



Building knowledge infrastructure for diverse stakeholders to scale up co-production equitably

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Emerging sustainability research has called for scaling up co-production because sustainability challenges span administrative, institutional, cultural, and physical boundaries and often occur at different scales than co-production tends to happen. To scale up co-production equitably, any such efforts must center the power dynamics intrinsic to rescaling. We highlight how scale itself is constructed by different actors and that the reconfiguration of scale has implications for power asymmetries among different stakeholders and communities. We call for new knowledge infrastructures to support and sustain multi-scalar and multi-stakeholder networks that reflect the impacts of sustainability challenges. We propose four principles to guide the development of knowledge infrastructure that will delineate the values, relationships, and power dynamics among different actors that produce knowledge, with the goal of building the capacity of local communities to reconfigure science and governance relationships that prioritize local needs in regional and global partnerships.

Addresses

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Current Opinion in Environmental Sustainability 2022, **54**:101156

This review comes from a themed issue on **The role of infrastructure in societal transformations**

Edited by **Melissa R Gilbert**, **Hallie Eakin** and **Timon McPhearson**

For complete overview of the section, please refer to the article collection, "[The role of infrastructure in societal transformations](#)"

Available online 11th February 2022

Received: 12 July 2021; Accepted: 01 February 2022

<https://doi.org/10.1016/j.cosust.2022.101156>

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Introduction

Knowledge co-production is a process that engages diverse stakeholders to collaboratively produce new knowledge and practices that promote sustainable

transformations, emphasizing the multiple perspectives and kinds of knowledge that different stakeholders bring to the table [1^{••}]. Co-production among researchers, policy makers, community organizations, residents, and industry has become a ‘best practice’ for creating usable knowledge in sustainability science [2]. Co-production makes knowledge usable by prioritizing meaningful and sustained interactions among researchers and decision-makers [3]. Bringing together diverse groups, embracing pluralism, being attentive to context, and focusing on goals and outcomes are all essential to knowledge co-production [4[•]].

Emerging sustainability research has called for scaling up co-production [5,6]. Efforts at co-producing knowledge often take place at a local scale, where stakeholders can have the meaningful, sustained, trust-building interactions needed to successfully collaborate in producing accessible, credible, and relevant knowledge [7–9]. Yet many urgent sustainability challenges occur at regional or global scales, such as coastal and riverine flooding or climate change. Further, sustainable infrastructure, like energy distribution systems, may connect proximate and distal communities [9,10]. Scaling up co-production faces both logistical and conceptual challenges. Researchers have started to detail the ways that such regional and global transdisciplinary collaborations may be encouraged through funding requirements [11^{••},12–14], boundary organizations [4[•],5,15–17], facilitators [18], and evaluation frameworks [3].

We argue that any such efforts to scale up co-production must center the power dynamics intrinsic to rescaling. Scaling up is often conceptualized as a process that engages more stakeholders across multiple places to address key sustainability challenges, where the scale at which the sustainability challenge is defined (e.g. a watershed) is predetermined by ecological processes [19]. However, it is important to recognize that the scales at which sustainability challenges are defined also result from the priorities and actions of differently empowered actors [20–23]. Consequently, scales are socio-spatial expressions of power. Scaling up co-production will create new configurations of stakeholders that are influenced by asymmetrical power dynamics, in addition to ecological processes [19]. If co-production is to produce usable knowledge that advances equity at broader scales, such rescaling processes must ensure that all communities,

voices, values, and perspectives are included and that local needs — particularly the needs of marginalized or vulnerable communities — are not subverted by regional or global power dynamics [24].

