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Right-scaling and scaling-up knowledge co-production for decarbonization, climate-resilience and equity through [multilevel] metropolitan climate action planning

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1. Why co-produce knowledge for sustainable, equitable urban infrastructure transitions?

Sustainable development, broadly defined as achieving wellbeing for all within planetary boundaries, requires transforming key infrastructure and food provisioning systems that foundationally connect people with nature (O' Neill *et al* 2018). Indeed, these key provisioning systems that supply energy, mobility, construction materials, food, water, greenery, and waste management, contribute to >98% of global water withdrawals and land use, and >94% of global greenhouse gas emission (Ramaswami *et al* 2016, 2023). At the urban scale, where a majority of the world's people live, these provisioning systems foundationally impact, and are impacted by, social inequality. For example, poverty and socioeconomic status, shaped by gender, caste and race, are associated with lack of access to clean water, energy, housing, mobility and nutritious food, which in turn negatively impact economic opportunity and human health. Further, these essential lifeline sectors are vulnerable to climate change-disruptions manifested by disruptions in power, transportation, food, water and fuel seen in human settlements worldwide that are being impacted by hurricanes, flooding and wildfires (Iglesias *et al* 2021). Thus, transforming urban infrastructure and food provisioning systems through new technologies, network designs, policies and social innovations has been recognized to be critical for achieving sustainability, both locally and globally (Ramaswami *et al* 2016, 2023). Such sustainability transitions seek to transform the above multiple sectors toward multiple interconnected goals of resource sustainability, pollution mitigation and decarbonization with climate resilience, health and equity co-benefits—thereby advancing many of the world's sustainable development goals. However, the challenge lies in engaging numerous stakeholders—individuals, communities, industry/businesses and a range of policy actors—in charting these sustainability transition pathways suited to local priorities and contexts, while also recognizing larger-scale (i.e. national or global-scale) drivers and constraints.

Knowledge co-production has emerged as an important and essential modality by which researchers can enable and inform such sustainability transitions at multiple societal scales. At its most fundamental level, knowledge co-production has been defined as: '*substantive interactions between producers and users of knowledge that results in knowledge that fits decisions contexts*' (Mach *et al* 2020). Knowledge co-production can be implemented at different spatial scales—including participatory research with communities as well as engaged research with policy actors spanning scale from urban to national and even international arenas (Norström *et al* 2020, ACERE, 2022). Thus, although co-production is often predominantly associated with community-based participatory research, it is important to recognize that such methods have been harnessed at larger scales and policy arenas such as city-wide climate action plans, regional pollution mitigation efforts and national power sector planning. Indeed, the scale of the action arena must match the scale of the sustainability challenge—i.e. addressing water sustainability must necessarily engage all the relevant actors (stakeholders) within a watershed, while addressing local solid waste management challenges can be achieved at the smaller city-or neighborhood scale.

Four key aspects distinguish knowledge co-production from other science-policy exchanges (Norström *et al* 2020): (i) being context specific rather than abstract; (ii) being goal oriented including articulating the purpose and planned outputs of co-production; (iii) engaging a plurality of actors; and, (iv) employing iterative processes to foster

co-creation of key research questions and collaborative interpretation of research findings. These four aspects are considered integral to the process of analytic deliberation which is defined as the combination of technical analysis and democratic deliberation essential for addressing society's grand challenges which are characterized by high levels of uncertainty, large and unequal impacts on different societal groups and valued differently by them, along with an urgency to act even with limited data/models (Stern 2005). Indeed, tackling climate change is the quintessential grand challenge because climate hazards impact different social groups differently, there is uncertainty in these impacts as well as the potential benefits of actions to address them, while simultaneously, there is also an urgency to act. In such cases, co-production enhances the credibility and legitimacy of the co-produced knowledge, which can facilitate society's adoption of the proposed socio-technical pathways towards sustainability and equity (Mach *et al* 2020, Ramaswami *et al* 2022). Thus, knowledge co-production is essential both to enable research on transition pathways ***and*** to rapidly scale-up transition pathways toward developing equitable, sustainable climate-resilient futures, particularly in urban areas that will be home to >66% of the world's population by 2050.

