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Can transnational municipal networks mitigate the carbon pollution of the world's power plants?: an empirical analysis

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Transnational municipal networks (TMNs) have been heralded as actors that can avert a climate catastrophe by filling the "emission gaps" left by national climate policies. But can these networks reduce the carbon pollution of power plants, the world's largest sites of climate-disrupting emissions? Using an international data source on individual power plants, we empirically analyze this issue. Findings reveal that after accounting for their structural properties and the national policies to which they are subject, power plants emit less CO_2 when nested in cities that are members of TMNs and this is especially true of plants in less developed countries. In contrast, national climate policies are unrelated to plants' environmental performance over time. Although our analyses suggest TMNs help to reduce the emissions of the typical power plant, they also indicate they have little bearing on the emissions of the world's most egregious polluting plants.

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INTRODUCTION

While climate policy has traditionally been conceived as driven by national governments, there is a growing recognition that their authorities have not undertaken action at a sufficient pace and scale, nor with adequate political support, to avert the most severe climate risks. Current national government emissions reduction commitments, in fact, are not enough to prevent a global temperature rise of 2 °C above preindustrial levels[1]. For this reason, the idea that society needs a new global climate regime that is both multilevel and polycentric was embedded in the preamble of the Paris Agreement, which asserts "the importance of engagements of all levels of government and various actors"[2].

In response to this treaty and dissatisfaction with national leadership more generally, networks of non-state actors (e.g., businesses, investors, civil society organizations) and subnational (e.g., city, local state, and regional) governments have proliferated in number and membership[3]. These networks coordinate activities, including those relevant to agenda setting, information sharing, policymaking, and capacity building[4]. They can also help to identify, scale up, and pilot innovative approaches to climate change to national governments. Chief among these groups are environmental transnational municipal networks (TMN), which are membership-based organizations of city government that give access to policy knowledge and relevant resources to help cities reduce greenhouse gas emissions[5]. While the issues and sectors addressed by TMNs vary from city to city, these networks each attempt to bypass national efforts to mitigate climate change by directly providing expertise and advice to member cities.

As more cities have participated in TMNs over the last few decades[6,7], increasing attention has been given to their efficacy in facilitating environmental improvements. Existing evidence shows that on a global scale, memberships in environmentally focused TMNs are associated with greater GHG emissions reductions on the collective urban-level, controlling for national-level climate policy[8]. However, important questions remain on both the matter of impacts on developing versus developed countries, and the decarbonizing impact specifically on a key GHG emissions source within cities: Power plants.

Optimists claim that TMNs' bottom-up approach is best suited for addressing complex problems like climate change. According to them, local actions and global cooperation among cities can bring about a "miracle of civic 'glocality' that promises pragmatism instead of politics, innovation rather than ideology, and solutions in place of sovereignty"[9]. This approach is said to be especially beneficial to developing countries that often lack the technical expertise to create climate-smart cities.

Pessimists argue that although TMNs purport to champion evidence-based solutions, they selectively produce and disseminate information to support their political priorities and pressure policymakers to adopt certain measures. From their perspective, TMNs too often replicate rather than create alternatives for policy networks[10]. Hence, they tend to promote the established solutions of advanced countries, ignoring how less developed ones frequently do not have the resources and infrastructures needed to implement them[11].

Despite their differences, both sides concur that if nonfederal actors like TMNs are to help limit climate change, they must decarbonize the facilities that supply energy to a local community and especially those that emit a disproportionate share of climate-disrupting emissions. Indeed, unless TMNs can mitigate the environmental damage created by the power sector and its most egregious emitters, plans to electrify other sectors such as transportation, building, and industry will likely provide limited benefits. Unfortunately, because researchers have lacked a global dataset on the CO_2 emissions of individual power plants, they have made little progress in determining whether TMNs affect the sites where electricity is generated through the burning of fossil fuels.

Using a novel international data source on individual power plants' CO_2 emissions between 2009 and 2018 (see Fig. 1), this study addresses this limitation by analyzing the association between TMNs and plants' emissions net of their countries' energy-climate policies and other factors. It also examines how the association differs in less and more developed countries, and whether TMNs are negatively related to the CO_2 releases of the world's worst polluting plants.

