ecosystem Change and Society (PECS) Conference in Oaxaca, Mexico (November 11-12, 2017). A number of scholars and practitioners working on different aspects of 'co-production' were invited to the Pew workshop, while participants self-selected into the PECS workshop, based on their interest and prior experience working on co-production. In these workshops, we grounded our analysis in the experience of the co-production cases. Case contributors responded to a series of open questions regarding co-production aims, practices, and outcomes, followed by participatory exercises to identify key differences and common challenges. The 25 participants in these workshops collectively represented more than 200 years of cumulative practical experience managing co-production initiatives for the sustainable development of ecosystems in 15 countries. Participants were diverse in terms of career stage, disciplinary background, and position, with half based in research institutes, and nearly all in positions operating at the interface of research and policy/practice (i.e. "scholar practitioners"). However, participants were predominantly women (80%) living in the Global North (85%), which undoubtedly shaped the discussions in the workshops. In an effort to rectify these biases, we subsequently conducted a wider review of relevant co-production literature to further develop the emerging common inquiry framework (i.e. a spreadsheet to inquire about important differences across diverse co-production cases) to guide subsequent data collection and analyses.

Systematic case selection

The 32 cases included some from the initial workshops (n=8) and others subsequently identified using Google Scholar (n=24). Our sampling approach followed an information-oriented, maximum variation approach to sampling – we selected cases that would give the greatest possible information about co-production for the

sustainable development of ecosystems – a sub-group in the domain of co-production for sustainability[30]. This selection strategy provided analytical power for exploring how different co-production aims, features, practices, and outcomes are interlinked. To select a broad range of cases, we chose to maximise diversity for sectoral involvement, the role of researchers, co-production practices, and geographical/scalar locations. While our sample has proven effective for identifying patterns, including the six modes of co-production, it has inherent limitations for attempting hypothetico-deduction. For example, we cannot determine which of these modes is more prevalent across the whole population of co-production for the sustainable development of ecosystems, or sustainability more broadly; nor can we draw general conclusions about the cause-effect linkages between modes and outcomes. A larger stratified random sample would be more effective for such purposes.

The eight cases selected from the workshops had been running for longer than 2 years and employed different co-production approaches to address challenges related to the sustainable development of ecosystems. The Google Scholar searches individually paired 10 ecosystem-focused variants of the term 'sustainability' such as 'social-ecological', 'ecosystem services' and 'marine conservation' with 22 variants of 'co-production' such as 'co-design', 'co-management', 'social learning', 'action research' and 'transdisciplinary' (see Supplementary Table 5 for a complete list of search terms). The co-production terms were selected by identifying key terminologies that appeared in co-production literature[1,13,14,16]. The range of sustainability and co-production terms ensured our selection of co-production initiatives that encompassed the diversity of approaches and contexts we found in the literature. Since we used Google Scholar to expand the diversity of our initial set of cases, our sample is biased towards co-production cases published in international peer-reviewed journals, as this work is more likely to be well known and highly cited. We set a clear 'co-production' boundary for our set of cases by excluding cases that were captured by our search terms, but were not interweaving knowledge, action and change. For example, collaborative governance interventions were only included in this study if they interweaved knowledge, action and change among participants; this meant excluding NGO or state led participatory interventions that did not involve researchers.

Despite the leading role of researchers in many cases, we sought to gather cases that spanned diverse research roles, from practitioners conducting knowledge synthesis, to researchers generating knowledge or facilitating dialogue. It was also difficult to engage local projects led by non-English speakers who do not have international networks. We therefore actively sought to include cases from a diverse range of contexts, with multiple cases in each broad geographical region, to incorporate some degree of cultural diversity. We acknowledge, however, that we first prioritised diversity in terms of co-production approaches, and only one-fifth of our sample is both located in the Global South *and* led by citizens of those countries. We therefore underscore the need for further work to examine approaches to co-production led by citizens of the Global South. Only three potential case contributors that we contacted declined to be involved in the project.

Data collection

Applying the common inquiry framework developed in the initial stage of the research, we collected the following qualitative data for each case: 1) how co-production and sustainability challenges are framed, 2) how co-production is designed and implemented in practice, 3) the rationales underpinning decisions on how to co-produce, 4) capacities which support or hinder co-production, and 5) outcomes of co-production. The lead author (J.M.C.) completed a qualitative spreadsheet in partnership with a key representative of each case. For 29 cases, this was a senior leader in the co-production process, while for 3 cases, this was someone who had extensively researched the case. The lead author interviewed most case representatives for approximately an hour to gather further qualitative information related to written responses in the spreadsheet. In a few cases, this was not necessary, as we gained sufficient case detail through email correspondence. To understand a broader range of perspectives of people involved in each project, we also reviewed a mean of 6 documents and publications per case (186 total), reviewing a greater number if the case was not yet published in peer-reviewed

literature. The lead author worked individually with each case contributor (an expert in the particular co-production process) to gather relevant and reliable materials to inform interpretations of the case, which spanned a mixture of scientific articles, grey literature, and internal documents. To ensure a robust assessment of outcomes across different forms of evidence, the lead author scored the quality of the evidence for each reported outcome by each case, and consulted with the case contributor to ensure further evidence was unavailable. The 22 missing data squares in Fig. 4 reflect the exercised judgment of the lead author that the quality of evidence was insufficient to substantiate claims regarding those outcomes. Given the sensitive nature of reporting outcomes and case difficulties, to enhance open exchange and accurate reporting, case contributors were given the opportunity to indicate any parts of the data gathered about their project that they wish to remain anonymous in any outputs related to this project.

