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PAPER

Transitioning the grid for climate change: power transmission futures and grid justice

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Abstract

Amid the ongoing international boom in renewable power generation, debates over the future of the grid are gaining increasing attention in the United States and beyond. Climate change poses parallel but entangled questions for the large-scale movement of electricity. On the one hand, grid operation is a profoundly altered undertaking in renewables-dominated grids, bringing new management challenges around multi-directional flows, variability, bids for long-distance renewable power transmission, and more. On the other hand, electricity operators and users simultaneously face new climate-related disruptions, repair needs, and risks. In this paper, we explore an important set of energy and climate justice debates emerging around these combined decarbonization and grid resilience challenges, particularly concerns related to high-voltage transmission in the United States and other countries with developed but aging grids. We consider questions of transmission grid (1) access, (2) ownership, (3) siting, and (4) scale/rescaling. We illustrate these issues via the exemplary case of New York State, as the state has become a high-profile focus for debates around grid congestion, rising financial sector ownership of transmission projects, and siting justice issues, as well as for varying progressive alternatives in campaigns for both large-scale public power and decentralized 'non-wires' solutions.

1. Introduction

Amid the ongoing international boom in renewable power generation, broader debates over the future of the grid have become an increasing preoccupation of the 2020s. The large-scale movement of electricity is a profoundly altered undertaking in renewables-dominated grids and power systems, including as electrification itself becomes a major strategy for low-carbon energy transition. Grid management for renewables means dealing with increasingly multi-directional and multi-scalar flows on both high-voltage transmission lines and lower-voltage distribution grids, time-variable power production, and strategic longer-distance flows of renewable power to market. At the same time, grid management under rising climate change impacts requires planning for worsening grid disruptions and repair needs, financial risks to operators, and more-than-financial risks to frontline communities. These challenges are entangled and must be addressed together. Equally, *how* they are addressed matters: high-profile United States (US) and international efforts to build big renewable grids and attract new private capital to the sector raise vital energy and climate justice concerns.

In this intervention, we consider these important climate-related grid challenges in two ways, foregrounding significant justice questions. As we discuss, building on Sovacool *et al* (2024), holistic examinations of both power transmission and distribution are a pressing gap in critical research, even as a now-substantial scholarship scrutinizes other inequities accompanying certain versions of renewable energy and electricity transition. In this paper, we focus chiefly on distinctive concerns related to transmission's backbone infrastructure, particularly central to the long-distance movement of electricity. First, we further set the scene on the US's mounting power transmission problems under renewable transition, which are nationally distinct in certain ways but echoed today in the United Kingdom, European Union and other contexts which must adapt already developed, frequently aging grids to new climate needs. Next, we frame the concept of grid justice, building upon broader energy justice and environmental justice literatures. We break these issues down into four distinct, though necessarily entangled lines of justice-minded questioning, around (1) Who and what will access the grid?, which considers grid access for progressive renewable power schemes (and present failures in that access); (2) Who will own the grid?, which investigates grid ownership and accumulation strategies, particularly amid calls for 'competitive transmission' and growing financial sector interest; (3) How will the grid be sited?, which introduces distinctive justice concerns and movement strategies arising around the siting of power transmission infrastructure; and (4) How will energy systems be (re)scaled?, which offers deeper considerations around scale in renewables transition, as more decentralized power and 'non-wires' grid solutions join—and perhaps contend with—varying visions for large-scale renewables and big grids.

These analytical lenses into grid justice under climate change are not intended to be exclusive. For example, Sovacool *et al*'s (2024) combined transmission-distribution lens captures more granular inequities in grid blackouts and multi-species environmental risk exposures than discussed here, as well as important climate challenges related to sulfur hexafluoride use in grid management. Similarly, while our discussion of non-wires grid interventions speaks to some equity questions arising around decentralized power, broader literature on smart grids/cities (e.g. Luque-Ayala *et al* 2014, Wiig 2016, Rutherford and Marvin 2023) and even more extensive work on community energy in and beyond the US context unpack more wrinkles than we have space to discuss here. Moving further beyond the United States raises similar equity questions in other countries' transmission siting, among other parallels (e.g. Knudsen *et al* 2015, Bailey *et al* 2016). However, a more expansive geographic lens likewise exposes diverging grid norms and forms of inequity, particularly though not exclusively in the Global South. Across much of the majority world, key grid justice questions remain widespread lack of access; inadequate, unstable, informal, and risky connections; and potential off-grid futures (e.g. Luque-Ayala and Silver 2016, Caprotti *et al* 2022, Yaguma *et al* 2022, Masuku 2024). Deeper structural inequities shape each of these grid justice questions. Other critical scholars, policymakers, and movement practitioners will undoubtedly uncover additional questions within and across these differentiated experiences. However, we suggest that situated thinking along the four transmission dimensions discussed here reveals politically timely opportunities for imagining and practically strategizing around grid futures in more progressive ways.

Second, we further explore each of these four dimensions via the grounded example of New York State's high-profile political initiatives and justice debates around transmission. The state has become an important early case for grid challenges and contending visions in the United States. New York's electricity transmission infrastructure has an upstate-downstate skew, as much power generated throughout the state is channeled to meet the concentrated coastal demand of the New York City metropolitan area. A similar skew is seen, for example, in electrical islands like Hawaii, as well as effective electrical islands like Texas, which has its own independent grid. More broadly, strained relationships between rural supply and urban demand seen in New York may also be replicated in other states and regions as the grid develops, as more rural areas tend to have more available land and renewable resources whereas urban areas tend to have less available land and higher demand. Accordingly, the ways in which New York is attempting to overcome these barriers may also inform grid management practices in other regions of the country.

In New York's case, renewable transition in the state has significantly worsened preexisting grid issues, as new renewable generation is developed in rural areas hundreds of miles upstate (or even further afield) while downstate fossil power plants—including particularly dirty urban 'peaker' plants which have long been targets for environmental justice campaigning—are slated for decommissioning. Grid congestion has become a significant and worsening problem in the state, obstructing the transport of renewable power to demand centers. Though notably acute in New York, as noted above such bottlenecks are an issue of growing national concern for the United States and other countries. Proposed solutions in the form of major new transmission lines have raised their own concerns as new financial owners enter the sector, and projects face significant siting justice questions. New York State has also become a center for alternative visions, from different forms of line upgrading to large-scale public power and grid ownership to decentralized non-wires solutions—some of the last galvanized by climate-related grid disruptions caused by Hurricane Sandy in 2012.

This discussion is primarily intended as a conceptual intervention, with illustrative empirics. The points made here are grounded in authors' longer parallel programs of participatory and public-facing research into US transmission questions conducted in the 2020s. These include varying work on and with public and community power campaigns for the last 2–3 years, both in New York State and targeting the United States as a whole. Methods utilized include nineteen expert interviews; participant observation of state policy proceedings, transmission planning meetings, and state advocacy efforts; and extensive ongoing document analysis of policy, utility industry, financial, and activist literatures.