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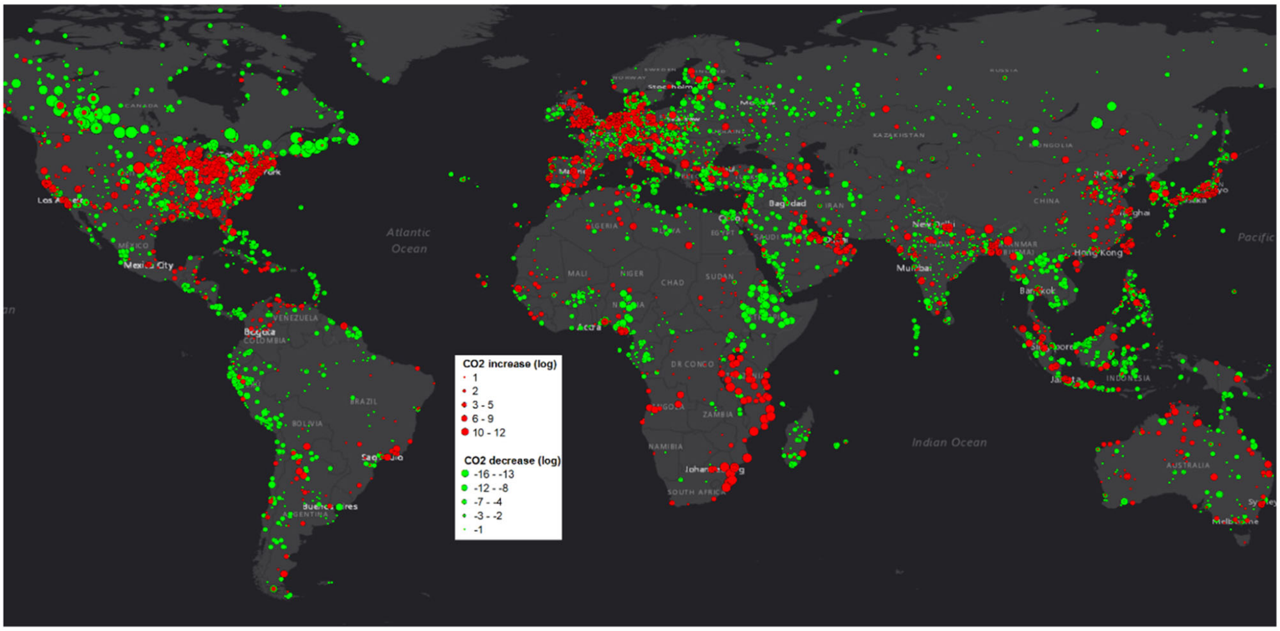

Fig. 1 Map of change in power plants' CO_2 (logged) emissions, 2009–2018. Green (red) nodes denote power plants that reduced (increased) emissions over the observed time period. Node size is proportional to the extent of emissions change.

Findings lend support to the arguments of both optimists and pessimists. On the one hand, after accounting for their structural properties and the national policies to which they are subject, power plants emit less CO_2 when nested in cities that are members of TMNs. This is especially true of plants in developing countries. On the other hand, TMNs are unrelated to changes in the emissions of the world's most egregious polluting plants. We discuss the implications of our results for future research on TMNs and suggest how granular analyses like this one of facility-level emission outcomes can complement and refine studies of city-level outcomes[4,8].

BACKGROUND

Networks among cities and other forms of subnational climate governance are by no means a new phenomenon[10,12,13]. At the 1992 United Nations Conference on Environment and Development (UNCED), local authorities were recognized as key stakeholders in the setting of public agendas. In 1993, the international alliance Local Governments for Sustainability (ICLEI) launched the Cities for Climate Protection program (CCP), which quickly grew to involve hundreds of cities[14]. However, the number of formalized networks has increased most rapidly in recent years as it has become apparent that Nationally Determined Contributions (NDCs), by themselves, are insufficient to meet the temperature goals established under the Paris Agreement. Hsu et al. [15] estimate that the gap between projected emissions of current policies and unconditional and conditional NDCs to be around 29 to 32 $GtCO_2e$ for 1.5 °C, and 12 to 15 $GtCO_2e$ for 2 °C, in 2030. Cities and other subnational actors, though, could play a significant role in closing this gap. They have the potential of mitigating up to potential of sub-national action for climate mitigation appears to be substantial—up to about 20 $GtCO_2e$ (Hsu et al. 2020).