However, two critical questions have emerged in the context of knowledge co-production for urban infrastructure transitions. First, what is the right-spatial scale of the action arena to facilitate urban infrastructure transitions for sustainability, equity and resilience? And, second, how can we 'scale-up' the impacts of co-produced knowledge—i.e. widely put into use the outputs of co-production (such as co-produced data, models and insights) to rapidly impact large numbers of people?

I recently worked in an engaged research partnership with the Twin Cities metropolitan council of governments to co-develop a zero-carbon pathways model for the region. That experience yielded learnings and conceptualizations about multi-level metropolitan-scale collaborative research, synthesized here. In this commentary, I posit that multilevel metropolitan regional climate action planning can achieve both 'right-scaling' and 'scaling up' of co-production of urban infrastructure transitions for equity and sustainability.

2. Right-scaling co-production at the metropolitan regional scale

In the US, urban metropolitan regions are emerging as a new action arena to advance zero-carbon infrastructure transitions with multiple potential co-benefits. While previous urban decarbonization efforts were dominated by major central cities (CNCA 2024), the US Inflation Reduction Act has recently (2021) stimulated 81 metropolitan regions to develop zero-carbon plans, highlighting their potential to advance climate resilience and social equity co-benefits (US EPA 2024). For example, the Washington DC Metro climate action plan aims to decarbonize buildings energy and mobility by 2035 while addressing extreme heat, coastal and urban flooding. The Denver metro has similar zero-carbon goals, while addressing extreme heat and water scarcity. The greater Twin Cities (Minneapolis–St Paul) region additionally recognizes urban–rural linkages for agriculture and municipal water security in a changing climate. California councils of governments (COGs) articulate decarbonization alongside addressing droughts, water scarcity, forest wildfires and coastal flooding. All plans seek to engage and address the needs of under-served and historically marginalized communities, centering on equity.

Metro-regions can be an ideal 'right-scaled' action arena for co-developing pathways towards zero-carbon, equitable, climate-resilient transitions. The reasons are multifold:

First, as noted above, more than 81 US Metro's have already initiated climate action plans, stimulated by the Inflation Reduction Act. These plans are goal oriented with a fixed timeline to develop a baseline GHG account, climate hazard and inequality/equity assessment (US EPA 2024). Thus, researchers collaborating with Metro Regions already have a structure that establishes a goal-orientation and context-specificity, both of which are critical aspects of co-production by Norström *et al* (2020).

Second, metro-regions encompass a diversity of community types across the urban–rural continuum. For example, the Twin Cities Metro includes 182 cities and towns, with half its population in suburban and rural edge communities (Met Council 2024). In my work with the Twin Cities, we developed models illustrating zero carbon pathways for these diverse city types—central cities, suburbs and rural edge communities. Feedback on the model was obtained from the individual city planners of these case study cities, as well from all the 163 communities, of which at least 50% attended initial and intermediate model presentations. Each city in turn, often uses its community/neighborhood outreach offices to get feedback on equity implications. For example, Minneapolis' efforts with its food action plans, or Denver's efforts to communicate its climate action plans through its neighborhood meetings. Together, this approach can yield what I call multi-level climate action planning—engaging a plurality of city-types (central cities, suburbs and rural communities) as well as plurality of actors/neighborhoods within each city. Such plurality is a third key aspect of co-production, and can be facilitated particularly well by Metropolitan Regional COGs.