1.1. Conceptualizing the grid

Practically, while the term ‘the grid’ is sometimes used to refer only to power distribution and transmission infrastructure, it is also invoked to refer to the larger system of interconnecting generators and consumer load along with storage, distribution, and transmission that serve to hold and carry that load. While recognizing that justice dimensions are central for each of these components and that conversations around grid justice should broadly conceptualize all of these components, for the purposes of this paper, we will focus our empirics on transmission lines as one distinctive element of the grid that warrants more sustained attention. This element of the grid has been relatively understudied in the social sciences, as evidenced by a 2020 review of energy geography literature that found that only 3% of articles focused on the transmission phase, compared to the remainder of papers focusing on either the energy extraction and production phase or energy consumption (Baka and Vaishnava 2020).

Briefly mapping out the transmission element, electric transmission lines carry high voltage electricity produced by a power generation source, which is then distributed to households at a lower voltage. Electricity voltage is increased or decreased for transfer at electrical substations. Transmission lines can be built overhead, underground, or submarine (underwater). Overhead transmission consists of wires to transfer the electricity and transmission pylons, which are the structures used to support overhead lines. Underground and underwater lines consist of cables interconnected via onshore and/or offshore substations. For US offshore wind generation, designs increasingly include inter-regional proposals for high-voltage direct current and mesh systems to improve physical and cost efficiencies, system redundancy, and overall resilience, as well as mitigating conflicts over marine uses and coastal interconnection points.

Electric transmission is considered a key component in bringing new sources of clean energy and enabling a large-scale clean energy transition that can help to address air quality and climate change impacts and meet electrification goals. Given the push at the federal and state level to expand transmission infrastructure across the United States, there is a need to fully understand its potential benefits, costs, and challenges. Again, this must go beyond the important attention already being focused on classed and racialized issues and inequities in energy generation, such as where fossil fuel facilities are located and the distributive effects on air pollution and health, or pushback to new renewables like wind, solar, and hydropower, and energy distribution. Frequently, the latter are being driven by legacy issues such as unequal energy cost burdens, energy insecurity, and access to energy efficiency and other cost-saving programs. Transmission serves as a linchpin connecting old and new sources of generation to areas of demand for distribution. As demand for grid modernization and new transmission projects rises due to both decarbonization imperatives and rising climate impacts, more attention is needed on their potential justice implications.

2. Setting the scene: grid questions under climate change

Climate change mitigation and adaptation pose diverse dilemmas for the management of gridded energy infrastructures, challenges which increasingly overlap and entangle in practice. In the 2020s, high-voltage power transmission and climate change-related troubles on these grid backbones have become a growing focus of concern for the US federal government—and the United States is far from alone.

On the one hand, a major emerging challenge in the low-carbon energy transition is how to manage large-scale electric power grids in which renewable sources like wind and solar are dominant, rather than additions at the margins. One key quality of most renewable power forms is that they are more temporally variable than the fossil electricity sources (coal, oil, or natural gas) that they are intended to replace, as well as existing nuclear generation. Solar power is not generated at night but reaches peak production at midday, historically a low time for power demand from the grid. Wind farms can generate surpluses on windy days, and deficits when the wind does not blow. These forms of variability are distinct from the questions of fuel supply and shifting costs which characterize fossil sourcing debates, as well as questions of seasonal water availability facing hydroelectric infrastructures—a growing issue with shifting rainfall patterns and diminishing summer snowpack under climate change. All present new questions for the operation of power grids, in which power supply and power demand (load) must be continually kept in balance to avoid dangerous instability and blackouts. Withdrawal of fossil baseload will compound these challenges, as will the otherwise-welcome decommissioning of typically older, dirtier, and more costly peaker fossil plants, historically brought onto the grid to cover periods of maximum demand. Though discussed less here, some advocates have used these variability challenges to argue for the ongoing role of natural gas and nuclear power on the grid, or to elevate more temporally constant renewable power forms like geothermal energy (e.g. Cantor and Knuth 2019).

Another important quality of incoming renewable power, and related grid management challenges, is the spatially extensive and geographically dependent nature of key renewable resources, in wind, solar, and water flows. Region- and site-variable qualities such as insolation rates, wind speeds, and the presence of river elevation drops and dammable sites shape the productivity, and sometimes the possibility, of renewable generation. With greater freedom of choice over siting, fossil incumbents have typically located near urban load centers and existing high-voltage transmission grids. Renewables, conversely, may continue to concentrate in rural greenfield locations as well as in particular US regions, like the growing cluster of solar photovoltaic (PV) generation in the US Southwest and Southern California and the onshore wind production belt running through the US Great Plains. This concentration is particularly likely for larger utility-scale generation and the private developers, owners, and financiers who favor such projects; entities for whom maximizing the productivity, profitability, and investability of each project is a driving concern. Decentralized and community scale renewables may respond more to the needs and locations of users themselves. Taken as a whole, renewable generation facilities remain on average smaller but more numerous than competing fossil plants.

All of the factors above make renewable power transition a major question for existing electric grids and grid management—the more so as electrification becomes more central for the broader low-carbon energy transition, via strategies for decarbonizing domestic transportation (via electric vehicles and charging infrastructures) and buildings (for example, via building-level heat pumps and district energy systems to replace natural gas grids). One widely promoted solution to this variability is new grid-scale energy storage, as lithium battery farms and other innovative technologies join the long-dominant form, hydroelectric pumped-storage via dam infrastructures (Turley *et al* 2022). Another energy storage form growing rapidly in the United States is hybrid storage built into utility-scale generation projects (Rand *et al* 2023). However, changed grid management practices will almost certainly be necessary to accommodate these resources. These may come in various forms, such as smart grid digitalization projects, virtual power plants (VPPs) and other modernization. Some innovations like VPPs and microgrids offer important options for decentralized power production and grid management. Other proposals seek to use very big grids for real-time balancing—i.e. moving renewable power surpluses to cover deficits a thousand or more miles away.

Renewables-dominated grids will require increased grid capacity full stop, though more or less depending on the mix of concentrated power production and long-distance transport to urban load centers versus more decentralized options. Under the Biden Administration, the US Department of Energy (DOE) recently completed a Transmission Needs Study (DOE 2023) that identified crucial needs for expansion and upgrading of the US's high-voltage transmission lines, notably to accommodate new renewables although also in response to broader concerns over the country's aging grid. At the high end, these varying DOE estimates stretched to a potential doubling of capacity within US transmission regions. For the two-thirds of US states which have deregulated their electricity markets, these regions are governed by independent system operators (ISOs) or similar regional transmission operators (RTOs) (Harrison 2022). Recent research by the Lawrence Berkeley National Laboratory (Rand *et al* 2023) points to a long history of underinvestment by ISOs/RTOs and the investor-owned utilities (IOUs) whose transmission infrastructures they operate and coordinate. DOE (2023) estimates stretch to potential quadrupling of grid capacity needed in inter-regional backbone lines, even more historically neglected.