In light of these and related developments, TMNs like ICLEI, C40 Cities Climate Leadership Group, Carbon Neutral Cities Alliance, and Global Compact of Mayors have shifted from the margins of the global climate regime to a position of greater prominence and ambition[16]. TMNs offer a range of benefits[4], including access to resources, city branding, learning and new ideas, lobbying, and goal setting and monitoring. And although they vary with respect to the focus of their efforts, there has been a good deal of consolidation around transnational city-networks as the primary vehicle through which cities participate in the global response to climate change.

Research on TMNs has examined the experiences of member cities, compared well-known TMNs such as Cities for Climate Protection (CCP)[14,17], Cities Climate Leadership Group, and C40[18–21], as well as popular ones like the International Solar Cities Initiative, ISCI, the Climate Alliance, and the Energy Cities network[22]. Several studies have investigated the factors driving cities to participate in transnational networks[23]. In addition, scholars have addressed such questions as: What determines the ambition levels of municipal climate actions? What policy instruments do TMNs use to address climate change? And which sectors do these networks target?[24–27].

In contrast to this substantial body of work, there has been surprisingly little research on the ultimate question of whether TMNs reduce CO_2 emissions, and how that compares to existing national climate policy. Notably, Leffel[8] shows that for cities globally, TMN memberships are linked to greater city-level GHG reductions, even when controlling for national climate policy, theorizing that TMNs facilitate bottom-up diffusion of climate policy knowledge across cities independently of traditional top-down national policy processes[28,29]. This mechanism of diffusion draws on world society theory, which emphasizes how institutions diffuse governance norms, or policy standards, globally and thus affect policy outcomes, including outcomes such as environmental change. For instance, research in this tradition argues that intergovernmental organizations such as the UN transmit normative environmental governance standards to participating national governments, which then implement said standards in the form of environmental treaty ratification or similar domestic environmental policy measures[30,31]. National policy implementation is argued to then lead to implementation at the subnational level, ultimately resulting in improved environmental conditions, including the reduction of CO_2 emissions[28,32]. While this is characterized as an exclusively a top-down, national government-led process[33–35], Leffel[8] demonstrates that bottom-up forces also contribute to this outcome, specifically that TMN memberships have a decarbonization impact on cities independently of the nation-state. Hence, TMNs bypass national governments by directly transmitting climate policy standards to participating cities. If the policy norm diffusion facilitated by TMNs is linked to CO_2 emissions reductions at the collective city-level, it is also plausible that power plants within cities are also similarly affected, a hypothesis we test in this study.

However, numerous scholars have raised doubts about the efficacy of TMNs. According to Peck and Theodore[36], for example, TMNs' bottom-up approach is reflective of what they label the era of "fast policy" in which policymakers increasingly borrow ideas said to "work" in other societies in a highly connected, temporally compressed, and market-driven world. The pursuit of politically expedient solutions both fuels the exploration of policies and leads countries to converge on a common set of "best practices." But whereas proponents of TMNs stress the democratic and problem-solving potential of such experimentation, Peck and Theodore warn that it may foster a form of technical rule-by-elites and result in overly simplified, decontextualized and "one-size-fits-all" understandings of policy. Once considered the domain of academics and in-house government employees, policy evaluation research has increasingly been conducted by international organizations like TMNs, aid agencies, philanthropies, think tanks and corporations. Although these well-resourced and -connected actors purport to champion evidence-based solutions, they selectively produce and disseminate information to support their political priorities and pressure policymakers to adopt certain measures[37]. To the extent they succeed in dominating policy discourse, these actors replace a deliberative, systematic and empirically validated approach to policymaking with one characterized by policy shortcuts, "governing by examples," and a "shoot first and ask questions later" mentality[38].

Similarly, Bansard et al. [9] questions whether TMNs are an effective substitute for aggressive international and binding mitigation actions. Specifically, his analysis suggests these networks fail to include members in regions with high emissions, avoid duplicating the work of national governments, set ambiguous and unambiguous targets that go beyond those of nations, and enforce monitoring mechanisms that report and verify commitments. Contrary to the suggestion that TMNs are especially beneficial to developing countries, these researchers and others[4,20,39,40] also contend that TMNs have a general bias towards wealthier countries and reproduce the solutions preferred by their cities by promoting a one-size-fits -all approach to sustainable development.

