Climate Modeling Knowledge and Its Local Adaptation Challenges with a Focus on Epistemic Co-production Strategies

Ting Zhao[1]*

[1] Hunan University of Science and Technology, China
* Correspondence: zhaotingz1996@126.com

https://doi.org/10.53104/j.acad.res.adv.2025.06002

Abstract: Climate modeling has a key role in shaping global and regional adaptation strategies. But its effectiveness often fails at the local level because of knowledge and institutional gaps. This paper examines the limits of traditional climate models in supporting local adaptation. It suggests epistemic co-production as a transformative framework to merge scientific and local knowledge. Using interdisciplinary literature and real-case studies from different places, the paper shows how co-production builds trust, fits local needs, and gives processes legitimacy. The analysis finds that while co-production makes climate info more useful, putting it into practice has big barriers—like rigid institutions, unequal power, and mismatched timelines. Through conceptual synthesis and diagram models, the paper pushes for a relational, step-by-step approach to adaptation planning. This approach is based on mutual learning and inclusive governance. It ends by pointing out the institutional changes and method innovations needed to make co-production part of mainstream climate science and policy. Epistemic co-production is seen not just as a way to make models more used, but as a force to democratize climate knowledge politics.

Keywords: climate modeling; local adaptation; epistemic co-production; adaptation planning

Received: 24 June 2025

Revised: 27 June 2025

Accepted: 27 June 2025

Published: 30 June 2025

Citation: Zhao, T. (2025) 'Climate modeling knowledge and its local adaptation challenges with a focus on epistemic co-production strategies', Journal of Academic Research and Advances, 1(1), pp. 12-26.

1. Introduction

Climate modeling is a key tool for global climate action. It makes predictions that help create policies to reduce and adapt to climate change at different levels. These models use complex math and large amounts of data. They show possible future changes like warmer temperatures, different rain patterns, higher sea levels, and more extreme weather. People making decisions use this information to plan how to adapt and where to spend money to face new climate dangers.

But global and regional models don't work well for small local areas. Big climate models cover large spaces. Because of this, they often miss important local details about the environment, culture, and money situations that affect how communities can handle climate problems.

This difference between big model knowledge and local needs is not just a technical problem. It's also about different ways of knowing things. So we need to ask: Which knowledge matters? How can science

knowledge, traditional knowledge, and experience work together fairly in decisions? Science knowledge is important, but it usually isn't enough for local climate risks. This is especially true in places with many different plants and animals, unfair social systems, or a history of being left out. Because of this, adaptation plans made only by experts often don't feel right to local people, are hard to use, and don't work well.

More people worldwide now want to connect big climate predictions with local realities. The newest IPCC report says adaptation plans that come only "from the top" have problems. Instead, it says plans should grow "from the ground up" in local places. The Paris Agreement (Article 7) also says countries should let local people help make and carry out adaptation plans that match their needs. This shows that good adaptation must understand power differences, use many kinds of knowledge, and remember past exclusions.

Also, climate modeling isn't free from personal or group opinions. Choices about what data to include, how to set up models, and how to understand results often favor big national or global goals over local community worries. For example, focusing too much on money losses or strong buildings might ignore local care about culture, community ties, or old ways of living. Fixing this needs not just better models, but also changes in how climate science institutions work—including respecting local and Indigenous knowledge as real knowledge.

To solve these problems, "epistemic co-production" is becoming popular. This means scientists, policymakers, and community members work together long-term to create and understand climate knowledge. The idea is: Knowledge comes from people talking together. Adaptation plans get better when different voices help find risks and solutions. Co-production isn't just scientists giving information to others. It means discussing together, balancing different needs, and sharing values. The goal is to create climate information that is good science and makes sense to people's daily lives.

This paper looks at why it's hard to use big climate models for local adaptation, and how co-production might help. We use ideas from science studies, environmental policy, and community development. By studying blockages in systems, thinking, and institutions, we see conflicts between science power and local trust. We share real examples where co-production made climate action more trusted and useful in different places. Overall, we argue climate science shouldn't stay separate and technical. It should become teamwork that learns from everyone and values all ways of knowing. This challenges old ideas about who is an expert. It opens the way for adaptation plans that are both scientifically strong and change society for the better.

2. Challenges of Local Adaptation in Climate Modeling

Local plans for dealing with climate change are often limited by the size, focus, and ideas behind big climate models. While Global Climate Models (GCMs) and even Regional Climate Models (RCMs) give useful information about big climate patterns, they work at a level that is too broad to help with decisions for towns, river areas, or villages. This difference in scale isn't just a computer problem. It shows that science ideas from a distance are often seen as more important than local, practical knowledge (Bremer & Meisch, 2017).

Because of this, plans to handle climate change often end up too general or don't fit the real situation on the ground. For example, advice from GCMs about water might suggest building things that don't match local water patterns. Or they might ignore old ways of watering crops that have worked well with changing weather for a long time. This gets worse in places with little data. Here, making the big models more local relies on guesses instead of good local measurements. This makes the results less reliable and less useful locally (Shaffer, 2014).

Climate models also usually miss the human and social factors that really affect whether plans work. Models mostly look at nature things—like temperature, rain, wind. But they overlook things like how decisions are made, how people make a living, or

the cultural meaning of land and water. This way of seeing climate information as just technical can push communities away, especially when what the models say doesn't match what people see and know from living there (Klenk et al., 2017).