In this article, we propose knowledge infrastructure as a conceptual and organizational resource that precedes, facilitates, and builds capacity for equitable regional and global co-production. If sustainable infrastructure is the apparatus supporting social and ecological sustainability, knowledge infrastructure is the substrate supporting how the issues are conceptualized and acted upon (Figure 1). Knowledge infrastructures are networks of people (e.g. policy makers, researchers, government officials, community members) and institutions who ‘generate, share, and maintain specific knowledge about the human and natural world.’ [40]. Knowledge infrastructures not only allow for the development of these shared understandings, but they also cultivate a community of stewards for shared knowledge over time across the boundaries of stakeholder organizations, similar to the role that long-tenured administrators perform in maintaining ‘institutional knowledge’ within organizations. These knowledge infrastructures are important because they directly inform how decisions are made about environmental problems [30,41], advance the development of global sustainability policies [40], and shape how sustainable infrastructure is conceptualized and addressed. We

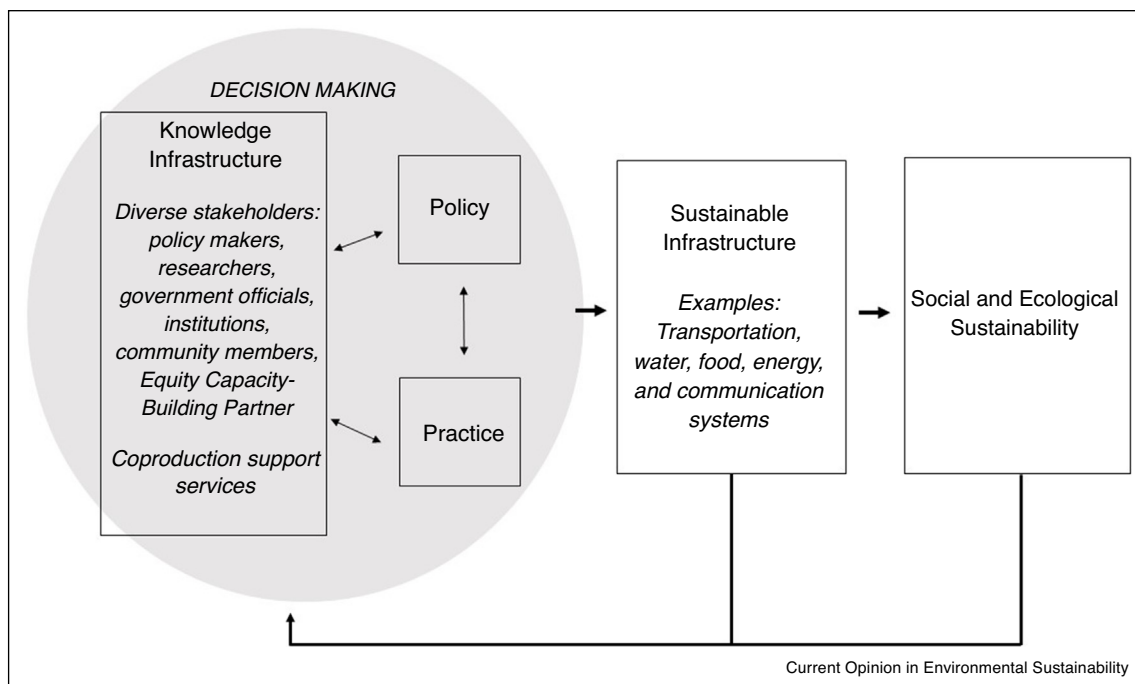
propose four principles to support the development of knowledge infrastructures that center power dynamics and build capacity to scale up co-production equitably across diverse regional and global network scaling.

Challenges to scaling up co-production

Knowledge co-production promises to provide usable and relevant knowledge because it brings together different yet complementary skills and contextual knowledge of diverse stakeholders. However, doing co-production effectively is complex and challenging. Diverse stakeholders may have competing interests, and there is a need to build trust among stakeholders who may not have prior relationships, or who may have a history marked by conflict or disputes [26]. Lemos *et al.* point out that co-production requires more time, funding, facilitation, and commitment than other modes of knowledge production [5]. Co-production, when done effectively, involves deliberation and debate [27] and requires embracing contestation in order to ensure that all perspectives maintain a voice in the process [28].