However, others argue that TMN efficacy in developing countries is broadly underappreciated. Even in developing country regimes that restrict TMN participation, as is the case in China[41], TMNs can nonetheless partner with central governments and still be successful in such settings. For example, with the PEMSEA Network of Local Governments gained many Chinese member cities via coordination with the Chinese State Oceanic Administration and successfully diffused new marine policy innovations[42]. Less understood yet critically important is the decarbonization impact, including in the energy sector, that TMNs may facilitate in developing nations. Existing research highlights that while cities globally draw on technical resources from both TMN memberships and local environmental services consultancies to implement mitigation strategies, the latter is more widely available in wealthy nations[8,43]. TMNs, however, have far greater geographic reach, which may afford cities in developing nations access to decarbonization resources which are otherwise unavailable to them. In this way, the diffusion of climate policy knowledge facilitated by TMNs may be particularly impactful.

Adding to the uncertainty surrounding the efficacy of TMNs is that the few studies that have examined their association with pollution outcomes have tended to focus on downstream consumers as opposed to upstream producers like the electricity sector whose CO_2 emissions have risen by 53% worldwide over the past two decades[44] and are predicted to be over half of all carbon releases in the future[45]. This is an important oversight also because the electricity sector will play a pivotal role in creating climate-smart cities. Electric vehicles, for example, are only as clean as their power supply, and the electricity sector offers some of the lowest hanging fruit for mitigation. According to one study, decarbonizing a small percentage of the worst polluting power plants, many of which are owned by city governments[46], would eliminate the lion's share of all electricity-based emissions[47]. For this reason and others, TMNs like C40 Cities have pursued a pollution reduction strategy of "focused acceleration" that prioritizes decarbonizing the electricity grid[48]. Whether they have succeeded in mitigating the pollution of the power sector, and especially its most profligate polluters, has yet to be determined.

To advance our understanding of whether TMNs are effective at reducing carbon pollution, we provide answers to the following empirical questions: Do power plans emit CO_2 at lower levels when their cities are members of TMNs? If so, is this more the case in developing than developed countries? And do TMNs help to lower the pollution of the most egregiously emitting plants? Supporters of TMNs would predict the answer to each to be yes, while their critics would anticipate the opposite.

RESULTS

TMNs and power plants' environmental performance

Model 1 of Table 1 provides an answer to the first question of whether TMNs are effective in reducing power plants' CO_2 emission levels. As would be expected, model 1 reveals that plants that use coal as their primary fuel source, have more electrical capacity, utilize a higher percentage of that capacity, are government utilities, whose nations' power capacity relies heavily on fossil fuels, and plants that previously released high levels of CO_2 tend to emit more carbon dioxide in the present. Conversely, older plants emit fewer carbon pollutants. Particularly noteworthy, net of these controls and in contrast to national energy-climate policies that have a negligible impact on changes in plants' environmental performance, plants whose cities are members of TMNs release significantly lower levels of CO_2 over time.

Model 2, which assesses whether TMNs are especially effective in reducing plants' emissions in less developed countries, offers further support for those who champion these networks. Here we see that the interaction term between TMN and less developed nations is negative and significant. This indicates that TMNs' ability to lower plants' CO_2 levels is particularly great in the cities of less developed nations. Contrary to pessimists, this suggests that TMNs provide cities in developing countries access to decarbonization resources which would otherwise be unavailable to them.

Models 3 and 4, however, qualify these encouraging results. They reveal that TMNs are unrelated to reductions in the carbon released by the top 10 and 25 percent of polluting plants. Figure 2 plots the interactions between transnational municipal networks and the three factors tested in model 2 through 4.

DISCUSSION AND CONCLUSION

That TMNs are especially effective at decreasing plants' emissions in less developed countries may be attributable to their provision of climate policy support which may otherwise be unavailable. Such support can be particularly important for the complex task of decarbonizing local power generation, which involves switching from fossil fuels to a range of different renewable energy sources, as well as energy efficiency improvements. We offer further qualitative insight to that end as follows.

Stehle et al. [49] observe across international south cities successful climate mitigation-related knowledge sharing and capacity building facilitated by ICLEI and C40 memberships. Our

Table 1. Determinants of power plants' CO_2 emission levels in 2018.