Preliminary analysis and testing of dimensions of difference

The lead author (J.M.C.) conducted a preliminary analysis by qualitatively coding each of the five aforementioned categories of data using NVivo Software, grounded in the data from and understanding about each case from the case contributors[69]. Two rounds of coding of the common inquiry spreadsheets (completed for each case) and additional case documents and interviews led to the identification of numerous qualitatively described dimensions of difference across all cases. These dimensions captured how the sample of co-production cases varied in how they were framed, designed, implemented, supported by certain capacities, and pursued and produced particular outcomes. These findings were then presented in a 13,000-word report and interrogated in an interactive two-day workshop in Colorado, United States (July 16-17, 2018) with 14 case contributors and experts in co-production. Participants discussed the content and framing of the dimensions through dynamic exercises, identified if important aspects were missing, and elaborated questions and methods for further analysis. A subsequent half-day workshop was held with 15 practitioners/researchers in Cambridge, United Kingdom (August 9, 2018) to explore the relevance and framing of the emerging list of dimensions of difference across cases with people who were generally not as familiar with co-production terminology and approaches. A final list of 72 specific dimensions therefore emerged from a rigorous iterative process that inductively identified critical points of difference across all cases.

Secondary analysis based on final analytical dimensions

The final list of 72 dimensions of difference across all cases guided the secondary analysis. The dimensions used in this analysis include different ways that co-production cases were framed (8), designed (16), and implemented (16), capacities that shaped how co-production cases functioned (4), and distinct outcomes that were intended (14) and produced (14). Each of the 14 outcomes were additionally scored on the extent to which they were assessed, if assessment had occurred. If the assessment method was evaluated by the lead author (in consultation with the case contributor) as being too poor of quality to assess particular outcomes, the achievement score was recorded as missing in the data set. Supplementary Table 4 presents the typical methods that were used to assess outcomes across the cases, including some of the most innovative approaches.

We employed fuzzy-set social science methods[70] to devise a scoring process to indicate the extent that cases exhibited particular dimensions. Fuzzy-sets provide a flexible approach for translating relevant and at times overlapping concepts that emerge from qualitative analysis into a quantitative framework that indicates the extent to which cases exhibit each feature (usually on a scale from 0-1)[70]. In this case, we found it was more straightforward to use a 7-point likert scale to define relevant steps for each dimension and then scored each case for each dimension. This allowed us to document step-wise differences, without needing to provide non-overlapping categories (i.e. exhibiting either one dimension or another, rather than some of each) that would lack precise meaning. To maintain a degree of independence of interpretation across all cases, for each of the 32 cases, the lead author (J.M.C.) then reviewed all case documents and interviews an additional time to score each case on a 7-point likert scale for each of the 72 dimensions. A score of 1 indicated that the case did not exhibit

that dimension, whereas a score of 7 indicated that the case highly exhibited that dimension (e.g. for the dimension 'intended networks'; 1 = no intention to reshape networks; 7; very strong intention to reshape networks).

Qualitative descriptions were recorded to justify each quantitative score, alongside illustrative quotes from case materials that further justified and explained those choices. Each case contributor reviewed and commented on the full set of scores and justifications/quotes to enhance the accuracy of the scoring process. The lead researcher also discussed dimensions that required further explanation with case contributors through a second hour-long skype call, or in a few cases, email correspondences. Following the revision of all scores and justifications, the lead researcher reviewed the qualitative descriptions for each numerical value of the likert scales to refine the precise meaning of each distinct step in all of the 7-point likert scales. Some case scores were then slightly adjusted according to the precise definitions to ensure consistency of the comparative scoring across all cases. The full list of definitions for all 7-point likert scales used in this analysis are available in Supplementary Tables 2, 3 and 4. The qualitative descriptions of all dimensions were coded and analysed in comparison to emerging literature on co-production approaches in order to identify the key dimensions of difference (the four 'Ps'). Quotes also helped explain the patterns that emerged in the statistical analyses.

The production of this study by 42 people, many of whom are leading scholars in co-production and sustainability scholarship and practice, was essential for producing a salient and legitimate output that accurately reflects a rich breadth of co-production experience and perspectives. Moreover, many of the authors both conduct research on as well as practice co-production. Given the diversity of backgrounds, expertise, and experiences of the authors who collaboratively produced this study, a key component of the analysis focused on dialogue around different perspectives and approaches to co-production. This facilitated an analytical design that was both rigorous and reflexive, in which all co-authors were able to question their own views of co-production against others and draw collective insights.

Statistical analyses

All statistical analyses and visualisations were done using R version 3.6.1[71]. Given the large number of descriptive dimensions (36) and outcome dimensions (14 intended and 14 achieved), with substantial missing data for 5 achieved outcomes, we did not seek to determine causal patterns leading to specific outcomes. Rather, we sought to identify important differences in the overall designs/goals of co-production cases, and then use complementary quantitative and qualitative analyses to identify key features and broad patterns associated with the full range of outcome dimensions. Our secondary analysis and review of related literature identified four overarching themes (Fig. 2), with two alternate approaches to each, as being particularly important in directing projects towards different types of practices and intended outcomes. These alternate approaches to co-production for each theme are: for purpose, either to more effectively solve predefined problems, or to reframe problems; for power either focusing on the behaviour of actors directly linked to sustainability problems, or targeting more systemic aspects; for politics either empowering marginalised actors, or influencing powerful actors to yield power; and for pathways, either by primarily producing scientific knowledge as a product that is expected to shape policy and/or practice, or through more integrated forms of knowing, relating and doing.