Third, the regional scope of the metropolitan organizations is particularly well-suited to enable infrastructure transitions because land use and

infrastructure planning/financing are often coordinated at the metro-regional scale via land-use plans for roads/mobility, buildings, water supply, wastewater treatment, renewable energy siting, and green infrastructure, alongside preservation of agricultural lands. Indeed, US Metros include urbanized land alongside significant forest and agricultural lands, contributing from 4% in the Los Angeles Metro to 20%–30% in the Twin Cities, Detroit, and Denver Metro Regions, thus facilitating beneficial urban–rural resource circularity of water, nutrients or bioenergy. Such urban–rural linkages are rarely addressed in national or in city-level zero-carbon plans, making the metro urban-regional scale unique in its capacity to leverage proximal and beneficial urban–rural linkages.

Fourth, extreme climate events are shaped substantially by interactions of the climate system with the built environment at *regional scales*, as evidenced by long-duration intense rainfalls over metro regions seen during Hurricane Harvey (Zhang *et al* 2018), and hence require regionally-coordinated solutions.

Last, the regional-scale enables addressing social inequality at multiple-levels, both intra-urban and across the urban–rural continuum, important to inform multiple dimensions of equity.

All the above features make metro regional scale the right-scaled action arena for sustainable and equitable infrastructure and food system transitions, since it can coordinate several of the key lifeline infrastructures—buildings and built form, transportation, water, wastewater and green infrastructure system, and to a lesser extent energy and agriculture.

3. Scaling up co-production

Innovatively, the multilevel mechanism for coproduction—wherein researchers partner with higher [Metropolitan] levels of government, who in turn engage policymakers in constituent central cities, suburbs, rural communities, and they in turn engage neighborhood groups—offers great potential to scale-up both [the process of] co-production itself and its impacts (i.e. its outputs).

Scaling up co-production refers to increasing the number of diverse stakeholders engaged (Lu *et al* 2022), which can be achieved via the multi-level co production processes, by engaging diverse city types and their constituent diverse communities in a structured manner shown in figure 1. Other approaches are also used to scale up co-production, e.g. via novel citizen engagement harnessing social media. The novel aspect of figure 1 is the structured process both to reach a diversity of cities/towns and their constituent neighborhoods.

Equally important is scaling-up the use and hence the impact of co-produced data, models and insights, which can be achieved by the process of *aggregation* (Lu *et al* 2022). In this mechanism, working with higher levels of government enables adoption of co-produced products impacting larger numbers of people. For example, in the US, the median population of metro regions is 244 000 people, while the median size of US cities is only 40 000 (US Census). Thus, rather than researchers working with individual cities, there is much greater potential for impact by collaborating with Metro Regions.

The aggregation effect can further be amplified by university researchers working with groups of metropolitan governments in *cohort-based co-production* (Tabory and Ramaswami 2020) wherein cohorts of metro regions work together with researchers, meeting frequently as a group and learning from each other. Here, the science of city types can be used to assess what insights are generally translatable to other metro regions or city types, versus those that require further deep and contextual study. The potential for combining multi-level co-production in individual metro regions with cohort-based learning across Metro Regions has potential to massively scale up the speed and the number of people impacted. For example, today, about 82 Metro-region climate-pollutant action plans are underway, together covering 204 million people (US EPA 2024), all planning zero-carbon pathways with resilience, resource and equity co-benefits. See figure 2. If scientists are able to co-produce knowledge, diving deeply into a few metro regions, and then cross-fertilize key learnings *across* metro regions, in processes facilitated by multi-city organizations such as ICLEI-"Local Governments for Sustainability"(ICLEI 2025), the process can be transformative in achieving large scale impact and yet retaining most relevant local context and specificity.

Based on the above insights, this commentary makes the case that knowledge coproduction for urban climate action planning must transition rapidly from working with individual cities to working with metro regions, ideally through multi-level collaboration. Metro-regions offer the right-spatial-scale to effect multi-infrastructure transitions toward decarbonization, equity and resilience goals. Further, multi-level coproduction in individual metros, combined with cohort based co-production *across* metros, can substantially scale up the number/plurality of people engaged in coproduction as well as massively expand the uptake of the coproduced knowledge, data, models and insights. Such an endeavor will advance research on design of urban infrastructure transition pathways in diverse regions and city types, and unlock innovative solutions to advance sustainability and equity. More importantly, researchers will also be able to advance the science of knowledge co-production itself, uncovering the barriers and enablers, and evaluating the potential for scaling up co-production through metropolitan climate action planning.