	Net association between TMNs and emissions (1)	TMNs and less developed country interaction (2)	TMNs and top 10% of polluters interaction (3)	TMNs and top 25% of polluters interaction (4)
Coal	0.240*** (0.044)	0.237*** (0.044)	0.154*** (0.045)	0.091* (0.042)
Plant Capacity	0.001*** (0.000)	0.001*** (0.000)	0.001*** (0.000)	0.001*** (0.000)
Plant Capacity Factor	2.157*** (0.053)	2.155*** (0.053)	2.100*** (0.053)	1.772*** (0.051)
Plant Age	−0.006*** (0.001)	−0.006*** (0.001)	−0.006*** (0.001)	−0.004*** (0.001)
Plant is a Government Utility	0.122*** (0.030)	0.121*** (0.030)	0.089*** (0.030)	0.025 (0.028)
GDP per Capita	0.003 (0.002)	0.003 (0.002)	0.003 (0.002)	0.003 (0.002)
Inflation	0.026 (0.017)	0.028 (0.018)	0.028 (0.017)	0.022 (0.01)
Unemployment Rate	0.019 (0.018)	0.019 (0.018)	0.018 (0.018)	0.020 (0.016)
Population Change	1.301 (2.106)	1.356 (2.106)	1.238 (2.093)	1.782 (1.881)
National Fossil Fuel Power Capacity	0.466* (0.205)	0.467* (0.205)	0.400* (0.205)	0.707*** (0.195)
Climate Risk	−0.003 (0.002)	−0.003 (0.002)	−0.003 (0.002)	−0.003 (0.002)
National Energy Consumption	−0.001 (0.020)	−0.001 (0.020)	−0.001 (0.021)	−0.001 (0.023)
NGOs	−0.011 (0.121)	−0.009 (0.126)	−0.010 (0.121)	−0.001 (0.109)
Liberal Democracy	−0.371 (0.449)	−0.356 (0.493)	−0.356 (0.446)	−0.223 (0.401)
National Energy-Climate Policies	−0.009 (0.026)	−0.008 (0.028)	−0.011 (0.026)	−0.008 (0.023)
Transnational Municipal Network (TMN)	−0.171*** (0.053)	−0.545*** (0.114)	−0.175*** (0.054)	−0.134** (0.053)
Less Developed Country		−0.031 (0.308)		
Less Developed Country * TMN		−0.476*** (0.129)		
Top 10% of Polluters			0.437*** (0.051)	
Top 10% of Polluters * TMN			0.136 (0.236)	
Top 25% of Polluters				1.420*** (0.036)
Top 25% of Polluters * TMN				0.132 (0.137)
Emission Levels 2009	0.805*** (0.005)	0.805*** (0.005)	0.794*** (0.005)	0.687*** (0.006)
Constant	0.860	0.847	0.972	1.592
Random Effects of Countries	0.967*** (0.129)	0.967*** (0.129)	0.954*** (.128)	0.758*** (0.102)
N / x̄ Observations per Group	147 / 95.1	147 / 95.1	147 / 95.1	147 / 95.1
Random Effects of Sub-National Areas	0.041*** (0.008)	0.040*** (0.008)	0.042*** (.008)	0.032*** (0.007)
N / x̄ Observations per Group	1683 / 8.3	1683 / 8.3	1683 / 8.3	1683 / 8.3
Random Effects of Parent Companies	0.370*** (0.018)	0.370*** (0.018)	0.367*** (.018)	0.338*** (0.016)
N / x̄ Observations per Group	10,360 / 1.3	10,360 / 1.3	10,360 / 1.3	10,360 / 1.3
Residual Variance	1.031***	1.030***	1.026***	0.923***
N	13,985	13,985	13.985	13.985

*$p < 0.05$, two-tailed test.
**$p < 0.01$, two-tailed test.
***$p < 0.001$, two-tailed test.