On the other hand, the multi-sided mitigation considerations above have been joined by growing grid resilience and adaptation questions. A major way in which climate change is affecting electricity infrastructures is more frequent grid disruptions and infrastructural repair and rebuilding needs related to acute events, of multiple types. A rising locus of US grid breakdowns are increasingly intense tropical storms and hurricanes along the Gulf Coast, East Coast, and in the Caribbean. Following Hurricane Maria in 2017, many Puerto Ricans residents lost power for months—provoking major adaptation debates which we return to below. The winter 2021 Texas Power Crisis, which included both deadly power cuts and extortionate spikes in some users' power costs, sparked another major controversy. Debates turned around both the resilience of decarbonized grids and the role of Texas' infamously isolated state grid in creating the conditions for system breakdown. These tensions were further stoked with the summer 2024 Texas Power Crisis that left people in Houston without power while under a heat advisory (Hennessy-Fiske *et al* 2024). Meanwhile, the now-chronic wildfire crisis in California and other Western states is generating major grid questions. The prominent case of the 2021 Camp Fire, sparked by the IOU Pacific Gas & Electric's undermaintained transmission lines, highlighted the link between grid infrastructures and wildfire risk (Schmidt 2024). A prominent wildfire risk management strategy has become controlled blackouts on high-fire risk days—a strategy that has controversially left many without power and air conditioning capability, sometimes in periods of high heat. Alongside grid underinvestment, ISOs/RTOs and IOUs have been critiqued for failing to plan for these growing climate-related challenges (e.g. Lieberman 2021).

The Biden Administration is pushing for significant reforms to these entangled challenges via high-profile programs like the DOE's Grid Deployment Office (GDO)'s Building a Better Grid Initiative and shake-ups at the Federal Energy Regulatory Commission (FERC), which governs interstate power transmission and sets rules for ISOs and RTOs. Such efforts are particularly pressing as expanded subsidies for renewable power generation under the 2022 Inflation Reduction Act (IRA) have prompted a raft of new projects and applications for grid interconnection (Penrod 2023). Proposed transmission reform programs involve significant new federal funds and regulatory changes around transmission planning, development and permitting, and grid operation. However, the energy and climate justice dimensions of these emerging interventions remain far from clear, and demand more investigation—particularly as some mainstream visions present significant equity concerns. In the next section, we raise four important lines of questioning intended to advance scholarly and public-facing research into these pressing issues. These questions are again not intended to be comprehensive; however, we maintain that all are important for justice-minded researchers in the United States and beyond.

2.1. Grid justice: Energy justice on and through the grid

We conceptualize grid justice as informed by the broader field of energy justice. Scholars, practitioners, and advocates have asserted that energy should be clean, accessible, affordable, safe, and reliable (see, e.g. Ahmad *et al* 2023). Energy justice is both a theoretical concept and an applied objective that focuses these broader aims of clean, accessible, affordable, safe, and reliable energy on the low-income communities, Tribal and Indigenous communities, and communities of color that have been disproportionately harmed by existing energy infrastructures and services. Its roots lie in the earlier US environmental justice movement, whose advocates have long called out the structural racism embedded in the country's siting practices for energy, waste, chemical, and other polluting infrastructures (Mock 2015). Environmental justice scholarship often employs the foundational concept of the distributional, procedural, and recognitional pillars of justice to assess injustices (Schlosberg 2009). More recent energy justice scholarship has adapted this framework with an explicit and narrowed analytical focus on energy systems and energy resources across their lifecycle to interrogate processes of energy supply and their outcomes (Carley and Konisky 2020). These pillars consider the distribution of benefits and burdens; procedural fairness, transparency, and participation in decision-making; recognition of the structural factors that influence who benefits from and who is burdened by energy systems; and the repair of past and ongoing harms and restoration of relationships and community power (Schlosberg 2009, Energy Equity Project 2022).

Baker's (2021) important intervention warns that we need to be careful that energy injustices are not perpetuated in the name of avoiding climate change—a timely reminder for this paper's discussion. In this crucial sense, energy justice must also intersect with the concept of climate justice, which focuses on remediating the disproportionate impacts of climate change on low-income communities and communities of color, understanding and addressing the deeper underlying causes for these unequal harms, and focusing ongoing attention on the risk that certain proposed climate solutions may deepen rather than remediate such harms (e.g. Schlosberg and Collins 2014).

A critical component that underlies justice tenets is the concept of infrastructure ownership and wealth building (Baker 2021). Private ownership, which is the predominant form of energy infrastructure ownership in the United States (CISA n.d.), has been found to inhibit justice outcomes and impede transformation of the electricity system (Biber *et al* 2016, Harrison 2022, Kennedy and Stock 2022). Under this model, wealth accrues to large, wealthy corporations and individuals instead of to environmental justice communities and other groups harmed by these mainstream practices. Instead, energy justice movement organizing has advocated for transitions away from an extractive economy grounded in structures of colonialism and militarism to a regenerative economy grounded in principles of cooperation and deep democracy for the purpose of ecological and social well-being (CJA n.d.). This framing belies critiques that observe the limits of environmental justice as 'militant particularism', which contends that the deeply local fights of the movement are not generalizable or do not consider the broader political economy or ecology in which they are grounded (Harvey 1996, Swyngedouw and Heynen 2003). A study of the grid is particularly exemplary of the practice and study of environmental, climate, and energy justice, as it materially ties together disparately sited energy infrastructures that are also situated within and service shared political economies.

To examine grid (in)justice, we adapt and narrow the concept of energy justice to focus on the grid, and more narrowly for our empirics, on transmission infrastructure. Examples of grid-specific justice considerations include grid infrastructure siting, access, and ownership and participation and meaningful engagement in grid planning and siting processes. We also engage with the large and unresolved question of scale, which points to the possibility of multiple versions of a 'just grid'. Here we contend that there is no singular or universal just grid, as both new and legacy grids yield contingencies and uncertainties grounded in the specifics of how they are designed, who they impact, and who they serve (or exclude, whether in chronically unequal access or prioritization in the case of disruption or disaster). In the following section, we propose a four-part research agenda to examine grid justice, informed throughout by such intersecting and overlapping dimensions of energy justice as a foundation.

3. Grid justice in the US context: a four-part research agenda

3.1. Who and what will access the grid?

A first line of questioning turns around how access to the grid shapes—and potentially constrains—the possibility of renewables generation. This may occur full stop, if new renewables cannot access the grid in an affordable and timely manner. Alongside the exacerbated climate risks of a delayed fossil fuel phase out, issues in getting new renewables on the grid also threaten more direct environmental justice outcomes, since fossil facilities slated for decommissioning contribute to or exacerbate environmental injustice in the communities where they are located, which are disproportionately low-income communities and communities of color in the United States. Grid interconnection obstacles take on a further justice dimension if they block potentially more progressive forms of renewable energy, as public, community, and other not-for-profit forms of generation contend with the increasingly large independent power producers (IPPs) which now dominate private US renewables development and ownership (Harrison 2022, Knuth 2023).