To identify distinct modes of co-production, we conducted Hierarchical Cluster Analysis (HCA) using the eight approaches to co-production outlined above (and in Fig. 2). The NbClust[72] package in R identified six clusters as the optimal number, based on the peak of the Dindex second differences plot. The R Packages tidyverse[73], cluster[74], factoextra[75], and dendextend[76] were used to conduct the HCA, using Euclidian distance as the dissimilarity matrix coefficient and Ward's method of hierarchical clustering to minimise the error in sum of squares[58]. The R package fmsb[77] was used to generate the radar charts displayed in Figure 3. The R stats package[71] heatmap function was used to generate visual diagrams to show how case clusters differ (Fig. 4). The

qualitative descriptions associated with the scores for each case were also reviewed to help describe each cluster (i.e. mode). The qualitative analysis confirmed that all modes were well defined by important differences, and that even though one mode was especially small (#3), its highly unique nature merited its separation from other modes.

Unique features of each mode were examined by testing for significant differences between mode means for each descriptive dimension, using the stats package[71] to conduct Kruskal-Wallis tests. Pairwise Wilcoxon signed-rank tests revealed which pairs of modes were significantly different for each dimension. Relatively few significant differences emerged between mode 3 and other modes due to there being only two cases in the mode. To reduce the large number of descriptive dimensions, Principal Component Analyses (PCA) were conducted on three different sets of highly inter-correlated dimensions using R packages stats[71] and ggbiplot[78]. For example, the dimension 'coproduced process' is a principal component that explains 82.1% of the variance of the extent to which the case was co-designed and co-practiced. Similarly, the dimension 'supportive context' explains 81.5% of the variance for two dimensions that indicate how well cases were supported by external funding and other contextual dynamics. Finally, the dimension 'expertly facilitated' explains 57.3% of the variance of nine highly intercorrelated dimensions related to the extent that cases organised roles, facilitated knowledge, and navigated issues of conflict and power.

The R packages qgraph[79], SemiPar[80] and Hmisc[81] were used to visualise correlation networks among the eight key dimensions (Fig. 2). To explore correlations between achieved outcomes, we calculated Spearman's Rank correlation coefficients and their p-values. For intended outcomes, we used the direct 7-point likert scale scores (see Supplementary Table 4). However, this was not possible for achieved outcomes because the meaning of an outcome that was highly achieved (i.e. score = 7) greatly varied for a case that highly intended that outcome versus one that weakly intended it and conducted few related activities. In order to calculate each achieved outcome, we therefore multiplied the extent to which it was achieved (e.g. score of 5 = 5/7) by the intention score (e.g. 5). In this way, a moderately achieved outcome that was highly intended was made equivalent to a moderately intended outcome that was highly achieved. To identify the list of nine descriptive dimensions significantly correlated to achieving outcomes across the board, we used the mean of eleven outcome dimensions, as three outcomes had insufficient data across cases.

Data availability

The data analysed in this study can be made available upon request, with a few limitations. Quantitative data on outcomes cannot be shared at the level of individual cases because some projects are still ongoing, and some projects have not met their anticipated outcomes; thus, sharing this data could negatively impact projects and their participants. However, complete quantitative data can be provided at the level of each of the six modes, keeping the specific case identities anonymous. In addition, qualitative codes can be shared to provide further details of the qualitative analytical process.

At the level of individual cases, if people wish to access data for a specific case, they will be put in touch with the contributor of that case (also a co-author of this manuscript), who must be informed of the data being requested and the intended use for it. Each case contributor will then provide the final say on whether they wish to share their own quantitative and qualitative case data on a case by case basis. These protective steps were critical for ensuring a safe environment for case contributors to share many critical perspectives related to the challenges and outcomes of their cases, thereby ensuring an ethical analysis with accurate results.