finding suggests that these benefits are particularly strong in the energy sector. Through the 2000s and 2010s, investment in renewable energy outpaced investment in fossil fuel power plants, the largest increase occurring in less developed countries including Indonesia[50,51]. During this time, the Indonesian government implemented a series of renewable energy transition policies, including in response to the Paris Accord, targeting power plants[52], which subsequently increased renewable power plant capacity in biofuels and other renewables for power plants nationwide[53]. The capital city of Jakarta, a member of both ICLEI and C40, responded to these national actions in 2012 by implementing a Local Action Plan for GHG Reductions, and by way of agreement with C40, Jakarta committed to reduce emissions by 30% by 2030[54]. Further, as an ICLEI member, Jakarta participated in ICLEI's "Ambitious City Promises" program, which provided assistance in the development of decarbonization strategies, including for the energy sector[55,56]. As of 2018, Jakarta reduced GHGs by 9.34 million tons from its total target reduction of 32.28 million tons by 2030, the majority of reductions (7 million tons) being from decarbonization actions targeting the energy sector, particularly energy efficiency improvements and fuel switch in the Muara Karang and Tanjung Priok power plants[57].

C40 membership influenced the level of ambition of Jakarta's carbon target while ICLEI membership assisted Jakarta's energy sector decarbonization actions, which together constitute important policy support from TMNs to help facilitate power plant GHG reductions. Similar narratives also occurred in other city participants in ICLEI's Ambitious City Promises program, including

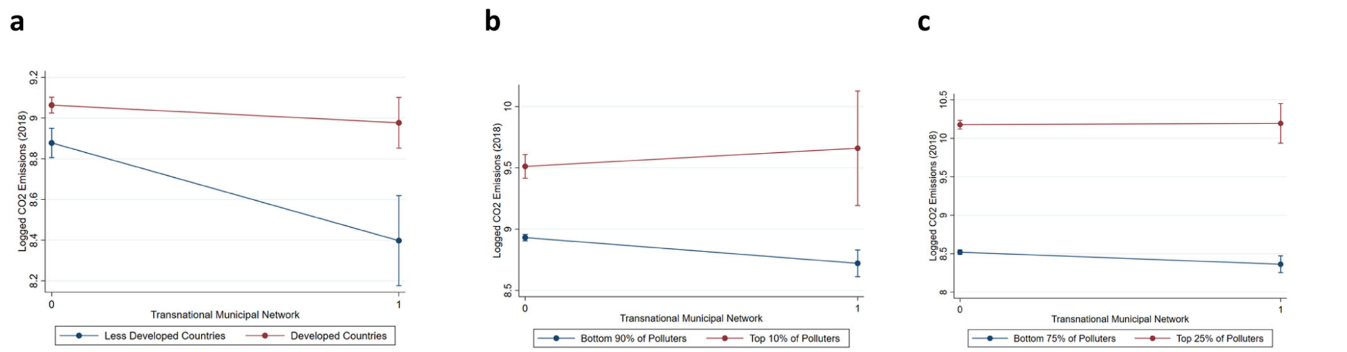

Fig. 2 Summary of the interaction analyses. a Plot of the interaction between transnational municipal network and country development status for Model 2 in Table 1 (point estimates and 95% Cis). **b** Plot of the interaction between transnational municipal network and top 10% of polluters for Model 3 in Table 1 (point estimates and 95% Cis). **c** Plot of the interaction between transnational municipal network and top 25% of polluters for Model 4 in Table 1 (point estimates and 95% Cis).

Manila, Philippines and Hanoi, Vietnam[56], which also housed emissions-reducing power plants. Beyond Southeast Asia, Sao Paulo, Brazil housed many emissions-reducing power plants in our data. The city's participation in ICLEI's Cities for Climate Protection Program and C40 facilitated the city's adoption and implementation of GHG inventorying, monitoring and reduction strategies, including the use of biofuel power generation through landfill gas-to-energy and methane-to-energy projects[58].

TMN memberships were by no means the sole driver of successful urban climate mitigation policy design, adoption and implementation, but the additive impact of the support they provided is consequential for the decarbonization outcomes observed. These TMN memberships provided resources that at the very least, accelerated existing city-level policy efforts to decarbonize power plants, and at most, were instrumental for achieving decarbonization outcomes. Future researchers will need to carefully distill the extent to which TMNs assist power plant decarbonization versus other sources of support, as well as what stage in the policymaking process they are most impactful.