One major outcome of the underinvestment discussed above has been rising concerns about grid capacity and congestion under renewables transition. These physical bottlenecks arise on existing power lines that have not been upgraded and/or technologically modernized to handle increased flows, particularly an issue where less infrastructurally connected rural and remote areas become central to power generation. Grid congestion risks overloading the grid, a source of instability and blackouts. This means that not all renewable power produced will actually make it to load centers, as it will be physically curtailed by operators or offloaded more locally at an economic loss. Curtailment and congestion represent economic losses that, if addressed, could change the cost-benefit ratio of renewables-dominated versus fossil fuel grids. Another outcome has been major issues and ballooning waiting times in interconnecting new generation to the grid. According to Rand *et al* (2023), interconnection queues mean that new US projects must now wait 5 years or more to be hooked up. Inequities in interconnection costs—in which the costs of grid upgrades that will benefit many users are devolved to the newest entrants—have escalated costs to over a hundred million dollars for some projects, a marked increase from just a few years ago (e.g. John 2021). Because almost all new generation facilities being added to US grids are now renewables, the sector bears the brunt of these issues. Grid interconnection problems are currently causing high rates of renewable project abandonment in the United States (Rand *et al* 2023).

These grid interconnection issues pose a serious problem even for larger utility-scale projects, developers, and investors with deeper pockets for weathering such delays and costs. They join other barriers imposed more directly by fossil fuel incumbents and their lobbyists, now taking various forms in the US power system and wholesale electricity markets. Spivey (2022) has explored how such incumbent resistance can work through barriers imposed on grid access for incoming renewable competitors, in his international case turning around conflicts over nuclear winddown in Japan after the Fukushima disaster. In other words, there is ongoing risk that incumbents and aligned regulators may block or structurally disadvantage renewables by making it impossible or unattractively costly for projects to join the grid. For example, under the Trump Administration, FERC controversially sought to impose price disadvantages on renewables entering the capacity auction run by the PJM Interconnection, the major RTO and transmission region operating in the Mid-Atlantic—a directive only defeated after years of resistance by activists and states protesting that these cost barriers would obstruct their regulatory commitments to increase renewable generation (Konidena 2021).

Speaking more directly to energy justice concerns, barriers arise with grid interconnection and access, particularly for nonprofit and household- and community-owned, smaller scale and distributed renewable energy systems. These typically smaller-scale visions for a transitioned energy system vary widely and are embedded in many contingent political questions in place; we do not have space to do them all justice here. However, a few material variations to keep in mind include a range of distributed energy options focused on the scale of individual buildings like homes for new designs and retrofits—interventions like rooftop PV, more recent solar plus storage interventions, building electrification and ground or air source heat pumps to replace natural gas heating, and so forth. Another generalized line are pathways that focus on broader community infrastructures. Microgrids and community-scale renewable projects do this with physical infrastructures; community choice aggregators and VPPs tend to repurpose existing grids and power marketing structures for new forms of economic and political organization.

Grid interconnection barriers are likely to pose even more pronounced challenges for smaller renewables players and progressive alternative visions—would-be developers and owners with less structural economic and political power to advance their interests against varying incumbents. For example, advocates for decentralized rooftop solar have fought various running battles with IOUs resistant to net-metering policies, in which households sell unused power back to the grid—with hostile lobbying from Florida Power & Light a high-profile recent case (Klas and Ariza 2021). In another example, a particular irony has emerged via the IRA's new federal subsidies for a variety of non-profit renewable power builders and owners, such as urban, local, and Tribal governments; non-profit organizations and community groups; and schools—generation supports not necessarily matched by help with interconnection. As Knuth (2023) explores, US national subsidies for renewables long excluded these not-for-profit actors, while enabling lucrative financialized extraction opportunities for major banks and creating systematic biases in favor of large IPPs. These exclusions also have climate adaptation implications for environmental justice communities, who historically have been disproportionately subject to blackouts and energy-related harms under grid strains like weather disasters (Jessel *et al* 2019, Sovacool *et al* 2024)—as seen, for example, during the winter Texas Power Crisis of 2021 (González 2021).

Decentralized renewables and their enabling grids are not inherently equitable—for example, research such as Sunter *et al* (2019) has demonstrated systemic unevenness in who owns rooftop photovoltaics (PV) in the United States, with racialized disparity over and above economic inequality. The rise of microgrids has likewise raised troubling questions of enclave protections, militarized security framings, and exclusions in grid disasters (e.g. Smeloff 2021, Rutherford and Marvin 2023). Though explored less here, another important equity question is the power of particular demand-side actors like large corporations and the military to shape where transmission is built, and to leverage public resources and incentives to enable their renewable power supply. Who should pay for new lines that chiefly or exclusively serve users like Google, Amazon, or the US military, or manage the grid demands of regional business incentivization initiatives—which otherwise, as in the recent case of Georgia, may justify a regression to legacy fossil fuels (Jones 2024)?

Despite these ongoing questions, more inclusive not-for-profit versions of both decentralized energy and larger-scale public power both undoubtedly have a new opening with the IRA—one which grid issues may threaten if unresolved. Alongside other partial reforms to federal renewable subsidies and a significant refunding of these incentive programs, the IRA's new direct pay (also known as elective pay) provisions in theory work to level the playing field for not-for-profit developers. However, where these projects require access to transmission grids (not all will), questions remain about their ability to weather the costs and delays discussed above, and what forms of fast-tracking and other aid may be preferentially available to them. More targeted aid and support for grid access may be necessary for progressing alternative visions of renewable futures, energy decommodification, and enhanced grid resilience for historically underserved environmental justice and frontline climate communities.

3.2. Who will own the grid?

A second important line of justice questioning responds to the grid underinvestment and capacity issues discussed above, and particular imagined solutions, in narratives that centralize the construction of new lines and major transmission projects (discussed more below) and that seek to bring more private capital and ownership forms into the sector.

Questions of grid capacity under renewables transition are not new in the US context, though they have become particularly urgent in the 2020s. Again, industry actors (e.g. Penrod 2023) argue that strains have deepened in part because of expanded subsidies available under the IRA, which have sparked a wave of new applications for grid interconnection. Today's debates were anticipated in a parallel moment of much-expanded federal support for renewables via the American Recovery and Reinvestment Act (ARRA), the Obama Administration's major economic stimulus package deployed amid the Global Financial Crisis of the late 2000s/early 2010s. An important feature of ARRA's subsidy was that, as with the IRA, much of it came as a direct pay option, via the Section 1603 grant program. Acting more like a straightforward grant (unlike today, then also available to for-profit developers), it sparked a wave of utility-scale onshore wind and solar projects (Knuth 2023).

Amidst this renewables boom, the Department of Energy had already begun to raise concerns about the ability of the grid to accommodate new interconnecting projects. The Obama Administration accordingly initiated new spending on the grid, notably via ARRA funds for smart grid modernization—an important exception to the histories of transmission underinvestment discussed above. However, another proposed solution was the entry of new for-profit private players as grid developers and owners, beyond traditional IOUs. Advocates framed these proposals as a model of 'competitive transmission', drawing connections to broader drives to de-/re-regulate the US electricity system from the mid-1990s (though as Harrison and

Welton 2021 illustrate, not all US states and regions joined this market liberalization push). Deregulation allowed IPPs to enter the power generation sector and access grids. They competed with IOUs, who remained the actual primary builder and owner of grids even in deregulated states (while handing off most grid operation to ISOs and RTOs). In 2011, FERC Order 1000 likewise opened up transmission development and ownership to market processes and competing IPP-style merchant players, particularly bigger regional and inter-regional lines.