Scaling up co-production only compounds the challenges experienced at local scales. With more groups and stakeholders involved, the network of competing, conflicting, and collaborating interests becomes even more complex. Further, these collaborations may have less history of working together and more divergent interests based

Figure 1



Relationship between knowledge infrastructure and sustainable infrastructure, building on Larkin [25]. Sustainable infrastructure is the apparatus supporting social and ecological sustainability, and knowledge infrastructure is the substrate supporting how the issues are conceptualized and acted upon.

on their geography, local experiences, and the scale of environmental challenges. Scaling up co-production must also contend with how scale itself is produced, which involves examining how different actors are empowered or disempowered at various scales and can shape the priorities and actions of these scalar arrangements [19,23]. For instance, researchers have raised questions about how to build trust across regions when that trust is typically built through repeated interactions among stakeholders [3,11^{••}]. Lemos *et al.* found that in-person interactions are important in situations involving uncertainty, highly complex information, local politics, or when distrust of science is present [8]. Many sustainability challenges have one or more of these characteristics, yet facilitating repeated in-person interactions is exponentially more challenging at regional or global scales than it is for local networks of actors.

Siloed institutions and existing governance arrangements can also create barriers to integrating knowledge across jurisdictions or sectors. This integration process may become increasingly complex at different scales created by the context and geographic extent of various and emerging environmental challenges, as well as the different stakeholders involved in these issues, rather than administrative regions, historic alliances, or metropolitan boundaries [3]. For instance, regional partnerships based on watershed concerns may be different from those required to address food or energy systems [29,30] (Figure 2). Multiple researchers have underscored the importance of boundary organizations [5] and boundary workers [18], knowledge brokers [4[•]], and intermediaries [31] to develop trust across disparate areas. Boundary organizations or spanners may cross over different types of boundaries, organizational, disciplinary, or cultural, and several studies suggest that this boundary spanning can build interpersonal relationships and improve natural resource management [16,18].

There has been less articulation of what types of institutions or governance arrangements are needed to sustain and support boundary organizations or knowledge brokers, especially when scaling up. We argue that there is a need for systemic institutional change. Miller and Wyborn [27] and Wyborn *et al.* [32] observe that co-production must involve reconfiguring science, social authority and political institutions. This process may be messy and challenging, but it is also necessary for creating institutions that provide credible, legitimate and accountable knowledge to support sustainable transformations. Efforts to scale up co-production will simultaneously need to work towards reconfiguring governance arrangements and relationships among institutions to prioritize equity [33]. Such institutional change may be necessary to meaningfully address the power imbalances that risk being reinforced and exacerbated by scaling up.

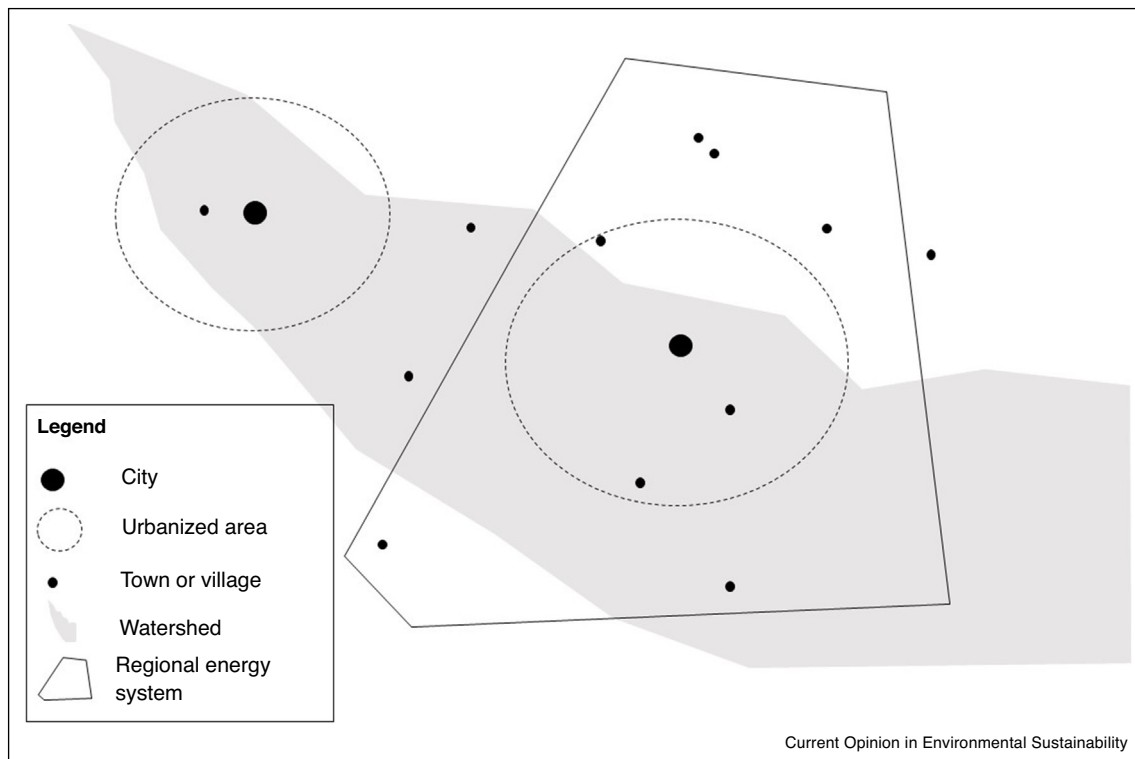
Scaling up for local needs: power asymmetries in co-production for sustainability