Ours is the first global analysis to empirically demonstrate that TMNs can reduce the electricity sector's CO_2 emissions above and beyond the measures taken by nation-states. Our finding that city-level (TMN) factors evidently matter more for power plant decarbonization than national policies lends support to the theory that TMNs mobilize impactful policy resources independently of nations[8]. This is an important contribution to the polycentricity literature and suggests that the climate governance landscape beyond nations (i.e., the bottom-up, polycentric landscape of TMNs) is novel, and shapes the environmental performance of the world's single largest polluters—power plants–in a manner not yet recognized and fully appreciated. TMNs also appear to fill leadership gaps left by nations particularly in less developed economies, where less climate mitigation-related resources are available, as the decarbonizing impact of TMNs is particularly acute in the developing world. In this way, the polycentric landscape of TMNs can be as valuable as traditional institutions in climate governance, especially in bridging climate policy resource availability gaps in less developed countries.

By the same token, our study reveals that the facilities within this sector responsible for most of its carbon pollution are impervious to the efforts of TMNs. In addition to examining whether TMNs reduce emission outcomes at the city level[4,8], therefore, scholars interested in how subnational actors can accelerate the transition to deep decarbonization will want to drill past the city level to determine if TMNs are reining in super polluting plants. In particular, future research needs to determine whether TMNs' ability to improve plants' environmental performance depends on cities' capacities and available resources[59,60] and/or whether cities choose to join TMNs that offer more-carefully tailored policy analysis[61].

METHODS

We use a novel international data file that contains information on individual power plants, their CO_2 emissions, their technical specifications, characteristics of their countries including their energy-climate climates, and, most importantly for the purposes of this paper, whether plants are situated in cities belonging to a TMN. Our unit of analysis is the individual power plant where carbon is most often burned and released to the environment.

Dependent variable

This study's dependent variable is power plants' CO_2 emission level defined as the total kilograms of carbon dioxide emitted by a plant in 2018. To assess changes in plants' emission levels, we include a lagged endogenous measure of this variable for the year 2009. Because both measures are highly skewed, we use the log transformation of each. Our data on plants' emissions are drawn from an updated version of the 2009 Carbon Monitoring for Action (CARMA) file, the most widely used bottom-up inventory for allocating power plant CO_2 emissions[62]. The 2018 edition of CARMA draws on three data sets: plant-level emissions reports from the United States, European Union, Australia, Canada, and India; global plant- and company-level data from Platt's World Electric Power Plants Database; and country-specific power production data from the International Energy Agency. For non-reporting plants, CARMA estimates emissions using a statistical model fitted to data for the reporting plants and detailed data from the other two sources on plant-level engineering specifications. Details on this estimation procedure can be found in Grant, Zelinka and Mitova[47].

Key independent variable

Transnational municipal network is a dummy variable, coded 1 if a plant is located in a city that is a member of a TMN with a program that focuses on that city's electricity sector (as opposed to others like transportation, buildings). This measure is sourced from the Carbon Disclosure Project's Full Cities Dataset. Table 2 lists the ten TMNs examined here. In other analyses not reported here, we experimented with alternative operationalizations of the key independent variable. Specifically, we tested the effects of the total years of experience a city had with all ten TMNs and the years of experience a city had with the TMN it belonged to longest. Neither had a significant effect, suggesting that a city's length of experience per se does not have a strong bearing on an individual power plant's environmental performance.

Table 2. Transnational municipal networks analyzed.

C40 Cities Climate Leadership Group
100% Renewable Energy Cities & Regions Network
Carbon Neutral Cities Alliance
City NET
Europe Covenant of Mayors
FCM and ICLEI's Partners for Climate Protection
Global Covenant of Mayors for Climate & Energy
ICLEI-Local Governments for Sustainability
ICLEIs Green Climate Cities Program
Urban-LEDS

Table 3. Descriptive statistics.