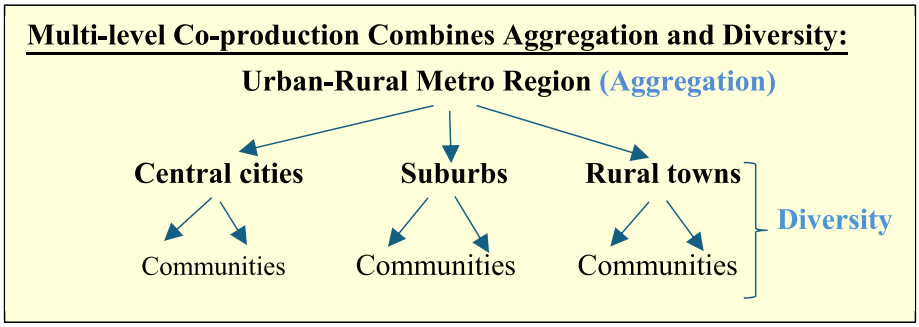

Figure 1. Schematic illustrating multi-level knowledge co-production in metropolitan regions that combines aggregation and diversity.

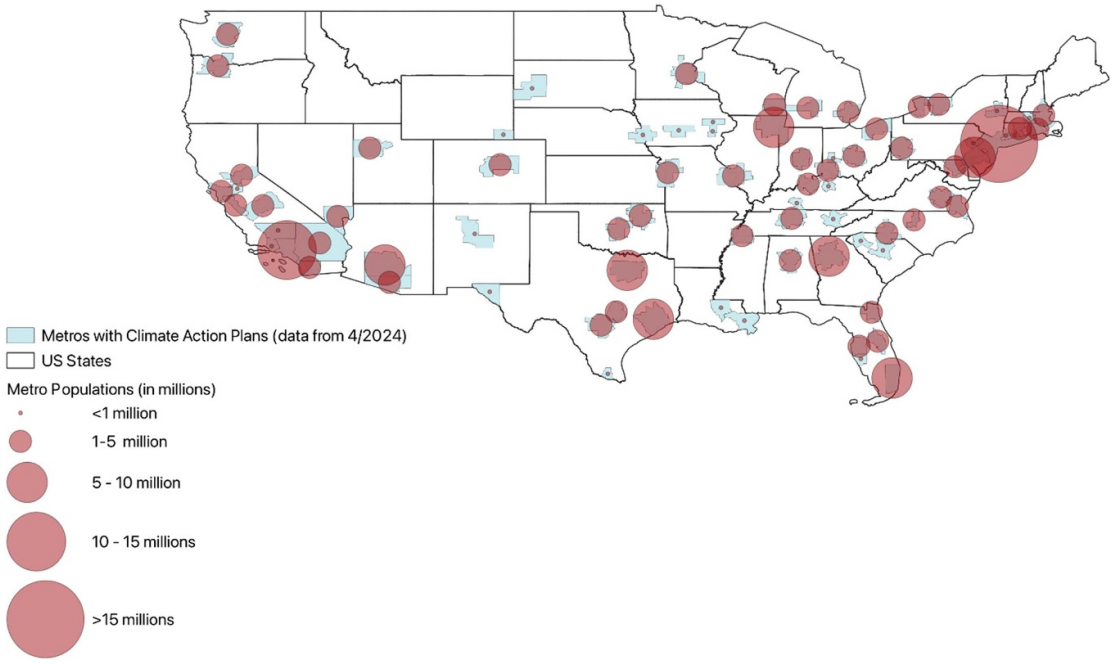

Figure 2. Eighty-one US metropolitan regions with climate action plans addressing mitigation, resilience, and equity, with population shown in bubbles. The collective population is 204 millions as per US Census estimates. Data from US EPA (2024).

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