Power asymmetries emerge on transdisciplinary teams because they involve patterns of both historical and current social interactions among diverse groups operating within a dominant set of structures in research and policy on topics that are value laden and potentially contested [34]. These power imbalances may determine the types of questions addressed, the partners invited to be involved, goals and outcomes of the project, decision-making procedures, whose knowledge is determined to be credible and how that knowledge fits into the knowledge-hierarchies of researchers, as well as financial and time commitments on the project [34,35]. In addition, how these power imbalances are addressed may introduce new barriers for small actors at wider scales. In-person collaboration might provide disempowered stakeholders a voice, but only if they have the resources and time to participate [5].

Vincent *et al.* observe that power imbalances emerge in Global North–South partnerships for climate action [12]. We extend this perspective and argue that power imbalances and struggles will be present and compounded during any rescaling process. Disempowered communities urgently need to improve their local conditions, which include environmental degradation, the presence of polluting facilities, or the absence of quality infrastructure and resources [36,37]. Many disempowered communities have faced these conditions for decades due to discriminatory policies, disinvestment or extractive governance [38,39[•],40], and thus have been advocating for change for a long time. These communities may also have more power and productive alliances at this local scale due to shared histories and common experiences in improving their local environment. However, other more empowered actors can leverage their influence at the regional scale, and local communities may quickly lose their voices if a new scale is prioritized over their local community [20]. Indeed, other interests are working to scale problems up so that their problems are placed in a scale that relates to a jurisdictional forum where certain actors can leverage their power. This scaling up process will be particularly perilous for disempowered communities when improving the sustainability of one place harms other places, as seen in the case of energy distribution networks, in which residents living near natural gas pipelines assume health and environmental risks so that distal communities have reliable and affordable energy [41,42].

Multiple researchers have called for making power dynamics more explicit in sustainability knowledge co-production [28,34], recognizing that reconfiguring science and governance relationships and embracing debate and contestation are part of making knowledge relevant and

Figure 2



How sustainability challenges are defined and characterized will create new configurations of stakeholders and necessitate new partnerships.

usable [27]. For example, Latulippe and Klenk critique the idea that knowledge from Indigenous groups can be extracted from these groups and neatly integrated into conventional sustainability decision-making [43]. They argue that knowledge cannot be functionally separated from its context of production, knowledge holders, and values. They identify the need to empower different ways of knowing (e.g. Indigenous research leadership) through Indigenous knowledge sovereignty. Thus, a key challenge for constituting new scalar relationships to produce usable knowledge that better matches the scale of sustainability problems will be integrating, from the outset, analysis of the multiple epistemic cultures and power dynamics at play in the process of knowledge co-production and institutionalizing support to sustain these networks and emergent scalar relationships in ways that are sensitive to power dynamics.