Trust in climate information is another big problem. When what science predicts doesn't match what weather people actually see, local users might doubt it or stop paying attention. This is especially true in places where local weather signs or seasons have always been trusted guides. Pushing outside modeling ideas without talking to people or checking with them can break local ways of coping instead of helping them (Boon et al., 2019).

How decisions about adapting are made often makes the gap between science and local views bigger. Policy decisions usually favor official data. This means community knowledge gets left out, even when it's more accurate or useful. Not valuing this local knowledge doesn't just make plans less effective. It can also be unfair because it ignores the people who are most at risk from climate problems (Briley et al., 2015).

The problems of using big climate models locally come from both technical limits and deeper disagreements about what counts as good knowledge. Fixing these problems needs more than better data or more detailed models. It needs a basic change in how we make, check, and use climate knowledge.

Climate change itself is speeding up faster than the usual way of turning model results into policy can keep up. Extreme weather is getting stronger and happening in unexpected ways. But climate models are often set using past weather patterns. This makes it hard for them to show sudden local changes or knock-on effects. This mismatch is very bad for small farmers whose lives depend on knowing the weather right now and expecting regular seasons. So, people worry more about "knowledge decoupling". This means the gap is growing between what models say and the practical rules local people use to adapt where they live. Sometimes, this leads to two separate systems: communities keep acting based on their own experience or local signs, while programs from outside push different solutions that don't fit. Without ways to truly bring these together or adjust plans as things change, these separate systems can cause confusion, waste money, or even make things worse.

3. Theoretical Foundations of Epistemic Co-production

The idea of epistemic co-production comes from science and technology studies. It is based on work by scholars like Sheila Jasanoff and Bruno Latour. They said knowledge isn't just found. Instead, it is made by people together. It is mixed up with power, organizations, and what people think is important. For climate science, this challenges the idea that climate models just show reality as it is. Instead, it sees models as things made together by scientists, politics, and technology.

This view fits with the idea of 'Mode 2 knowledge production'. Mode 2 focuses on science that solves real problems in real situations. It uses ideas from many fields. Unlike older science that wanted big truths for everywhere, Mode 2 wants knowledge that works well in society. This means knowledge made by talking with people who care and can be used for decisions. Epistemic co-production uses this idea. But it adds something important: it says we must not just work together. We must also make it fair for everyone to say what the problems are and what the answers should be.

This makes co-production different from other ideas like participatory action research, citizen science, or transdisciplinarity. Those ideas also want people involved. But they might still let scientists have the main say over what questions to ask or what results mean. Co-production, on the other hand, puts sharing power and respecting everyone's knowledge first. It asks for a careful process where everyone—not just scientists—helps plan the study, decide how to look at the information, and choose what goals are right. This is why co-production works well for climate adaptation. Here, the problems are local, but the science often comes from far away.

How much people suffer from climate change isn't the same everywhere. It depends on unfairness in places,

being left out in the past, and facing different dangers. This means we need climate knowledge that is both local and shared. Co-production helps do this. It says no to the old way where "science talks, society listens." Instead, it helps everyone learn together. In this way, science ideas (like risk, resilience, limits) get new meaning from local values, stories, and words.

In terms of ideas, this way of thinking matches constructivist views about knowledge and theories about talking together to make decisions. Both say that knowledge and making rules are connected. Jasanoff (2004) talked about "civic epistemologies". She meant different groups of people have their own ways, based on their culture, to decide if knowledge is good. Co-production makes this real by creating shared spaces for knowledge. In these spaces, people don't just trust climate models. They talk about why they should trust them. These talks can happen in meetings, planning workshops, or programs where people watch things together. There, science power is clear and people can question it. By doing this, co-production fights the idea that models are just neutral tools. It admits that even science that means well can push one strong way of thinking or ignore other possible futures.

Another important idea in co-production is about 'boundary work'. Gieryn (1983) first talked about this. Boundary work is how people draw lines between science, politics, and other areas to make their ideas seem stronger or protect their power. Co-production tries to blur these lines on purpose. It does this to help talk across different ways of knowing. Tools called 'boundary objects' help with this. These are things like maps, pictures, or models. They work because they are solid enough to keep their main meaning in different groups, but loose enough for different people to understand them in their own way (Star & Griesemer, 1989). So, thinking about boundaries helps us see how knowledge moves, stays steady, and changes between different groups.

Co-production theory also cares about unequal power and fairness in knowledge. The 'co-' part doesn't just mean adding people. It means we need to change who has the power to decide. It questions whose voices are listened to most and whose are left out. This matters a lot for climate adaptation. Groups that are pushed aside are studied a lot, but not really heard. As scholars like Fricker (2007) and Medina (2013) say, unfairness in knowledge isn't just about wrong facts. It is also about systems stopping people from being seen as knowers. Co-production tries to fix this by putting fairness into how we make knowledge. It sees that saying knowledge is good is also about respecting people's worth, their ability to act, and their special knowledge of their place.

The co-production idea has its own problems. Some people say it might make us think everyone agrees when they don't, or hide real fights. Others warn that powerful groups might use it just to look like they are including people, to make their own plans seem right. These criticisms show why thinking carefully about oneself is important. This careful thinking is a key part of co-production theory. It asks researchers and workers to look at their own place, what their organization wants, and what their choices mean for politics. In this way, co-production isn't just a tool. It is a way of working that always asks: Who decides what the problem is? Who controls the information? Who gains from the answer?

Epistemic co-production is both a tool to understand problems and a plan for action. As a tool, it helps us see why climate adaptation fails when it ignores how knowledge lives in society. As a plan, it gives a way to make climate actions that use many kinds of knowledge, work well in society, and are fair. Today, science power is very important, but people also question it. Co-production offers a way forward. It does this not by avoiding hard things, but by facing them, to build fairer and stronger futures for the climate.