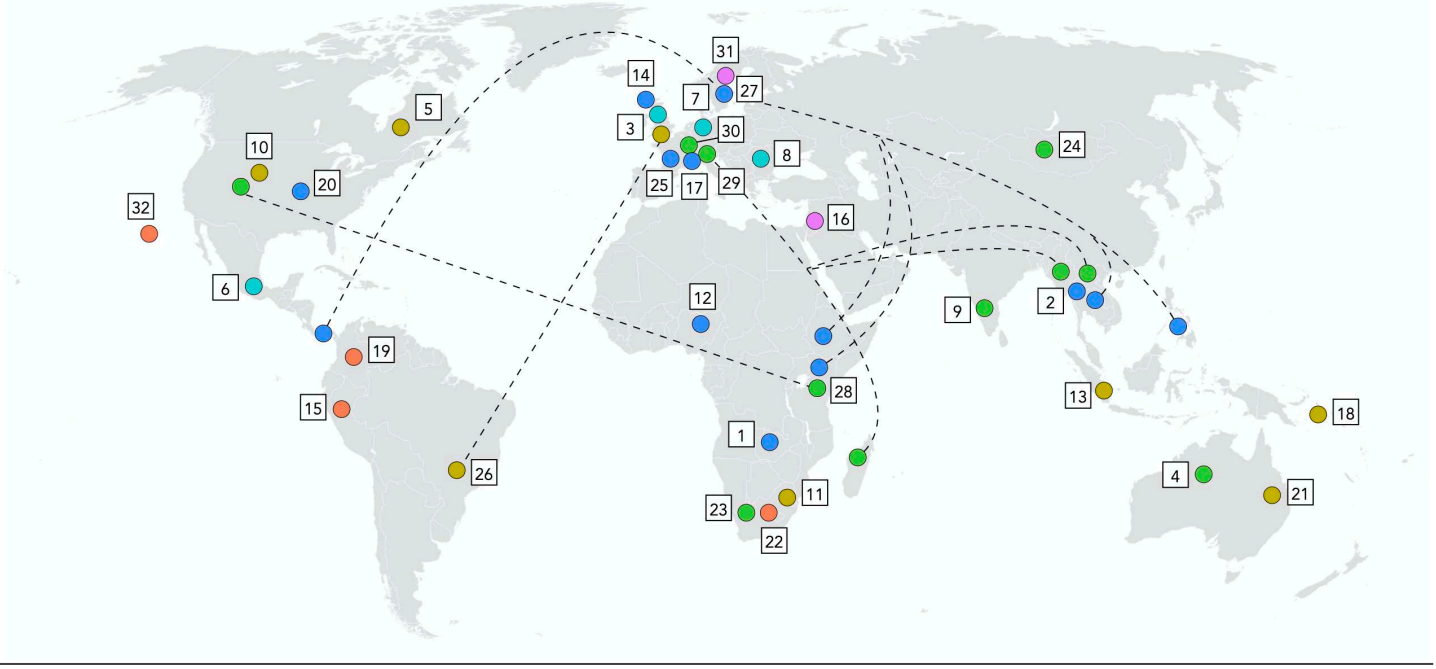
Code availability

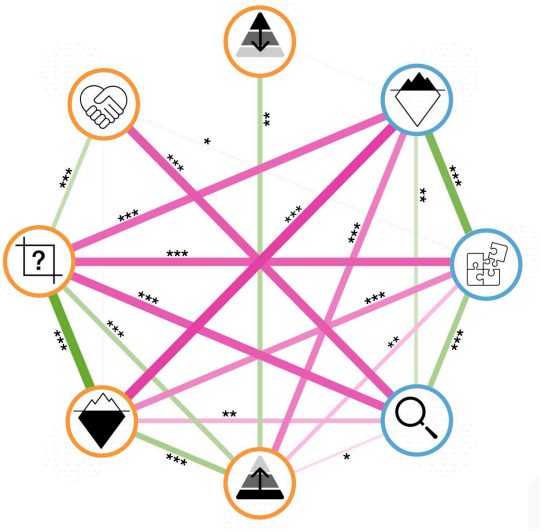
The codes used in R to produce all statistics and figures can be made available upon request.