Knowledge infrastructure for scaling up co-production

We argue that there is a need to reconfigure existing and build new knowledge infrastructures — networks of people (e.g. policy makers, researchers, government officials, community members) and institutions — to create the social and institutional conditions that facilitate

equitable co-production. Knowledge infrastructures based on existing institutions and governance arrangements may fail to include diverse stakeholders and can exacerbate power imbalances [44^{••}]. Prioritizing the development of new knowledge infrastructures that are deeply attentive to power dynamics has the potential to reduce cultural and institutional barriers to co-production by emphasizing inclusivity and local context, adaptability and reflexivity, and knowledge-action networks that link up the formal and informal places where sustainability knowledge is generated and put into practice [33].

We propose four principles for building new knowledge infrastructures for equitable co-production at regional and global scales.

- (1) First, we suggest that the scale and impacts of environmental problems or sustainable infrastructure should guide the configuration of knowledge infrastructure networks, rather than relying on existing governance arrangements based on administrative boundaries or other historic alliances that may exclude impacted communities (Figure 2). Focusing on the scale of impacts will mean that the communities directly affected will have a greater voice in

decision-making than regional power brokers seeking to maximize benefits/minimize harms for their jurisdictions.

- (2) Second, analysis of the pre-existing knowledge systems should become a best practice for understanding how existing governance arrangements shape co-production of knowledge across scales by mapping the organizational, operational, and political complexity of these existing network configurations [6,13,14]. Such analysis centers power by making visible the values, relationships, and power asymmetries among different actors involved in producing the knowledge that is used by diverse stakeholders. For instance, Muñoz-Erickson used knowledge system analysis to map a network of organizations, including state and municipal agencies, involved in generating knowledge about land use in San Juan, Puerto Rico to show how land use issues were framed and which organizations had greater power in decision-making about the development of green space [45]. Such an approach makes explicit configurations between science, social authority and political institutions and creates opportunities to address power imbalances in decision-making.
- (3) Third, there is a need to build and sustain these new knowledge infrastructures over time. Treating knowledge infrastructures as valuable decision-making support by providing funding, support for conversations and conflict mediation across communities and regions, and enabling data sharing and storage will allow diverse stakeholders to develop the type of trust needed to support equitable co-production. Equitable multi-scalar knowledge co-production may also require an Equity Capacity-Building Partner who seeks to level the playing field by providing resources to community partners that support meaningful participation in co-production planning and decision-making efforts. One example is the Near-Port Community Capacity Building Project established by the United States Environmental Protection Agency (<https://www.epa.gov/community-port-collaboration>). This pilot project sought to address health and economic inequities in communities located near ports across the United States by supporting Port-Community collaborations to sustain shared decision-making. In the Duwamish Valley near the Port of Seattle in Washington, this project led to the creation of a community advisory group to advise port staff on inclusive engagement practices, as well as a community benefits agreement to guide future decision-making. The Equity Capacity-Building Partner could step forward from the public, private, non-profit, or academic sectors and should be identified at the beginning of any public or private planning effort that has the potential to impact community members.
- (4) Finally, knowledge infrastructures should also build the ‘scalecraft’ of local communities. Scalecraft refers

to the aptitudes, skills, experiences and knowledge that different actors have learned through negotiating spaces of engagement relevant to their specific scale of influence [46]. Davies *et al.* study of urban food sharing in 100 urban areas around the world illustrates the scalecraft of information and communication technology-mediated networks to support food security at multiple scales within and beyond the urban boundaries [47**]. Thus, a central question for knowledge infrastructure networks is how to empower the scalecraft of local communities to reconfigure the power-laden relationships between diverse interests involved in addressing the sustainability issue at hand. This requires we shift our conceptualizations of co-production to center the knowledges, resource needs, and decision-making practices of communities on the frontlines.

