indirect evidence that *S. typhimurium* alters β-catenin signaling by inhibiting Wnt signaling. Interestingly, the canonical Wnt pathway also plays a role in the development and integrity of the BBB (*12*).

Spadoni *et al.* report intriguing observations that call for more investigation. In particular, it remains to be determined whether Wnt and β-catenin signaling in intestinal vascular endothelial cells, and the interaction between glial and endothelial cells, play a role in regulating GVB and preventing the translocation of bacteria under homeostatic and pathological conditions. That *Salmonella* discretely regulates β-catenin in host cells is a striking example of how pathogens evolve intricate mechanisms to harness host pathways in a cell-specific manner for their own benefit. Altering GVB makes evolutionary sense for *S. typhimurium* because it could enable it to disseminate and reside in the gall bladder. Dissecting the mechanisms that allow *Salmonella* to block β-catenin signaling in vascular endothelial cells—in particular, determining which effector proteins encoded by the pathogen's (spi)-2 pathogenic island promote β-catenin degradation, and how they do so—may enable therapeutic strategies that prevent the chronic infection and spread of *S. typhimurium* by asymptomatic carriers (*8*).

The findings of Spadoni *et al.* also may lend insight into liver damage in celiac disease. This condition is an enteropathy with an autoimmune component induced by dietary gluten in genetically susceptible individuals (*13*), and it may be linked to disruption of the GVB. Although patients with active celiac disease show an increase in β-catenin protein expression and phosphorylation in intestinal epithelial cells (*14, 15*), studies in intestinal vascular endothelial cells, and specifically in patients with liver disease, have not been performed. More generally, the notion that breaches in the GVB may disrupt systemic immune homeostasis and promote liver damage in patients with autoimmune and intestinal inflammatory disorders warrants investigation in different pathological settings. ■

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GLOBAL CHANGE SCIENCE

# Stakeholders in climate science: Beyond lip service?

## Local knowledge coproduction must be rewarded

*By* **Nicole L. Klenk,[1]* Katie Meehan,[2] Sandra Lee Pinel,[3] Fabian Mendez,[4] Pablo Torres Lima,[5] Daniel M. Kammen[6]**

Research models are evolving in response to the need for on-the-ground knowledge of climate change impacts on communities. Partnership between researcher and practitioner is vital for adaptive policy efforts (*1*). Transdisciplinary research teams present new opportunities by involving academics and local stakeholders, who actively conceive, enact, and apply research on adaptation and mitigation actions (*2, 3*). In transdisciplinary research, stakeholders are also researchers. But if we want to engage stakeholders in climate research, then we cannot simply pay lip service to the idea while treating them as participants for extractive research.

> ***"...global change science can strengthen its social robustness...when ethical...dilemmas... are... addressed...."***

We categorized a set of 27 climate change research networks (see supplementary materials) that perform various knowledge functions (*4*) and exhibit different forms of stakeholder engagement, from distributing knowledge to users to coproducing it with stakeholders (see the table). These networks represent various investments of time and resources to build the capacity of researchers and stakeholders to coproduce knowledge.

POLICY

Our analysis has three goals: (i) to document and compare examples of climate change research networks and elicit the patterns of knowledge functions; (ii) to demonstrate that many networks are emphasizing knowledge coproduction with stakeholders, with attendant policy implications; and (iii) to build an interactive database of networks so as to ignite broader dialogue on the role of stakeholders in science.

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Some of the networks reviewed, such as the Climate and Development Knowledge Network (classified as "linking"), are focused on improving how knowledge streams from scientists to relevant stakeholders. Others, such as the Climate Action Network for South Asia ("match-making"), have adopted a more "consultative" approach to knowledge exchange with stakeholders. Transdisciplinarity requires more labor. For example, the Future Earth program ("co-producing") works directly with stakeholders to help script research schemes, frame questions, and collect and analyze data, with the hope that coproduction will result in more policy-relevant knowledge and local empowerment. The key point is not that one model of knowledge production is better than another—nor that all models should be fully "integrative" (*5*)—but that many climate change research networks invite stakeholders to be part of the community of peer experts who assess the validity and relevance of science itself (*6*).

**COMPENSATION, INTEGRATION, AND ACCOUNTABILITY.** Scholarship on community-engaged research in public health has shown that collaborative research that involves stakeholders as researchers presents a number of ethical and political implications for the governance of science (*7*).