4. Epistemic Co-production as a Strategy

Epistemic co-production means scientists and local people work together to make knowledge. This is a big change in how we do climate adaptation. It challenges the old way where science just tells people what to do. Instead, it focuses on including everyone, talking together, and learning from each other. This fixes a big

problem in climate planning: models made for the whole world often don't make sense for local places.

Old climate modeling usually thought good science was enough for good policy. But these models are often too big, too complicated, and too different from daily life. Because of this, local people often do not trust them. Epistemic co-production fixes this. It lets local groups understand climate predictions better. They do this by talking together, using local knowledge about the environment (Traditional Ecological Knowledge, TEK), and using tools where everyone participates (Klenk et al., 2017). Klenk and others say this is an ethical change. It moves from taking knowledge to making knowledge together. They say adaptation planning must break down old systems that always think expert science is better than local knowledge.

Figure 1 shows how epistemic co-production works. It pictures knowledge flowing both ways between local people and climate scientists. Local knowledge, like farming calendars or weather signs, helps explain and put science predictions in context. At the same time, model results are understood and checked locally by talking with people. The result of this back-and-forth is a co-produced adaptation plan. This plan is made through talking, explaining things clearly, and learning step by step.

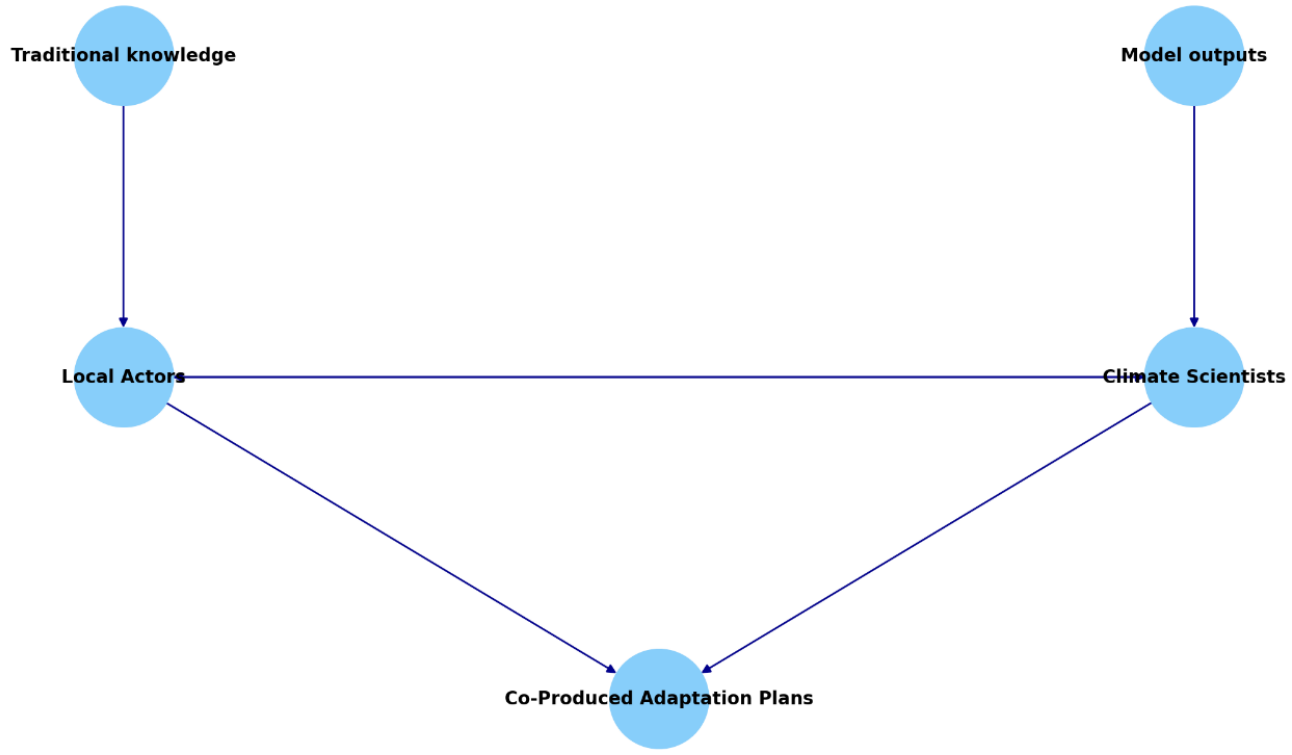

Figure 1. Conceptual Diagram of Epistemic Co-production in Climate Adaptation

This figure shows co-production is not a straight line where one group tells the other. In practice, co-production often uses set methods. These include workshops with different people over several meetings, guided talks, and tools everyone designs together, like making future stories (scenarios) as a group. People chosen usually represent different kinds of knowledge. This includes local leaders, farmers, experts, and people who help groups talk. These repeated, inclusive meetings help turn model results into decisions the community agrees with, while keeping the science sound. It is a circle of talking and learning between local people and scientists. Local knowledge and model results are not the end. They start new talks about climate risks and what to do about them. The feedback in this process is very important. It builds trust, makes sure plans fit the place, and helps long-term learning.