The histories of underinvestment discussed above cast an unflattering light on IOUs as adequate builders, owners, and maintainers of needed grid infrastructure for a renewables transition. However, the proposed expansion of other for-profit competitors has likewise raised justice concerns, particularly around the entry of speculative financial players as builders and owners of nationally important infrastructure. As we will see below, New York State has been an early test case for this financial sector interest and its issues. Elsewhere in the United States, competitive transmission has been slow to take off in the ten-plus years since Order 1000. Pfeifenberger *et al* (2019), advocates for competitive transmission, calculate that from 2013 to 2017, only 3% of transmission development occurred under these competitive market processes. However, merchant investment has picked up in the 2020s (Wilson 2022). Today, new Biden Administration programs are channeling increased federal support toward merchant transmission development projects nationally, including billions of dollars in derisking funding from its new Transmission Facilitation Program (TFP) (Grid Deployment Office 2023).

The TFP's first round of awards announced in October 2023 is indicative of the widening mix of developers involved in these projects, with awardees such as Grid United, a merchant developer; Berkshire U.S. Transmission, a subsidiary of Berkshire Hathaway Energy which is an energy holding company, and LS Power, an IPP/non-incumbent cost-based developer. Finalist National Grid, an IOU, ultimately withdrew its application. More work is needed to understand how differences between IOUs and merchant projects unfold on the ground. Their financing mechanisms differ, as IOUs receive guaranteed cost recovery through ratepayers, whereas merchant developers will generally take on higher risk and therefore promise higher returns for investors. Incumbent utilities may face less resistance to their typically local transmission builds, whereas merchant developers and partner IOUs collaborating on longer regional and inter-regional lines may encounter more challenges, but also take more efforts to engage communities because the success of their business model hinges on community acceptance. However, these differences are likely to be contextually dependent, and require more empirical examination.

These developments likewise demand strategic advance and ongoing questioning from a justice perspective. What might it mean to have private equity, asset managers, IPPs, and other private players dominate major grid projects? How responsible and democratic will they be as developers and as owners? How will they respond to new grid risks, planning, and management challenges under climate change? Might public builders and owners provide a more patient, forward-looking, and accountable custodian of this crucial infrastructure?

3.3. How will the grid be sited?

Accompanying these questions of who will build new lines and significant grid upgrades are how these projects will be constructed, with what distinctive justice considerations, forms of potential community benefit, and redress for experienced harms. Though large-scale renewable generation projects are now receiving significant scholarly and activist attention for their role in land dispossessions and the creation of new forms of sacrifice zone, once again transmission infrastructures have seen less of this justice-minded investigation to date—though see important exceptions such as Vogel and McCourt (2020/21) in the United States-Canadian context and Knudsen *et al* (2015) and Bailey *et al* (2016) internationally. With growing numbers of big grid projects in development in the United States and beyond, these questions urgently require further research.

A central concern for critical research on renewables transition has been the potential for large-scale land conversions to build spatially extensive renewable power facilities—as Huber and McCarthy (2017) have argued, a paradigm shift from the 'subterranean' regime that characterized fossil-dominated energy systems. Large utility-scale and greenfield renewable power projects are not the only way to build renewable generation, as the next section emphasizes. However, today's ongoing renewables investment boom internationally (BloombergNEF 2023) has demonstrated a marked preference for these types of large projects and developers (Baker 2022). These investment trends have been reinforced in the US context by the rise of large IPP players under deregulation and the regulatory favoritism for them discussed above (Harrison 2022, Knuth 2023). The rush of capital into utility-scale generation and now energy storage projects has provoked a wave of attention in the US context (e.g. Mulvaney 2019, Kennedy and Stock 2022, Knuth *et al* 2022, Turley *et al* 2022). This US research joins a growing international scholarship on renewable land politics, dispossessions, and other potential socioecological harms of big projects—particularly when they are built with profit-maximizing conditions at the forefront and under regulatory regimes willing to cut corners to bring renewables in quickly. As renewable power developers and investors have gained more structural power, this justice-minded scholarship has shifted from a narrower early focus on NIMBYism (aka 'not in my back yard' anti-development advocacy, which has drawn on various constituencies, conservative and right-wing populist as well as progressive) to broadened considerations of rural sacrifice zones, Tribal land rights, and other forms of land (in)justice.

Questions of the grid cannot be disentangled from these broader considerations of utility-scale renewable power generation and its geographies. Big grids and long-distance flows of electricity through them are key enabling infrastructures/elements of large-scale, regionally concentrated renewable power production. However, transmission infrastructures likewise demand more justice consideration in their own right (and see Sovacool *et al* 2024). For example, a distinctive feature of high-voltage lines and infrastructures is that they pass through spaces, sometimes for thousands of miles, without off-taking power from or delivering power to communities affected. Specific promises of local jobs or free or cheap power potentially associated with generation projects—eligible targets for energy justice campaigns—are less available to communities affected by grid projects. Meanwhile, these proximal communities may be affected by a range of potential socioecological harms, from aesthetic impacts to land takings for corridor projects, as well as environmental justice considerations in where lines are and are not sited (and see Sovacool *et al* 2024). These considerations are heightened under climate change impacts like worsened large-scale wildfires, where proximity to high-voltage transmission grids may mean exacerbated local and regional risk exposures (Schmidt 2024).

More research is needed on these distinctive justice questions, as well as forms of redress to inform future activist demands. For example, what capacity is there to co-locate other forms of needed gridded infrastructures alongside transmission lines and corridors, such as improved broadband internet access? Conversely, can new lines be sited along preexisting grid corridors rather than new greenfield sites? To what extent can improved processes of planning and democratized development consultation mitigate some harms and forms of resistance (Bozuwa *et al* 2023)? These questions of how to facilitate grid construction where needed, but also to avoid unnecessary harms and extractions in grid development, must join broader national debates around speeding the renewables transition. For example, as Bozuwa and Mulvaney (2023) have argued, many delays supposedly addressed by controversial US national processes of permitting reform and weakened environmental review rules are equally rooted in these broader siting injustices. Will weakened regulatory protections in the name of building renewables faster actually address some of the root causes of delay? Will it actually make these harms and delays worse?

3.4. How will energy systems be (re)scaled?

An overarching consideration in this discussion is what kinds of climate change mitigation and adaptation needs require a big grid—and which might not. Is continuing to forward the case for decentralized and non-wires solutions in and of itself a central task for energy and climate justice-minded researchers? Where and where not?