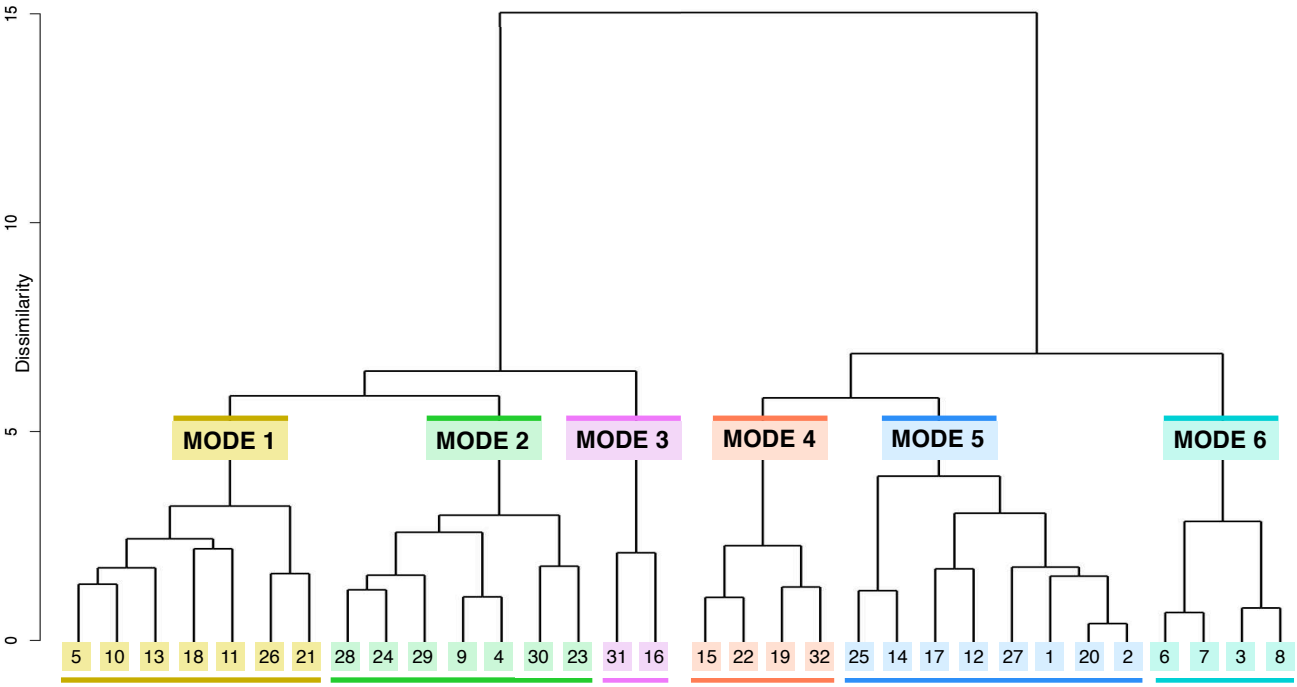
Ethics

The institution that hosted this study (Luc Hoffmann Institute) does not have a formal research ethics approval process; however, we nevertheless developed our own procedure for this project, which complied with the Department of Geography Ethics Review Group guidelines at the University of Cambridge. Furthermore, all interviewees of this study are also co-authors on this manuscript, so they were involved in the decisions made throughout the entire process related to ethical concerns, with active steps taken to recognise their individual contributions, and to protect the confidentiality of their data. Each case contributor additionally communicated with the main proponents of their initiative to seek informed consent for the inclusion of the case in this research. In the majority of cases, case contributors were themselves a main project proponent, although in some cases, they had extensively researched it.

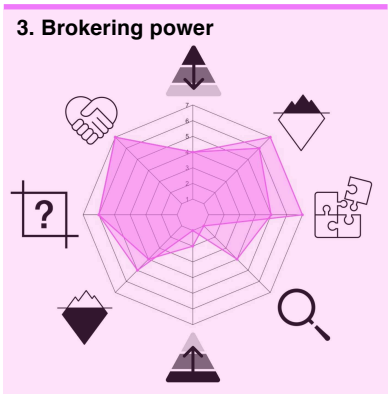
	Id	Case description	Timeline	Contributor(s)*
Mostly Local scale	1	Crafting local ownership of institution-building processes (i.e. Constitutionality): The case of the Kafue Flats fisheries in Zambia	2005-2010	Tobias Haller
	2	Gaming and simulation for co-learning to mitigate conflict and support collective action in Doi Tiew village, Northern Thailand	2007-2010	Pongchai Dumrongrojwatthana
	3	Exploring radically different institutional personae to recast urban governance through co-production laboratories in Leeds, UK	2015-2017	Paul Chatterton
	4	Co-producing knowledge to manage Indigenous lands under a changing climate with an Arrernte community in Northern Australia	2013-2019	Rosemary Hill
	5	Montérégie Connection: Developing ecosystem models to improve land management in Mont-Saint-Hilaire, Quebec	2011-2014	Elena Bennett
	6	Promoting agency for social-ecological transformation through a Transformation-Lab in Xochimilco, Mexico City	2016-2019	Lakshmi Charli-Joseph
	7	Favourite places: Exploring emotional responses to landscape change in Oldenburg, Germany through social landart (land art)	2017-2018	Maraja Riechers
Sub-national & Local	8	Amplifying sustainability initiatives in Southern Transylvania through strengthening networks and analyzing leverage points	2016-2019	Andra Horcea-Milcu
	9	Assessing the socioeconomic and environmental implications of land sharing and land sparing strategies in the Western Ghats	2013-2018	Anca Serban
	10	Developing climate scenarios and ecological response models to build social-ecological climate resilience in Colorado, US	2013-2018	Renee Rondeau & Carina Wyborn
	11	Building the Durban Research Action Partnership to improve local land-use planning and management around Durban, South Africa	2011-pres.	Jessica Cockburn
	12	GyaraYankari: Establishing inclusive participatory protected area management in Yankari Game Reserve, Nigeria	2016-2018	Salamatu Fada
	13	Co-producing knowledge to develop and negotiate payment for watershed services schemes in Indonesia	2012-2015	Beria Leimona
	14	Probing the cultural depths of a nature conservation conflict in the Outer Hebrides, Scotland	2009-2015	Ruth Brennan
	15	Reframing 'win-win' conservation and development theory and practice with conservation organizations in northeast Peru	2013-2019	Josephine Chambers
National, Sub-national & Local	16	Alexander River Restoration Project: Restoring a heavily polluted river and fostering cooperation across the Israel-Palestine border	1995-pres.	Amos Brandeis
	17	Chasseral Regional Nature Park: Top-down and bottom-up institution building for landscape management in Switzerland	1997-pres.	Jean-David Gerber
	18	Improving the uptake of climate models by South Pacific communities and NGOs to build adaptive capacity to climate change	2013-2014	Chris Cvitanovic
	19	Future-Proofing Conservation: Enabling adaptive governance in Colombia's protected areas amidst climate uncertainty	2015-2018	Claudia Munera & Carina Wyborn
	20	Enhancing fire-adaptation capacity at multiple scales in the US through The Fire Adapted Community Learning Network (FAC-NET)	2013-pres.	Bruce Goldstein
	21	eWater Cooperative Research Centre: Developing a national eco-hydrological modeling and decision support platform in Australia	2005-2012	Melanie Ryan
	22	Addressing the socio-ecological impacts of conversions to game farming amidst post-Apartheid conflicts and power imbalances	2007-2014	Marja Spierenburg
	23	Co-producing knowledge and spanning boundaries to promote implementation of freshwater conservation plans in South Africa	2008-2012	Jeanne Nel
	24	Mongolian Rangelands and Resilience (MOR2) Project: Examining pastoral social-ecological systems in rural Mongolia	2008-2015	María Fernández-Giménez
	25	SLIM project: Analyzing and developing social learning processes for integrated water management in 12 sites across Europe	2001-2004	Patrick Steyaert
Global & Other scales	26	Contacted: Developing a science-policy-practice framework to reduce environmental risks from production and trade of soy in Cerrado, Brazil	2014-2018	Paz Durán, Jonathan Green & Angela Guerrero
	27	Connecting diverse knowledge systems at multiple scales in IPBES assessments and related science-policy contexts	2011-pres.	Maria Tengö
	28	Using science to support community-level and national-level action on conservation and pastoral development issues in East Africa	1999-pres.	Robin Reid & Kathleen Galvin
	29	Innovating to secure ecosystem services and well-being in telecoupled landscapes in Madagascar, Myanmar and Laos	2015-2020	Julie Zähringer
	30	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES): Strengthening science-policy interfaces	2012-pres.	Jasper Montana
	31	SeaBOS, emerging from Keystone Dialogues: Connecting science with global seafood industry leaders for ocean stewardship	2012-pres.	Henrik Österblom
	32	Developing a global think tank to address the human dimensions of Large Scale Marine Protected Areas (LSMPAs)	2014-2017	Nathan Bennett