One very good method is Companion Modeling (ComMod). This method uses computer models where people pretend to be farmers making choices. It helps everyone see how their choices mix with climate changes over time. By playing roles and changing the model step by step, communities can see the good and bad of different land uses, water sharing, and ways to handle risk. This helps them think about the whole system and plan better. Another common method is Climate Risk Narratives (CRNs). These are local stories about the future. They are based on science predictions and what people know about their society and culture. CRNs help experts and non-experts talk together. They do this by putting number forecasts into stories people understand from their culture. This helps everyone share an understanding of what might happen and what's unsure. These tools show how designing things together not only helps people understand better but also includes different groups by letting everyone share their ideas and values about the future.

This way of working has worked well in many different places and under different governments. Looking at different cases helps us see how co-production changes to fit different political and management systems. For example, in the Chaco region of South America, scientists and community members held workshops. Together, they made stories (scenarios) about drought. In these meetings, science models were shown next to local knowledge, like memories of past rain and signs from the soil. Then, everyone together talked about the risks and what to do. They paid special attention to making sure everyone's knowledge was respected. Scientists were asked to say their findings were not final and could change. Local stories were written down and used in the tools. This mutual respect helped make things fairer and find agreement on what to do first. It let communities see future drought risks using both science and local farming memory. This led to better water plans (Hernández et al., 2022). Similarly, in rural Tanzania, people used community weather diaries along with model predictions. This helped match advice about seasons with what people saw locally. It made the advice more accurate and trusted (Shaffer, 2014). Shaffer's study shows the diaries were not just for watching weather. They were also tools that showed local knowledge was good. This challenged the power of official forecasts and moved the power to make adaptation decisions closer to the people.

5. Institutional and Political Barriers to Co-production

Although conceptually attractive and practically promising, the actual implementation of epistemic co-production faces significant institutional and political challenges. One main constraint is the rigid structure of existing scientific and governance institutions. These institutions often focus on linear outputs, expert-driven metrics, and short project cycles. Such priorities are not compatible with the iterative and time-consuming nature of co-production. For example, funding agencies often evaluate projects based on deliverables and publication metrics. This limits support for adaptive, relationship-based engagement processes.

Another key challenge is the deep-rooted authority of scientific knowledge systems over other ways of knowing. In many policy and planning situations, formal climate data—especially model outputs—are given more importance than local observations or indigenous forecasting traditions. This hierarchy of knowledge not only discourages non-scientific actors from contributing meaningfully but also causes resistance or doubt among communities. These communities feel their knowledge is dismissed as anecdotal or unproven. Such imbalances in knowledge legitimacy get worse when adaptation programs are funded from outside or linked to international reporting systems.

Power imbalances show up in how stakeholders are selected. In some cases, "invited spaces" for participation only include elite community members or those who already agree with institutional priorities. This keeps excluding marginalized groups. Genuine co-production needs active creation of "claimed spaces." In these spaces, marginalized voices can shape both the data and the institutional framework. However, such restructuring is rarely

politically neutral—it often meets opposition from bureaucracies used to central control.

Global climate institutions also create structural barriers. Standardized vulnerability indices, adaptation metrics, and cost-benefit models may make reporting easier, but they discourage strategies that fit specific contexts. So, embedding co-production needs both flexibility from the top and empowerment from the bottom. This includes creating protective spaces and reflective monitoring mechanisms within institutions.

Epistemic co-production not only makes climate knowledge more relevant but also democratizes its creation. Compared with other participatory methods like transdisciplinary research or citizen science (which often focus on knowledge exchange or voluntary data contribution), epistemic co-production uniquely focuses on redistributing epistemic authority. It helps co-define both the problem and the solution space. This turns adaptation from a top-down delivery of solutions into a socially embedded, negotiated, and evolving process. It is based on both science and the daily realities of those most affected by climate risks.

Co-production is increasingly accepted in global adaptation discussions. But without institutional change, its application may become symbolic instead of meaningful. A central issue is the mismatch between the timelines of institutions and communities. Research timelines, grant periods, and policy windows are usually short-term. Co-production, however, needs long-term trust-building, repeated feedback, and patience. The lack of institutional incentives for "slow science" means researchers who engage in co-production often face professional costs: delayed publications, uncertain career rewards, or lower funding competitiveness. These systemic pressures discourage deep community engagement, especially among early-career scholars or institutions under performance-based evaluation systems.

Another deep-seated barrier is the disciplinary division in academic and policy systems. Co-production requires integration across climate science, anthropology, political ecology, communication studies, and indigenous epistemologies. But most institutional frameworks are still organized around discipline-specific funding, journals, and career paths. This division of knowledge blocks holistic problem-solving and prevents the cross-domain skills needed for effective facilitation and knowledge translation. Without institutional reforms that support interdisciplinarity and collaborative reflection, co-production efforts may be fragmented or too dependent on individual leaders rather than structural support.

There is a persistent problem of who gets to represent "the local." Local actors in co-production processes are intermediaries—NGO staff, municipal officers, or academic collaborators—rather than the directly affected communities. While these intermediaries play important roles, they may also reshape or weaken local perspectives, especially when institutional pressures make them align with donor expectations or state narratives. The result can be a false appearance of participation, where local inputs are adjusted to fit pre-existing policy templates. This dynamic strengthens what scholars call "epistemic extractivism"—taking local knowledge without giving reciprocal benefits or agency.

Even in well-meaning institutions, language politics and technical jargon can exclude people. Climate adaptation discussions are full of technical acronyms, probabilistic language, and abstract systems thinking. This can marginalize participants who are not familiar with such language. Translating scientific concepts into accessible forms is not just a communication issue—it's a power negotiation. It determines whose interpretations are accepted and whose are ignored. Effective co-production therefore needs linguistic and narrative diversity: the ability to communicate across different ways of expertise, emotion, and lived experience.