First, at present, transdisciplinary models in climate research assume that stakeholders are rewarded with new knowledge, capacities, and "voice" by taking part in research networks. This assumption only serves to reproduce the power imbalance between scientists and stakeholders, the former remaining in control of the coproduction process. Although stakeholders may be willing to volunteer for the opportunity to engage in research, reliance on self-selected individuals can lead to further marginalization of vulnerable populations whose knowledge and experience is sought, but whose time and resources are limited.

Unlike scientists, stakeholders are not paid for making insights and discoveries.

## Collaborative models of climate research

Framework for categorizing the primary knowledge function of research networks

| KNOWLEDGE FUNCTION | DESCRIPTION | MODEL OF KNOWLEDGE EXCHANGE | WORK REQUIRED OF STAKEHOLDERS |
|---|---|---|---|
| **Linking** | Targeted dissemination of knowledge to inform decision-making | From knowledge producers to knowledge users | Together, stakeholders and knowledge producers interpret research evidence for decision-making |
| **Match-making** | Connects diverse knowledge producers with users to frame research questions and interpret results | Knowledge producers consult knowledge users | Stakeholders participate in research but do not engage in research themselves |
| **Collaborating** | Knowledge users are active throughout the process, including articulation of research questions, design of projects, collection and analysis of data, and production of outputs | Knowledge producers work with knowledge users to produce, understand, and apply knowledge in decision-making | Stakeholder organizations dedicate financial, human, and infrastructure resources to participate in projects; stakeholders and knowledge producers agree on timelines, outputs, and outcomes |
| **Coproducing** | Empower and build capacity of stakeholders to critically assess and lead research projects that shape the social order of their communities | Encourages exposure of different and conflicting values, which makes knowledge production more political | Stakeholders and their organizations have institutional structures and processes to enable recursive evaluation of knowledge production and application |

Genuine transdisciplinary research requires elevating the role of stakeholders as equal to scientists because of the work they do as coproducers, regardless of the potential instrumental value of the knowledge coproduced. Yet, ethical issues often arise when directly paying research partners, and many institutional review boards (IRBs) flag remuneration as a possible conflict of interest, even for knowledge coproducers. IRBs may need to revisit ethical guidelines and procedures when stakeholders—no longer just participants—are active agents in generating knowledge. IRBs already allow honoraria to incentivize and help defray some costs of stakeholder engagement in research, but this nominal amount is not commensurate with compensating stakeholders as coproducers. A "pay-for-services" model of stakeholder engagement is not the only option, but although equating coproduction with pay may not be appropriate everywhere, neither should it be rejected a priori.

Second, power imbalances between technical expertise and local knowledge point to wider problems of integration and knowledge coproduction in climate science (*8*). The Intergovernmental Panel on Climate Change (IPCC) continues to emphasize quantitative versus qualitative scientific research, expert judgment over local knowledge, and a rather limited understanding of the "human dimensions" of global change (*9, 10*). To effectively scale-up local knowledge coproduction, we need to foster a variety of knowledge-sharing and social-learning platforms, such as the interactive database of research networks to which we invite readers to contribute (rael.berkeley.edu/project/stakeholders-in-science). At the global scale, there is urgent need for the institutionalization of mechanisms of local knowledge mobilization, perhaps within the IPCC, to prevent continued fragmentation of coproduction initiatives. Whereas many networks we examine seek to do this, without a more systematic global means of knowledge integration and dialogue, their efforts will remain local or regional.

Finally, transdisciplinary models of research collaboration have important policy implications, including the need for granting agencies to develop transdisciplinary research governance criteria (*7*) and for universities to revisit their proprietary policies and to develop rights of shared ownership of the knowledge coproduced. Although funding agencies generally require that research partnerships with communities have formal governance structures, such governance agreements are of little use if there are no mechanisms to hold researchers accountable. Granting agencies need to put into place mechanisms for addressing complaints from knowledge coproducers when agreed-upon requirements are not followed through. Drawing on literature on community-based research partnerships, other actions might include a memorandum of understanding outlining goals, principles, and intellectual property rights of partnerships with nonacademic stakeholders; clear roles and responsibilities of knowledge coproducers; and, guidelines for how partnerships will accumulate, store, and mobilize data.

Whether through financial compensation, new modes of recognition, or new governance arrangements, global change science can strengthen its social robustness and relevance when ethical and political dilemmas at the core of knowledge coproduction are openly acknowledged, honestly assessed, and meaningfully addressed. If climate change demands all hands on deck, then it's time to raise the stakes. ■

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### SUPPLEMENTARY MATERIALS

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