	Mean	S.D.	Minimum	Maximum
CO_2 Emissions (2018)	9.11	3.43	−1.84	17.44
CO_2 Emissions (2009)	9.48	3.27	−3.65	17.41
Coal	0.14	0.342	0	1
Plant Capacity	191.49	510.48	0	6720
Plant Capacity Factor	0.314	0..260	0	1
Plant Age	26.24	12.48	0.1	92
Plant is a Government Utility	0.39	0.49	0	1
GDP per Capita	95.85	38.02	1	169
Inflation	0.18	0.09	0.02	0.39
Unemployment Rate	5.79	3.27	0.14	26.06
Population Change	0.03	0.03	−0.04	0.25
National Fossil Fuel Power Capacity	0.99	0.08	0	1
Climate Risk	64.25	24.54	11.33	173.17
National Energy Consumption	909.16	884.19	7.72	3132.18
NGOs	7.92	0.41	4.8	8.38
Liberal Democracy	0.59	0.25	0.01	0.89
National Energy-Climate Policies	9.58	6.46	0	20
Less Developed Country	0.35	0.47	0	1
Transnational Municipal Network (TMN)	0.05	0.20	0	1

Controls and other indicators

Our models control for several internal and external properties of power plants that prior research[63] has found or suggests condition their environmental performance. With respect to their internal features, we control for whether coal is a power plant's primary fuel (1=yes), plants' electrical capacity, plants' capacity utilization rate (percentage of potential output that was produced), their age, and whether plants are a government utility. With respect to external or macrolevel factors that could shape plants' CO_2 emissions, our models control for national gross domestic product (GDP) per capita in constant dollar, national inflation rate, unemployment rate, national population change, percentage of a nation's power capacity that depends on fossil fuels, national climate risk index, national energy consumption, number of NGOs in a country (logged), and the extent to which a plant's nation is a liberal democracy.

To assess whether TMNs are especially efficacious in less developed countries, we use a dummy variable that assigns a value of 0 to plants whose nations are classified as "high income economies" according to the World Bank and 1 to those whose nations are in the remaining lower income categories[64]. And to determine whether TMNs shape power plants' environmental performances above and beyond the measures taken by national governments, we use an indicator of energy-climate change policies taken from the International Energy Agency's Policies database. It includes information on whether a variety of measures—economic instruments (e.g., fiscal/financial incentives), information and education (e.g., performance labels), policy support (e.g., strategic planning, regulatory instruments) (e.g., auditing), research, development and deployment (e.g., demonstration projects), and voluntary approaches (e.g., negotiated private-public agreements)—are used by a nation to mitigate its electricity sector's carbon pollution. Consistent with past comparative studies of policy output[65–67], we score the total number of electricity-related climate policies in a nation.

Each of the predictors examined here is lagged at least one year to ensure it is not influenced by plants' emissions in 2018. This is particularly important with respect to TMNs. By measuring whether a plant's city had a TMN membership in the previous year (2017), we minimize the chance that a city joined a TMN as a result of a particular plant's emission level. Table 3 provides descriptive statistics of the dependent variable, key independent variable, and controls. Among other things, it shows that only a small percentage of power plants are in a city belonging to a TMN. Researchers need to keep this in mind when interpreting results because it suggests that TMNs have the potential to cover a much larger portion of the world's power fleet.

Modeling strategy

Our data structure is such that power plants are cross-nested within countries, sub-national areas, and parent companies. In keeping with prior research on plants' emissions[57], we account for this nesting when conducting our regression analysis of power plants' CO_2 emissions for 2018 by using a hierarchical, linear mixed effects model with three random intercepts (one for countries, one for sub-national areas (first-level administrative divisions), and another for parent companies)[68]. Our model also incorporates an unbalanced design that accounts for the fact that there are not the same numbers of plants in each company.

Reporting summary

Further information on research design is available in the Nature Research Reporting Summary linked to this article.

DATA AVAILABILITY

The data that support the findings of this study are available upon reasonable request from the authors.

CODE AVAILABILITY

The computer code and algorithm can be obtained from the authors upon reasonable request.

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AUTHOR CONTRIBUTIONS

D.G. contributed to the Conceptualization, Methodology, Investigation, and Writing. B.L. contributed to Conceptualization, Methodology, Investigation, and Writing. E.J. contributed to the Conceptualization, Investigation and Writing.

COMPETING INTERESTS

The authors declare no competing interests.

INCLUSION & ETHICS

All collaborators of this study have fulfilled the criteria for authorship required by Nature Portfolio journals have been included as authors, as their participation was essential for the design and implementation of the study. Roles and responsibilities were agreed among collaborators ahead of the research. This research was not severely restricted or prohibited in the setting of the researchers, and does not result in stigmatization, incrimination, discrimination or personal risk to participants.

ADDITIONAL INFORMATION

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