Resistance to co-production also comes from fears of losing control. For scientific agencies and policy planners, letting non-experts into decision-making can seem risky, inefficient, or threatening to professional authority. Concerns about data misuse, unpredictability, or reduced scientific rigor often

make institutions limit participation to "safe" or symbolic forms. These fears, while reasonable, often hide deeper anxieties about sharing power and challenging technocratic logic. Addressing them requires not only building capacity for local actors but also providing reflective training for scientists and officials. This helps them engage with uncertainty, ambiguity, and power-sharing in constructive ways.

Embedding co-production into climate governance requires reconfiguring institutional norms, cultures, and infrastructures. This includes diversifying peer review and funding panels to include local knowledge holders, creating reward systems for collaborative and iterative work, and investing in the long-term relational effort that co-production needs. Only by challenging underlying knowledge hierarchies and bureaucratic inertia can epistemic co-production move from the edge of innovation pilots to the mainstream of climate adaptation practice.

6. Co-production Across Political Systems

The institutionalization of epistemic co-production differs a lot across different political and administrative systems, especially between centralized and decentralized governance structures. In centralized regimes, like those in parts of East Asia or North Africa, climate adaptation planning is usually vertically integrated. National agencies have strong control over local decisions. Although this can make implementation and resource mobilization easier, it often limits the freedom of local actors to shape adaptation strategies based on their real-life experiences or specific needs. In such cases, co-production is typically "invited" from the top, and local participation may be limited to consultation instead of full collaboration.

But decentralized or federal systems—such as those in India, Brazil, or the U.S.—often have more varied co-production practices. Here, local governments or community organizations have more formal power over adaptation planning. This allows for more natural and repeated forms of knowledge co-creation. However, decentralization also brings its own problems: differences in institutional ability, unequal access to climate data, and broken policy frameworks can stop coordinated co-production across regions. When higher-level agencies don't have ways to include bottom-up ideas, local innovations might stay isolated instead of spreading.

These differences show why "institutional fit" is important when designing co-production frameworks. In centralized systems, effective co-production might need "protective spaces"—special areas where local actors can work with scientists and officials equally, without hierarchy. These can be advisory councils, pilot zones, or discussion forums that work independently. On the other hand, in decentralized settings, we must focus on "knowledge docking mechanisms"—institutional links that make sure local insights go into broader planning and don't get lost in separate departments. Comparative studies also show differences in how legitimacy is built. In centralized regimes, scientific authority is favored, and co-production gets legitimacy through state approval. But decentralized systems usually get legitimacy from having diverse stakeholders and transparent processes. These dynamics affect not only who takes part in co-production but also which types of knowledge are seen as reliable and how adaptation results are judged. Understanding these governance-specific dynamics is key for designing flexible co-production strategies. Instead of looking for a one-size-fits-all model, policymakers and practitioners should adapt co-production approaches to real institutional situations—making sure they fit the context and are part of the structure. Only by engaging with the political ecology of governance systems can epistemic co-production live up to its promise as a democratizing force in climate adaptation.

Only by engaging with the political ecology of governance systems can epistemic co-production live up to its promise as a democratizing force in climate adaptation. But matching governance logics with co-production ideals isn't just a technical challenge—it's a deeply political negotiation that involves institutional duties, legal structures, and social contracts.

In authoritarian or semi-authoritarian situations, co-production often has to work in limited civic spaces and under centralized authority. While top-down control can speed up implementation, it also causes worries about token participation, monitoring of dissent, and using local knowledge to make the regime look legitimate. In such cases, "invited spaces" might be strictly controlled, with participation limited to state-approved ideas. However, new forms of co-production can still appear through informal networks, hidden spaces, or mixed governance nodes. There, local actors work with supportive officials, NGOs, or academic partners to try adaptive planning without strict formal rules.

In democracies with strong participation traditions, like some European or Latin American countries, co-production can use civic platforms, public hearings, and participatory budgeting to include local voices in climate adaptation. But even in these places, structural exclusions still exist—especially based on race, gender, and class. Studies from Brazil's semi-arid Northeast, for example, show that decentralized co-production projects often miss quilombola and indigenous groups, even though there are rules for inclusion. This shows that political openness doesn't guarantee diverse knowledge; we still need active design to ensure inclusive representation, language accessibility, and fair processes.

More and more comparative political ecology research also suggests that the political culture of governance systems affects not just the form of co-production but also its speed and rhythm. In highly bureaucratic regimes, adaptation decisions might go through many layers of approval, which slows down changes and risks losing local details. But more flexible governance settings—like city-level "climate laboratories" in federal systems—might allow faster cycles of testing and feedback. These timings matter for co-production: trust builds over time, learning needs repetition, and legitimacy often comes from consistency.

In mixed governance situations, like metro areas with overlapping powers or post-conflict areas becoming decentralized, co-production becomes more urgent and complex. Having multiple, sometimes competing, authorities can create chances for multi-center innovation, but it also risks confusing institutions and splitting decisions. Here, intermediaries—like boundary organizations, regional platforms, or international NGOs—play a key role in mediating co-production across different levels. Their success depends not only on technical skills but also on political legitimacy, cultural understanding, and relationship-building.

Institutionalizing co-production often depends on legal and procedural rules. Constitutional parts about public participation, environmental rights, or indigenous autonomy can formalize the need for co-productive engagement. If these legal supports are missing, co-production depends on temporary goodwill or donor conditions. Comparative case studies show that even when co-production is done as projects, its growth and sustainability depend on being institutionalized—through planning laws, funding rules, civil service training, and process norms.