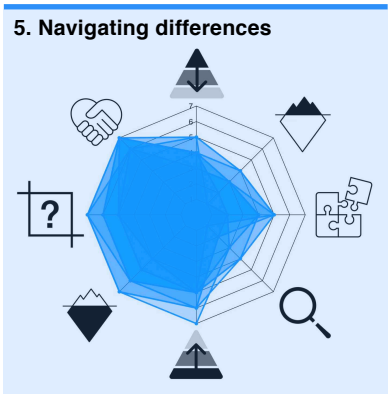


Theme	Approach
Purpose Why do actors co-produce?	**To solve problems** 1 5 2 5 6 9 4 Extent the case uses co-production to pursue solutions to problems defined near the beginning **To reframe problems** 0 3 3 3 8 5 10 Extent the case actively facilitates reframing of views of problems and solutions during co-production
Power How is human agency conceptualised?	**Shaping direct agency** 3 2 8 4 5 6 4 Extent the case focuses on changing the behaviour of actors directly linked to sustainability problems **Shaping systemic agency** 1 2 3 4 10 6 6 Extent the case focuses on challenging paradigms and goals at higher governance scales
Politics How are power relations changed?	**Influencing powerful actors** 2 4 9 9 8 0 0 Extent the case engages powerful actors to reduce their own and peers' power over marginalised actors **Empowering marginalised actors** 1 8 3 5 11 3 1 Extent the case engages marginalised actors to iteratively shift power relations with powerful actors
Pathways How are impacts cataylsed?	**By producing knowledge** 2 4 4 4 6 6 6 Extent the case relies on expected transfer of scientific knowledge products to generate intended impacts **By relating together** 0 1 6 8 3 6 8 Extent the case focuses on relating and doing together to create space for emergent outcomes
Dimension relations 1 0.8 0.6 0.4 0.2 0 -0.2 -0.4 -0.6 -0.8 -1 * p<0.05 ** p<0.01 *** p<0.001	

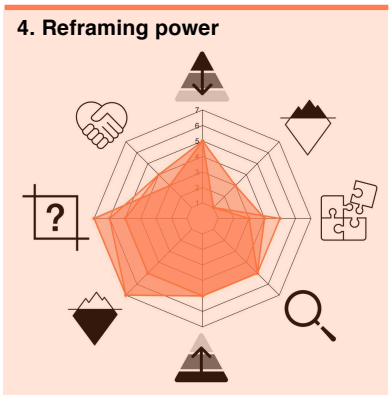

Dissimilarity
15
10
5
0
MODE 1
MODE 2
MODE 3
MODE 4
MODE 5
MODE 6
5 10 13 18 11 26 21
28 24 29 9 4 30 23
31 16
15 22 19 32
25 14 17 12 27 1 20 2
6 7 3 8