A major argument for justice-minded researchers to continue to think creatively about the scale of renewable transition are the ways in which the rush to large-scale generation by for-profit players may obscure more decentralized and community alternatives, as both a level of system organization and alternate vision for plural system ownership. Grid infrastructures have a crucial role to play in these broader conversations. Assumptions that the chief future of renewable power transition lies in large utility-scale power projects—and accompanying prioritization of productivity, profitability, and broader attractiveness to private capital—demand the big grid. More diverse scalings and spatial imaginations (including, for example, choices of alternate generation geographies and balancing options like offshore wind projects more closely adjacent to coastal load centers) may require less extensive grid upgrades, modernizations, and new lines, again particularly where power generation infrastructures are located closer to existing grid infrastructures and urban load centers. However, it is likewise important to note that these multiple solutions will not eliminate all need for new development. Notably, such expanded (re)imaginations might mean more brownfield and community-scale projects, as well as rooftop generation and storage infrastructures. Non-grid solutions to power movement challenges may also mean more VPPs, microgrids, and smaller scale/alternative grid management options.

The justice politics of decentralized and community power are complex today. On the one hand, in the United States as internationally, movements for community energy are advancing visions for energy justice and democracy that valorize local ownership models as central to advancing long-held values of energy prosumption as well as potential energy decommodification under renewables transition. On the other hand, new support for larger-scale power systems is a feature of recent public power advocacy, particularly under the framework of a Green New Deal. These alternative models for non-profit power regimes point to the potential exclusions of power transitions relying heavily on individualized and community-scale deployment and/or ownership, particularly in societies as economically and racially unequal as the United States (Aronoff *et al* 2019, and see again, Sunter *et al* 2019)[3]. More recent Green New Deal entrants have advanced multi-scalar visions for public power, which articulate more progressive visions for community renewables with public power developed at scale (e.g. Bozuwa *et al* 2021, 2023).

In these unfolding justice discussions, the need to secure the grid itself against rising climate change impacts and other security threats—and frontline power users, not always the same question—are rising concerns (Rutherford and Marvin 2023). A major outcome of grid disasters like Puerto Rico's experience following Hurricane Maria, the 2021 Texas Power Crisis, and growing disruptions related to storms, wildfires, and other acute climate-related events has been the question of how big grids do and do not work to protect uninterrupted power supply and prevent unneeded costs and extractions in and after events. A major line of argument following the winter Texas crisis of 2021 was that better interconnecting the state's grid could have worked to mitigate power deficits and disastrous cost spikes to households (González 2021). Conversely, mainstream drives to rebuild larger grids (and reinscribed fossil power reliance) as opposed to more decentralized renewables have been crucial to accusations of disaster capitalism and counter-organizing in Puerto Rico (Klein 2018, Ponder 2023). In Puerto Rico and in wildfire-prone areas across the United States, more frequent blackouts—following disruptions or instituted as precautions—have provoked increased advocacy for decentralized, non-wires solutions from rooftop solar to 'islandable' microgrids (e.g. Smeloff 2021, Rutherford and Marvin 2023). These are again crucial climate justice considerations for frontline environmental justice communities—at once at heightened relative risk if more affluent communities are able to secure protected enclaves via these technologies, and particularly able to benefit from more progressive versions.

4. Thinking through the New York State Case

We suggest that high-profile transmission debates underway in New York State provide a valuable window into how these grid-related justice concerns are playing out on the ground. The dimensions laid out above emerge in entangled ways across the state's transmission challenges and diverse grid justice discussions.

New York State's longstanding geographic divides mean that its grid has contended with transmission congestion challenges for decades. However, calls to alleviate these constraints have gained growing force amid a recent ramp-up in the state's climate change mitigation and energy transition commitments. The most prominent policy here is the state's 2019 Climate Leadership and Community Protection Act (CLCPA), which established an interim target to increase renewables from 28% to 70% by 2030, with a goal of reaching a 100% zero-emission grid by 2040. This monumental shift in energy resources is challenged by the state's worsening transmission bottlenecks, which prevent electricity generated from renewable sources upstate to high demand load centers downstate and have resulted in curtailments of upstate renewable energy (Singer 2023). Issues here relate both to limitations in grid capacity and to the aging condition of the existing grid. The upstate grid was not originally designed for transferring electricity long distances, leading to challenges with adding generation capacity to the existing grid and prompting drives to construct new transmission lines. Moreover, 84% of the state's high-voltage lines were put in service before 1980 (New York Independent System Operator (NYISO) 2019) and require major upgrades.

Adding to these challenges, spatial constraints to building renewables, endemic to urban areas and particularly urban islands like New York City, have contributed to fossil fuels comprising around 95% of New York's downstate energy production mix (NYISO 2023). Despite concerted state efforts to meet CLCPA targets, the proportion of fossil fuels in the downstate energy mix today is paradoxically the highest in years due to the decommissioning of the Indian Point nuclear plant north of Manhattan and its replacement with several natural gas plants. Meanwhile, as with the United States as a whole, a compounding pressure in New York State and the regional ISO that operates its transmission grid, the New York Independent System Operator (NYISO), is a growing interconnection queue. Interconnection delays are creating worsening grid access concerns in the state (Rand *et al* 2023, Advanced Energy United *et al* 2024). As in other states throughout the country, New York's congested legacy grid presents barriers to the interconnection of both community and larger scale renewables.

New York State's responses to these grid barriers—a combination of transmission upgrades, construction of new transmission, and proposed legislation to accelerate environmental review and permitting—have brought their own set of challenges. As the state promotes the development of new power transmission to fulfill its climate agenda, it raises the question of who will plan, build, and own this grid infrastructure. Enabled by New York's power sector deregulation in the late 1990s and FERC's permissions for competitive

[3] And, of course, decentralized technologies like rooftop solar have also become targets for financialized extraction in the United States, for example a financialized rush to exploit federal residential tax credits under ARRA via schemes like solar leasing (Knuth 2019).

transmission there as in other deregulated US states, grid planning and development has become a privatized process in key ways. Notably, although New York State has allocated billions of dollars in funding to local transmission upgrades (Singer 2023), a central plank of its transmission provisioning has been a competitive solicitation process led by the New York State Research and Development Authority (NYSERDA). The solicitation generated contracts for two high-profile merchant transmission projects, both of which have generated controversies over grid access, ownership, and siting justice. The first, the multinational Champlain Hudson Power Express (CHPE), is a 375 mile, 1250 MW high voltage direct current (HVDC) transmission line which connects New York State (effectively, New York City, through a dedicated substation) directly to a hydroelectric power station in Québec (and see Vogel and McCourt 2020/21). Notably, this $6 billion inter-regional line excludes any other generators from interconnecting. The second, the regional Clean Path NY transmission line, is a 174 mile, 1300 MW line designed to interconnect wind and solar generation sources across the state; it will cost $11 billion in total.