The international scene also shapes national co-production structures. Global adaptation funding like the Green Climate Fund or Global Environment Facility increasingly requires stakeholder engagement plans, but how they're carried out often reflects local political cultures. In some centralized states, these requirements are met on paper with little real change. In more open systems, they can lead to institutional innovation, like creating climate adaptation councils, local knowledge centers, or cross-ministerial teams. These differences show the multi-level politics of co-production, where global norms mix with national systems and local realities in complex ways.

Digital technologies are starting to change co-production possibilities across governance systems. In decentralized places, digital platforms let scattered communities share observations, analyze data together, and take part in online discussions. In centralized systems, they can be monitoring tools, story-telling devices, or even spaces for bottom-up testing. But digital divides, data colonialism, and platform governance bring new risks, making existing power imbalances worse if not managed carefully.

Political systems greatly affect the opportunities and problems of epistemic co-production. Effective strategies need more than just procedures—they need to understand institutional cultures, participation norms, and power structures in context. Policymakers and researchers must go beyond ideal goals to deal with the real, messy realities of governance ecologies. Only then can co-production become more than a method—it can become a movement toward fairer, more inclusive, and more adaptive climate futures.

7. Pathways Forward: Embedding Co-production in Climate Governance

Reforming climate education is a basic step in making epistemic co-production part of institutions. Universities and training centers must add interdisciplinary and participatory modules to climate courses. They should focus on social learning, helping stakeholders work together, and ethically engaging with non-scientific knowledge systems. This change is not just about teaching; it's a strategy. It trains a new generation of climate workers who can bridge knowledge gaps and create knowledge together in different social and political situations. Education programs can also include hands-on learning, like field placements in community adaptation projects or internships with groups that use co-production. These experiences help future workers develop skills in mediating, reflecting, and cross-cultural communication. These skills are key for long-term engagement.

Digital platforms have a lot of unused power to help with co-production. Tools like participatory GIS, citizen science websites, and online discussion platforms let stakeholders in different places work together to understand climate data and design adaptation plans. Making these tools part of planning processes means co-production isn't just in meetings. It can happen continuously and at different times. Digital co-production can include more people, especially those left out because of where they live, language problems, or not being able to move easily. But depending on digital systems needs investing in tech infrastructure, building skills, and making rules to protect data ownership and respect local ways of sharing information.

International efforts have started to make co-production a main part of adaptation planning. For example, the Green Climate Fund (GCF) requires approved projects to show good stakeholder engagement plans. The European Union's Mission on Adaptation to Climate Change pushes for regional innovation platforms that connect science institutions with local governments and civil society groups. These methods show how co-production can be scaled up without losing its local focus. They use process rules, funding rewards, and networked learning structures. The UNFCCC's Local Communities and Indigenous Peoples Platform has also become a place to put traditional knowledge into adaptation policy, but how it works is very different in each country.

Putting co-production into climate adaptation needs strategic changes at many governance levels. For research institutions, this means moving from project-based funding to longer-term, process-focused support. This support should value long-term community engagement and learning through repetition. Success measures should go beyond publications and model building. They should include shared learning results, how much stakeholders trust each other, and how much adaptation plans match local priorities. Institutions can encourage interdisciplinary teams by recognizing collaborative work in career growth and grant evaluation.

Local governments can make process frameworks that don't just invite participation but build it into structures. This can be through participatory planning units, multi-stakeholder advisory boards, and community knowledge platforms. It needs investing in people who can translate between scientific and public languages while being accountable to both. Creating local climate knowledge libraries can help record shared experiences, traditional practices, and lessons from past adaptation efforts. Policies should require not just consultation but co-defining goals and metrics, especially in areas with big climate risks or deep inequalities.

For international climate partnerships, embedding co-production means being more flexible in implementation frameworks. This lets adaptation strategies come from communities, not be forced through standard models. It includes funding safe spaces where different knowledge systems can meet openly. It also needs ways for institutions to reflect, so they can rethink their ideas about knowledge hierarchies and power relations over time. International donors and development agencies can invest in regional hubs that connect co-production projects in different places. This allows peer learning and mutual support.

These steps can turn co-production from an ideal into a real institutional practice. This helps build climate governance that's based on science, connected to society, and includes many ways of knowing. Unlike other participatory methods like transdisciplinary research or citizen science (which often focus on knowledge exchange or voluntary data giving), epistemic co-production specifically focuses on sharing knowledge power and co-defining both the problem and solution. It sees adaptation as a social process shaped by values, experiences, relationships, and scientific expertise. With careful design and ongoing investment, co-production can make climate governance more legitimate, match adaptation plans to community needs, and strengthen policy credibility at all levels.

8. Practices in Co-Production

The practical effects of epistemic co-production are best shown through real-world examples across ecological, cultural, and institutional settings. One example is from the western United States. The Nevada Water Initiative shows how co-production can turn climate data into useful local plans. In this project, researchers worked with irrigators and basin water managers. They together understood precipitation and temperature model results using local water knowledge and past drought experiences. Instead of giving a fixed forecast, the collaboration had repeated meetings, scenario simulations, and role-playing activities. This let scientific data be constantly re-interpreted with farmers' real-time observations. The result was a set of adaptive irrigation schedules. These schedules included both GCM-driven climate scenarios and indigenous seasonal signs. This increased trust in the science and made it more useful (Singletary & Sterle, 2020).