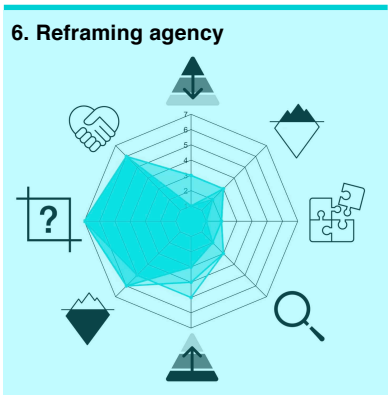

1. Researching solutions

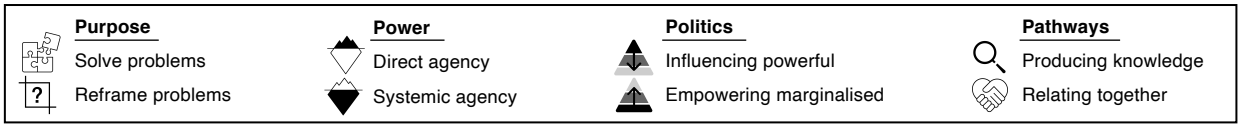

3. Brokering power

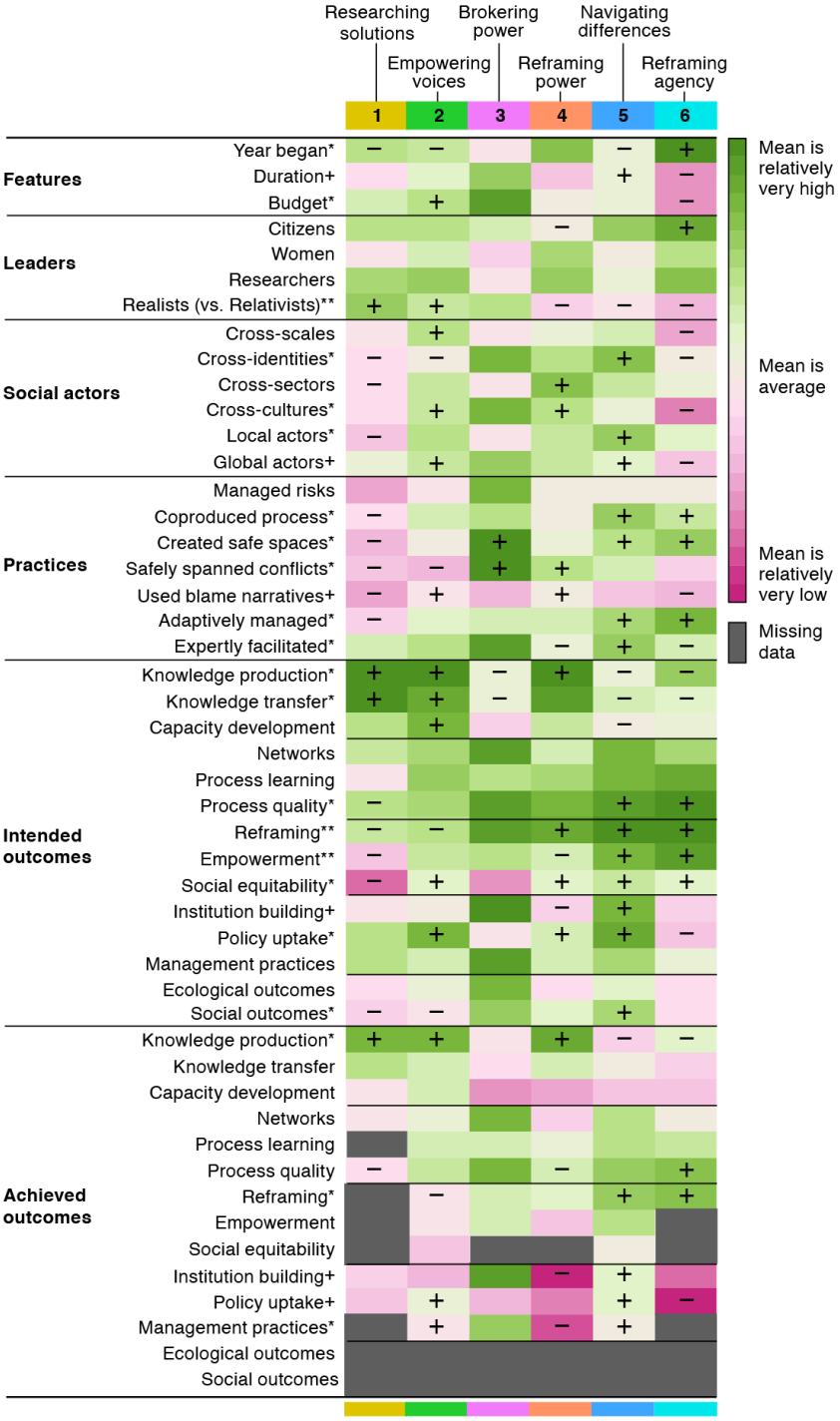

5. Navigating differences


2. Empowering voices

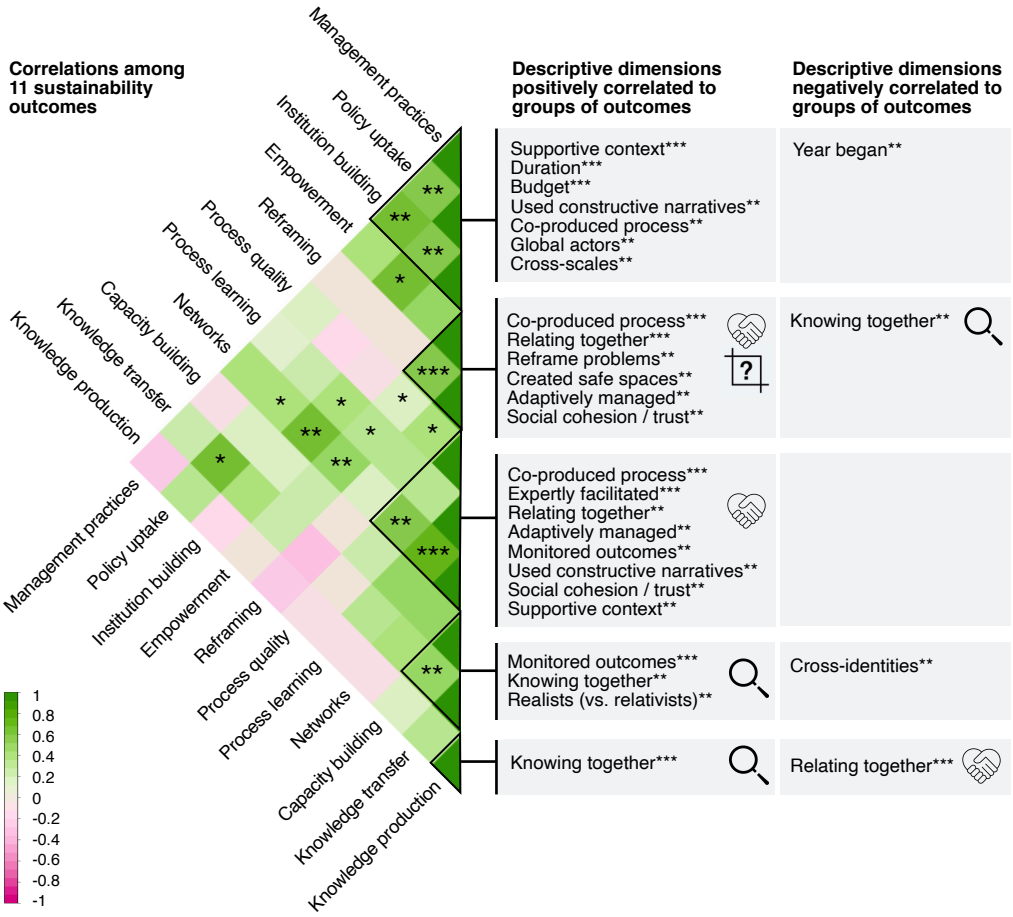

4. Reframing power


6. Reframing agency


Purpose
Solve problems
Reframe problems
Power
Direct agency
Systemic agency
Politics
Influencing powerful
Empowering marginalised
Pathways
Producing knowledge
Relating together


Researching solutions
Empowering voices
Brokering power
Reframing power
Navigating differences
Reframing agency
1
2
3
4
5
6
Features
Year began*
Duration+
Budget*
Leaders
Citizens
Women
Researchers
Realists (vs. Relativists)**
Social actors
Cross-scales
Cross-identities*
Cross-sectors
Cross-cultures*
Local actors*
Global actors+
Practices
Managed risks
Coproduced process*
Created safe spaces*
Safely spanned conflicts*
Used blame narratives+
Adaptively managed*
Expertly facilitated*
Intended outcomes
Knowledge production*
Knowledge transfer*
Capacity development
Networks
Process learning
Process quality*
Reframing**
Empowerment**
Social equitability*
Institution building+
Policy uptake*
Management practices
Ecological outcomes
Social outcomes*
Achieved outcomes
Knowledge production*
Knowledge transfer
Capacity development
Networks
Process learning
Process quality
Reframing*
Empowerment
Social equitability
Institution building+
Policy uptake+
Management practices*
Ecological outcomes
Social outcomes
Mean is relatively very high
Mean is average
Mean is relatively very low
Missing data

Clusters	Approach	Unique opportunities	Critical risks
Researching solutions; Empowering voices; Reframing power; Navigating differences; Reframing agency; Brokering power	 **Direct agency**	*Can achieve specific set goals (e.g. building an ecosystem model)*	• More likely to overly place blame on marginalized actors for sustainability problems • Less attention to process and equitability can result in superficial engagement with marginalized actors • Interventions may legitimize existing power relations and systems
	 **Solve problems**	*Can produce and transfer knowledge to inform and justify policy changes that decision-makers already want to make*	• Projects may struggle to engage actors that they seek to influence due to prioritizing their own values and solutions • More likely to reinforce already dominant views of problems and solutions and to obscure alternatives • Can inhibit the potential to reframe perspectives
	 **Producing knowledge**		• May create echo chambers that fetishize the power of knowledge to create desired impacts • Emphasis on the value of scientific knowledge can crowd out alternative expertise and ideas • Tying of budgets to fixed knowledge production activities may inhibit the pursuit of emergent goals