The landscape of financial actors in New York State power transmission has grown increasingly complex, anticipating rising financial interest in the sector nationwide. Both of the newly contracted merchant transmission projects outlined above involve private equity and asset management firms, IPPs, IOUs, and state-owned power companies in varying arrangements. CHPE links a state-owned hydropower corporation in Québec (Hydro-Québec), its United States-based subsidiary (H.Q. Energy Services U.S., or HQUS), and Transmission Developers Inc. (TDI), a United States-based company acquired by the private equity firm Blackstone in 2010. Here it is crucial to note that Blackstone has simultaneously become one of the largest holders of residential properties in the United States and globally, particularly following the Global Financial Crisis of the late 2000s-early 2010s (Christophers 2022). Hydro-Québec owns the large-scale hydroelectric facility that will generate electricity for the line, and its TransÉnergie and Équipement group manage engineering, procurement, and construction of the Québec portion of the line; they will also oversee operation and maintenance following construction. Meanwhile, TDI oversees the construction and operation of the New York portion of the line. HQUS, which sells power in the US market, is responsible for the sale of generated renewable energy credits (RECs) to NYSERDA.

Clean Path NY, the other transmission line contracted under the same competitive solicitation, links IPPs, the New York Power Authority (NYPA, New York's state-owned power company), a private real estate firm, and a multinational private developer. IPPs benefiting from grid access via this project include Invenergy, Northland, Boralex, RWE, Apex, and Terra-Gen. Meanwhile, Invenergy Renewables and energyRe, combined in a venture called Forward Power, will own Clean Path New York Infrastructure LLC, which will develop and own the southern portion of the transmission line. NYPA will develop the northern portion. Invenergy is a multinational private developer of energy infrastructure that has received $4 billion in private equity investment from Blackstone since 2022 (Invenergy 2023); the Canadian pension fund firm CDPQ also has an ownership stake. Project investor and developer energyRe is an affiliate of The Related Companies, the real estate firm which developed the highly controversial Hudson Yards development (Galbraith 2021). Principals of Related went on to become founding investors for energyRe, and Related and energyRe's owner, Stephen Ross, is the chair emeritus of the Real Estate Board of NY (REBNY), an influential landlord lobbying group in the state (Corser and Kink 2023).

NYPA's partnership with the groups above may signal a continuation and perhaps growth of the state's reliance on public-private partnerships, despite new public ownership options presented by direct pay provisions under the IRA and new developments in the state itself. Following a major public power campaign, in 2023 New York passed the Build Public Renewables Act (BPRA), which directs NYPA to build, own, and operate renewable energy projects to meet CLCPA targets. The BPRA expands on NYPA's existing authority to build new transmission in the state (and see Bozuwa *et al* 2021). NYPA owns and operates core legacy renewable power in the form of the state's hydropower and hydroelectric pumped-storage facilities, including but not limited to its major dam infrastructure at Niagara Falls. However, the utility has had limited appetite for building and owning further renewables generation, and before the BPRA preferred to contract in new renewable generation capacity and some transmission capacity via public-private partnerships and power purchase agreements. Notwithstanding new openings for public power at the state and federal level, a BPRA concession allows NYPA to continue to engage in public-private partnerships if it wishes (Spivack 2023)—a source of ongoing uncertainty in the state's power ownership debates.

In practice, the CHPE and Clean Path NY projects together are expected to meet over a third of New York City's annual electric consumption (NYSERDA 2022) and are illustrative of the vast amounts of capital required for major transmission projects as well as the complex, multinational network of public and private stakeholders that may be involved in developing them. Moreover, these projects' engagement with complex financing schemes further illustrates the marked financialization of the renewables industry in the United States and internationally (Baker 2022, Harrison 2022, Knuth 2023, Christophers 2024)—and how such practices are being extended to transmission. CHPE and Clean Path were both selected through NYSERDA's

Tier 4 competitive solicitation process, which was created through the NY Public Service Commission (PSC)'s modification of New York's Clean Energy Standard in 2020. Tier 4 was designed for the explicit purpose of bringing additional electricity from renewable sources to New York City. Both projects are financially supported with RECs, which have been controversial because they allow building owners in the city to evade direct energy efficiency retrofits mandated through Local Law 97. This law created a new market for RECs, via an emissions offset scheme which allows building owners to purchase renewable energy credits generated by Tier 4 projects (1 credit = 1 MWh of electricity) instead of making direct retrofits to their buildings (Kinniburgh 2022). Environmental groups criticized the influence of New York's real estate lobby for loose limits on the amount of RECs allowed for developers, calling out resulting weakening of intended building-level energy efficiency/emissions reduction measures (Evelly 2023, FWW 2023). Such controversies highlight the political nature of emerging debates on interdependent, contradictory financing and climate policies and the potential for them to undermine one another.

As part of its efforts to accelerate transmission construction, New York State has also sought to expedite siting processes, another move that has generated significant justice questions. The state's 2025 budget proposal introduced and passed the Renewable Action through Project Interconnection and Deployment (RAPID) Act, intended to consolidate and expedite environmental review and permitting procedures for major electric transmission facilities and transfer permitting review from the state's public utility commission to the Office of Renewable Energy Siting (JD Supra 2024). Environmental justice advocates have voiced concerns about the proposed expedition of environmental review and permitting at the federal level (e.g. Bozuwa and Mulvaney 2023), arguments that may become increasingly salient in the state. The major line projects discussed have disrupted Indigenous communities, communities of color, and rural communities, generating a range of controversies.

First, CHPE has encountered contention over the location of its hydroelectric facilities in First Nation territories. Concessions have been made for the portion of the transmission line that transects Kahnawà:ke territory, in which the community entered into an agreement with Hydro-Québec to own a minority equity stake in the line. However, the decision to enter into the agreement was made by the newly appointed Grand Chief of the Band Council, the governance structure of which has faced criticism and may preclude more populist forms of governance (Campney 2019). Further south, upstate New Yorkers have expressed discontent with TDI's lack of full disclosure to residents about where underground transmission lines would pass through (Karlin 2023, Szacik 2023). While TDI did relocate some parts of the line or gain landowner consent, it resorted to the use of forcible takings in the form of state-enabled eminent domain for other remaining easements (Karlin 2024).

More broadly, the siting of the CHPE line upstate and statewide cost allocations made for the perceived benefit of downstate residents have ignited regional tensions (Kaufman 2022), speaking to broader trends of land takings and power imbalances emerging in renewable energy transition/s internationally (e.g. Knuth *et al* 2022). In New York, these new forms of sacrifice zone have been accompanied by older urban-industrial patterns (and see Sovacool *et al* 2024 for further discussion of some of the environmental risks involved with grid infrastructures). Notably, Clean Path NY originally planned to site a key substation, used to convert high-voltage electricity to lower voltage power for distribution, in an environmental justice community in the South Bronx—one already host to significant polluting infrastructures and frequently called 'asthma alley' for its high rates of asthma prevalence (Donovan 2021). While project developers ultimately relocated the substation to a non-residential area amid protest, areas with less organizing power may struggle to push back as effectively against these types of siting decisions. These examples illustrate entangled rural and urban terrains of protest that may emerge in many other places as high-voltage grids are expanded.