We offer these four principles to advance new knowledge infrastructure supporting the equitable scaling up of co-production. There are several ways scholars have conceptualized knowledge networks for co-production including change system networks [13], global action networks [14], and global research networks [48]. The concept of knowledge infrastructure extends these other foci by foregrounding the supporting work required to operationalize, give coherence to, and sustain equitable co-production networks over the long term. While we caution against providing a priori conceptualizations of knowledge infrastructure, our view recognizes aspects of the broader activities and services involved in actualizing co-production networks. These activities and services may include sustaining repositories for information and data sharing, designing and providing trainings, creating spaces of engagement, compensating community partners, facilitating decision-making practices, mediating conflicts, developing mechanisms for reflection and evaluation, fostering innovation, convening and mobilizing resources equitably, fostering ways to share and honor non-traditional, vernacular and expressive accounts of experience and values, and sustaining access to the infrastructure systems undergirding such activities (i.e. information technology systems, transportation systems). However, knowledge infrastructure is not only about resourcing co-production networks — it is about reconfiguring the power-dynamics inherent in the co-production of knowledge and developing action supporting and empowering communities at the frontline.

The development of new knowledge infrastructures will facilitate the recommendations of other scholars to support the steps needed to scale up knowledge co-production equitably, including providing equitable funding to all partners [11**], embedding inclusive decision-making structures [12], and recognizing the importance of having Indigenous and other marginalized researchers, decision makers, and community members among the leadership

structure [43]. Additionally, with knowledge infrastructure in place to support the process of doing co-production effectively and equitably, projects can better focus on reaching their outcomes. Several scholars have noted that much work on co-production focuses on the process, rather than whether projects achieve their goals, which are important for addressing sustainability challenges [3,5]. Finally, we see an important role for evaluation frameworks that assess whether the co-production process leads to desirable outcomes for local communities, including elevating those voices in future sustainability projects [3].

Conclusion

Sustainability challenges span administrative, institutional, cultural, spatiotemporal and physical boundaries and often occur at different scales than co-production tends to happen. To support scaling up co-production, sustainability scientists have called for boundary organizations [5], equitable funding [11^{••}], facilitators [18], and in-person collaborations [8]. We contribute to this body of literature by highlighting how scale itself is constructed by different actors and that the reconfiguration of scale has implications for the reinforcement or reduction of power asymmetries among different stakeholders and communities. As efforts at co-production move beyond the local scale, the potential for an inequitable distribution of benefits and burdens across diverse communities grows. We propose building new knowledge infrastructures based on four principles as a way to create a valuable decision-making support mechanism, supported by an Equity-Capacity Building Partner, that reconfigures science and governance relationships that prioritize local needs in regional and global partnerships while empowering the scalecraft of local communities.

Funding

This research was supported by the National Science Foundation Award #1929834, Temple University's Center for Sustainable Communities, and a Temple University Liberal Arts Undergraduate Research Award.

Conflict of interest statement

Nothing declared.

CRedit authorship contribution statement

Hamil Pearsall: Conceptualization, Writing – original draft, Visualization. **Sarah Heck:** Conceptualization, Writing – original draft. **Madison Tablas:** Conceptualization, Writing – original draft. **Joseph Pierce:** Conceptualization, Writing – review & editing. **Clare Hinrichs:** Conceptualization, Writing – review & editing. **Lara A Roman:** Conceptualization, Writing – review & editing. **Jerome Shabazz:** Conceptualization, Writing – review & editing.

Acknowledgements

The opinions and findings expressed in this paper are those of the authors and should not be construed to represent any official USDA or US Government determination or policy.

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- of special interest
- of outstanding interest

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This review article examines the concept of co-production from the perspectives of sustainability science, public administration, and science and technology studies. The authors contend that co-production needs to reconfigure institutional relationships to transform society. A key point of this article is that co-production in sustainability science has not adequately addressed power asymmetries among diverse stakeholders.

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This article identifies four principles that are foundational for high quality knowledge co-production in sustainability science, while also recognizing that there are multiple approaches to doing co-production. The authors contend that quality knowledge co-production should be context-specific, such that it starts with the recognition that the co-production process occurs within particular social, economic and ecological contexts. Second, co-production should include different and diverse perspectives and kinds of knowledge. Third, co-production should be goal-oriented and include a collective agreement on measures of success. Fourth, co-production should include frequent and meaningful interactions among all participants for the duration of the process. This article provides multiple case studies and guidance for assessing the principles.

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