	 **Empowering marginalised**	*Can produce and transfer knowledge to advocate for higher level policy changes, build capacities, and address local needs*	• May fetishize the role of speaking 'truth' to power to shift higher level views and policies • Efforts to empower particular views can inhibit possibilities for reframing perspectives • Powerful actors may block processes that are against their interests, especially if blame narratives are used • May overlook power imbalances and politics occurring within local settings
	 **Systemic agency**	*Can fundamentally shift views to co-develop more creative and transformative possibilities*	• Expanding the problem frame can disempower actors if problems then feel too 'big' to handle • May be less effective if emotional aspects such as anxieties about losing power are not addressed • Efforts that span few identity conflicts and power differentials can result in echo chambers • May result in talk shops that don't produce action
	 **Reframe problems**		• Solution-oriented actors may not want to engage • Reflexivity can inhibit developing concrete actions • Successful reframing alone may fail to trigger shifts in policies and practices • Emphasizing points of difference too soon can inhibit common ground
	 **Relating together**	*Can build legitimate and flexible processes to empower tangible changes to perspectives, networks, institutions, policies, and practices*	• Apparent cooperation and consensus can be the result of subjugation if power dynamics are poorly managed • Social inequalities may be accelerated if voluntary contributions are not suitably valued
	 **Influencing powerful**		• Very risky without high legitimacy, strong networks and highly skilled facilitation and brokering to create safe spaces for reflection and dialogue • Actors involved may try to co-opt the process to serve their own interests • Exclusion of marginalized actors may lead to solutions that further marginalize them



Dimensions significantly linked to higher attainment of outcomes across the board

1. Highly collaboratively designed and practiced process (co-produced process***)
2. Very effective facilitation across social-political differences (expertly facilitated***)
3. Very supportive funding arrangement and broader context (supportive context***)
4. Extensive effort to monitor process and results oriented outcomes (monitored outcomes***)
5. Strong levels of social cohesion and trust reached among actors (social cohesion/trust***)
6. Use of narratives that frame issues constructively (use constructive narratives**)
7. Engagement with actors that work at higher scales during the process (global actors**)
8. Collaborative processes that continue to engage over long periods (duration*)
9. Processes that connect work across local/regional and national/global scales (cross-scales*)