A similar example is in rural Tanzania. Efforts to make climate projections meaningful locally led to using community-maintained climate diaries. These diaries recorded seasonal signs like bird migrations, flowering times, and wind changes. They were used to check downscaled climate models. The project's participatory design not only made scientific forecasts easier to understand but also showed traditional ecological knowledge (TEK) is valid. This co-production method helped people take more ownership of adaptation steps, like changing crop cycles and planning for disasters. It also made farmers who used to think scientific results were irrelevant or wrong start to use forecast-based advice more (Shaffer, 2014).

The South American Chaco region also shows how co-production can change things in complex socio-environmental situations. There, farming communities facing regular droughts worked with researchers to make future climate scenarios. These scenarios were based on science and matched local culture. Using participatory simulation games and agro-pastoral calendars, stakeholders looked at different adaptation ways. For example, changing planting times or livestock rotations. They did this by combining regional forecasts with local knowledge of rainfall cycles. The result was better preparedness and stronger governance for water and land use planning (Hernández et al., 2022).

These different cases together show that epistemic co-production is not a one-size-fits-all method. It's a flexible framework that adapts to local needs. It depends more on building relationships than on technical tools: trust-building, recognizing different knowledge is valid, and working together to interpret information. Importantly, it also changes where climate science happens—from central expert areas to shared, discussed spaces for adaptation.

To see the structural difference between traditional modeling and epistemic co-production, Table 1 sums up key parts like knowledge source, decision engagement, and legitimacy. The table shows that while traditional models often work in a fixed, low-trust way, co-produced methods allow for flexible adaptation and more stakeholder ownership.

Table 1. Comparison of Traditional and Co-Production Approaches

Dimension	**Traditional Modeling**	**Epistemic Co-production**
Knowledge Source	Scientific Institutions	Scientists + Local Communities
Model Resolution	Global/Regional Scale	Downscaled + Context-Specific
Decision Engagement	Top-down	Collaborative and Iterative
Trust and Legitimacy	Often low	High through stakeholder ownership
Adaptation Outcomes	Prescriptive	Adaptive and Flexible

Comparing these cases shows several things that help epistemic co-production succeed. First, spending time is important—projects that lasted multiple years were better at building trust, forming stable relationships, and allowing learning over time. Second, using "boundary objects" like simple climate models, participatory maps, or mixed scenario tools helped bridge different knowledge types by creating shared ways to understand information. Third, trust grew when facilitators translated scientific language into cultural terms, often using visual, oral, or local codes.

Besides these operational parts, institutional setups also mattered. Co-governance groups with both community representatives and technical experts made sure co-produced knowledge stayed relevant and credible. In areas with many languages, providing multilingual materials and local facilitators made things more accessible and showed local ways of knowing are valid. These structural supports show that good co-production isn't just about who joins. It's about designing knowledge systems to support inclusive, repeated, and context-sensitive decision-making.

9. Obstacles to Implementation

Though it's more recognized in academic and policy talks, putting epistemic co-production into practice still has many complex barriers—structural, epistemological, and political. One big problem is how rigid institutional frameworks are. Bureaucratic rules, funding ways, and reporting systems like linear, short-term results more than the repeated and relational nature of co-production. Government agencies and research institutions are often judged by measurable, deliverable-based outcomes. This leaves little space for the adaptive testing and community-level talking that co-production needs. So, there's a tendency to add participatory words to basically technocratic processes. This hurts the mutual learning that real co-production is based on (Boon et al., 2019).

Epistemological barriers also make implementation harder. Scientific authority is often more valued than other ways of knowing, especially in formal adaptation planning where standard metrics, models, and frameworks rule. This ranking of knowledge systems not only pushes local voices to the side but also stops epistemic pluralism. It turns co-production into token consultation instead of real collaboration. Disciplinary silos in academia and between science and policy make transdisciplinary integration hard. It's tough to keep the continuity and coherence needed for long-term co-productive engagement (Bremer & Meisch, 2017).

Power asymmetries also mess up co-production spaces, often favoring actors with more institutional legitimacy, better technical language skills, or access

to funding. In many projects, participation is invited but limited—communities are asked for input only after key decisions are made, or their ideas are picked to support existing conclusions. This creates what some scholars call "instrumental co-production," where engagement is to make decisions look legitimate, not change them. Such practices break trust and can make existing social inequalities worse, especially in communities already pushed to the side by climate governance systems (Daly, 2016).

Besides these structural and knowledge challenges, there are also logistical and timing mismatches between communities and institutions. The timescales of research funding, policy cycles, and academic publishing don't match the slower speed of building community relationships, forming trust, and doing adaptive testing. As a result, co-production efforts often end too early or don't have enough resources. This makes it hard for them to become part of institutions and grow.

Overcoming these obstacles needs deliberate changes in how co-production is thought about and done. Protective spaces—places where actors can engage without pressure to follow disciplinary or bureaucratic rules—are key for building trust and reflection. Inclusive governance frameworks must also be changed to make sure diverse knowledge systems are not just recognized but given equal power in shaping adaptation priorities. Institutional reflection—the ability of organizations to check and change their own assumptions and power dynamics—is a necessary first step for any real form of epistemic co-production.

10. Conclusion

Traditional climate modeling has a problem: while it gives more precise global and regional projections, its effect on actual adaptation practices is uneven and often limited. The main problem isn't the accuracy of climate models themselves, but the gap between how knowledge is made and the contexts where it's used. This essay argues that bridging this gap needs more than technical improvements in downscaling or data resolution—it needs a basic rethink of how climate knowledge is made, proven, and used. Epistemic co-production offers exactly this new approach.

By bringing together different ways of knowing—from traditional ecological knowledge and local experiential insights to institutional and academic climate science—co-production helps make not just more useful knowledge, but more legitimate and inclusive decision-making. It sees adaptation as a social process: one that's repeated, argued about, and shaped by values, identities, and power relations as much as by climate variables. Doing this improves both the scientific trust and social relevance of adaptation strategies, making sure they're based on local realities and still use the best evidence.

But the success of this approach depends on things. It needs institutional flexibility, political will, and the ability of scientific and policy actors to give up control, be humble about knowledge, and build long-term partnerships with communities. It also needs governance frameworks that can handle non-linear learning and resist pressure for quick, measurable results. These are big changes—they challenge the usual way climate governance works, which is often centralised, metric-driven, and afraid of risk.

But the global use of co-production must also face deep cultural, institutional, and political inequalities. While the ideal of democratising knowledge is appealing everywhere, how it works varies a lot in different contexts. In some societies, traditional ecological knowledge is closely guarded, hierarchical, or gendered, which challenges the idea that it's naturally inclusive. So effective co-production needs not just recognizing diverse knowledge systems but also critically engaging with the internal power relations that shape how they're made and shared.

Co-production shouldn't just be seen as building consensus or looking participatory. It needs real efforts to build capacity—developing local interpretation skills, investing in cross-cultural facilitation, and building long-term institutional memory. Without these basic supports, co-production might become extractive or symbolic, copying the inequalities it wants to fix. So, democratising climate

modeling must go with democratising epistemic access and interpretive authority.

Putting co-production into climate modeling and adaptation needs more than just small test projects. It calls for structural change: reforming climate education curricula to include social learning theories; changing funding criteria to support repeated engagement over fixed deliverables; and creating protective spaces where marginalized voices can participate equally. Research must also keep improving co-production methods, finding context-sensitive signs of success and failure, and exploring how local practices can grow without losing their roots.

The epistemic co-production of climate adaptation knowledge is not just a methodological need but a moral necessity. As climate impacts get worse, the legitimacy of adaptation will depend more on whether it's socially just, rooted in context, and co-created with those who bear its consequences. Co-production isn't just a complement to scientific modeling—it's its democratic extension.

References

Agyei-Mensah, S., Owusu, G., Awuni, C., Howard, B., Fuseini, I., Buytaert, W. and Berkhout, F. (2024) 'Chiefs and floods: hybrid governance and co-production of flood risk adaptation in Tamale, Ghana', Journal of Environmental Policy & Planning, 26(6), pp. 656–672. doi: https://doi.org/10.1080/1523908X.2024.2410899.

Atkinson, R., Dörfler, T. and Rothfuß, E. (2018) 'Self-organisation and the co-production of governance: The challenge of local responses to climate change', Politics and Governance, 6(1), pp. 169–179.

Bernal Llanos, M. (2021) Co-producing knowledge and politics for climate change adaptation: The case of Colombia's Capital Region. Doctoral dissertation. University College London.

Boon, W.P.C., Hessels, L.K. and Horlings, E. (2019) 'Knowledge co-production in protective spaces: case studies of two climate adaptation projects', Regional Environmental Change, 19, pp. 1935–1947. doi: https://doi.org/10.1007/s10113-019-01517-4.

Bremer, S. and Meisch, S. (2017) 'Co-production in climate change research: reviewing different perspectives', WIREs Climate Change, 8(6), e482. doi: https://doi.org/10.1002/wcc.482.

Briones, A. (2020) EU's External Climate Governance: The Role of Decentralised Cooperation and Multi-level Governance in Climate Adaptation. Master's thesis. Utrecht University.

Daly, M. (2016) Co-production and the politics of usable knowledge for climate adaptation in Tanzania. Doctoral dissertation. Colorado State University.

Hernández, V., Riglos, M.F.F. and Vera, C. (2022) 'Addressing climate services in South American Chaco region through a knowledge co-production process', Global Environmental Change, 72, 102443. doi: https://doi.org/10.1016/j.gloenvcha.2021.102443.

Klenk, N., Fiume, A., Meehan, K. and Gibbes, C. (2017) 'Local knowledge in climate adaptation research: moving knowledge frameworks from extraction to co-production', WIREs Climate Change, 8(6), e475. doi: https://doi.org/10.1002/wcc.475.

Mees, H., Alexander, M., Gralepois, M. and Matczak, P. (2018) 'Typologies of citizen co-production in flood risk governance', Environmental Science & Policy, 89, pp. 330–339.

Mees, H., Crabbé, A. and Driessen, P.P.J. (2017) 'Conditions for citizen co-production in a resilient, efficient and legitimate flood risk governance arrangement: A tentative framework', Journal of Environmental Policy & Planning, 19(6), pp. 827–842. doi: https://doi.org/10.1080/1523908X.2017.1299623.

Ragolane, M. and Khoza, N.G. (2024) 'The use of hybrid governance and co-production for effective service delivery: A South African local government perspective', International Journal of Social Science Research and Review, 7(1), pp. 135–152.

Shaffer, L.J. (2023) 'Making sense of local climate change in rural Tanzania through knowledge co-production', Journal of Ethnobiology, 34(3), pp. 315–334. doi: https://doi.org/10.2993/0278-0771-34.3.315.

Singletary, L. and Sterle, K. (2020) 'Supporting local adaptation through the co-production of climate information: An evaluation of collaborative research processes and outcomes', Climate Services, 20, 100201. doi: https://doi.org/10.1016/j.cliser.2020.100201.