Finally, questions abound about the broader future of the grid in New York State, marked by uncertainties around desired scales of the system, nature of energy sources and demand, and technologies and policies which may be employed for grid planning, development, and management. Ongoing legislative, regulatory, and planning processes in the state contribute to these uncertainties and possibilities for what the grid could look like. Facing the challenges discussed above, the state has considered non-wires solutions such as decentralized renewable generation, energy storage, VPPs, and demand management. In a legislative example, elected officials introduced a bill which would require state utilities to evaluate modernization technologies that enable the existing grid to operate more efficiently, opening up grid capacity to enable the interconnection of new renewables (Grid Enhancement Technologies Act 2024, RMI 2024). Similarly, a recently launched planning process will generate scenarios for new generation and bulk transmission based on where load is located in the state, and New York's battery and energy storage consortium has closely examined the role of energy storage as a complement to transmission (NY-BEST 2023).

These efforts to technologically modernize New York's grid, rethink how grid capacity issues are envisioned and managed, and bring on new balancing options like grid-scale energy storage innovations may all work to mitigate the need for new lines. Such initiatives have faced their own challenges, however, and may fall short of a true reimagination in how energy systems and the grid are understood and planned. For example, while prioritizing energy storage development over new lines may alleviate unfettered grid expansion, energy storage still faces questions and justice issues in large-scale uptake (e.g. Turley *et al* 2022), as well as immediate safety concerns following a series of battery storage fires in the state (Colthorpe 2023, Balaraman 2024). An overarching challenge is that New York State's energy system and grid decision-making processes rely on largely technocratic bodies which optimize for cost, possibly sidelining openings for community ownership of grid infrastructures and other alternative solutions. Though state processes present some formal channels for participation, these opportunities remain a challenge for meaningful participation in practice as they rely on a baseline level of technical knowledge that may be prohibitive for many.

In pushes for more progressive and expansively imagined energy futures, thinking on the grid is mediated by differing perspectives on scale and scalar politics for these futures, in New York State as in broader debates. Some voices in the state call for strictly small-scale, local approaches as the chief route to energy justice, centering decentralized power and non-wires solutions to the grid congestion problems discussed above. In theory, generating more power locally will eliminate unneeded lines and move beyond profit and financial motives in rolling out new renewables. As discussed in the previous section, other advocates support decentralized, large-scale generators connected with bulk transmission, valued for its economies of scale and ability to provide low-cost renewable power to the broader public. This view is characteristic of the Green New Deal-style public power campaigning that led to the passage of the BPRA (and see Bozuwa *et al* 2021). At the same time, critics argue that these hoped-for efficiencies may fail to materialize if large-scale public projects still introduce new injustices of the kinds discussed above. Such issues may arise in the direct sense of potentially long timelines and high costs incurred in obtaining approval for projects, or projects' cancellation if obstacles prove insurmountable. Larger concerns include potential undermining of interconnected climate and equity goals. These debates remain live and require ongoing engaged research and discussion.

These conflicting conceptualizations are important to debates about grid scale(s) and rescaling for climate change mitigation, and simultaneously significant for questions of future grid resilience under new climate-related threats. Such scalar questions are important to climate change adaptation efforts in New York State. After Hurricane Sandy struck the New York City metropolitan area in 2012, New York became a central case internationally for the use of islandable microgrids to promote grid resilience. The experience proved a 'game changer' for the technology, galvanizing an ongoing wave of experimentation with these decentralized grid solutions (Kuckro 2013). However, Hurricane Sandy also served an early exemplar of privileged access and enclave use of these technologies without more deliberate steering toward frontline environmental justice communities. As the regional grid went down in the superstorm, Manhattan skyscrapers retained or quickly regained power while millions across the region remained in protracted blackout. Broadening microgrid rollout to more vulnerable frontline communities continues to be a focus of environmental justice advocates in New York City (e.g. NYC-EJA 2017) as in other US cities and regions facing heightened climate risks.

5. Conclusion

In this intervention, we have considered a range of questions arising as today's electric power grids face new challenges associated with climate change, with a particular focus on transmission. As discussed, these include a range of potential issues related to climate change mitigation and low-carbon energy transition, particularly as a raft of new renewable power projects seek entry to high-voltage power grids—in the United States as in other contexts internationally, given particular impetus by more ambitious emissions reduction commitments and accelerated timelines. The necessary task of expanding renewables rapidly to meet these targets faces a range of difficulties in contexts like the United States, characterized by developed but aging grid infrastructures and an array of sector incumbents. Incumbent generators and utilities may delay transitioning the grid—and the broader electric power system it mediates and shapes access to—through both active resistance and ongoing underinvestment in needed infrastructures. In the 2020s, grid access and capacity questions have become central concerns for powerful renewable sector players with privileged access to resources and political influence for forwarding their interests. They are all the more significant for alternative not-for-profit players of various kinds, who must work harder and more strategically to win access to renewables-led grids and futures.

The framework of grid justice that we introduce here opens up multiple points for progressive justice intervention. For example, some dimensions of the framework might become points of strategic attention for justice movement organizers on the ground, in tactics for resisting or calling for reforms to mainstream projects on a project-by-project basis and/or at the federal level, as reform efforts continue to unfold at FERC, the DOE, and beyond. Similar opportunities may arise as progressive organizers seek to shape public power advocacy and new and reformed authorities proposed within such visions. Interventions around climate impacts and grid disasters will present yet another line of intervention for organizers, both as an element of the grid processes already discussed and in distinctive spaces such as federal disaster preparedness and response initiatives—themselves being targeted by justice organizers due to both legacy inequalities (e.g. the structural injustice of Hurricane Katrina and other climate-related disasters since) and mounting classed and racialized harms from climate change. In all this, organizers must account for and leverage the forms of contingency introduced above—just as grid problems and inequities will vary by place and context, so will salient moments and institutional openings for progressive visions to win a foothold and consolidate advances.

Much of this intervention has also focused on the justice costs of expanding renewable power with insufficient attention to who develops and owns it, how it is built, and whether it needs to be built in certain ways and places at all—a broader sectoral question which assumes distinctive forms when power lines and infrastructures rather than generation facilities are centered. An overarching justice problem in the renewables transition is the compulsion to build fast at all costs. This speed may backfire for both the justice outcomes of projects and their ultimate effectiveness, risks that may be heightened if certain kinds of for-profit and financial players become central owners of key national infrastructures. New York State's early example suggests some of the issues that may arise when financial players and competitive transmission development lead. Major transmission projects must cross hundreds of miles of service territory, presenting uncertain benefits to host communities and ample opportunity for resistance along the line—far more than a typical utility-scale generation project, even the largest. How transmission projects are planned and negotiated with communities has an important bearing on their political reception, and accordingly their likelihood of success without significant delays and costs—potentially of even greater concern to private developers than the in-theory more patient public alternatives considered above, as such delays risk anticipated profits and investability.

Questions of whether public transmission developers might be better planners, builders, and managers of grids than IOUs, new merchant competitors, or todays' ISOs and RTOs must be speculative to some extent—historical experiences in the United States include both private and public land takings and undemocratic processes. Larger-scale public power visions today provide visions of how grids might be developed more justly, increasingly informed by discussions of where large-scale generation projects and grids are and are not the best way of advancing combined climate and climate justice needs.

In all these discussions, the necessity to both decarbonize the grid and manage it under increasing climate risks and uncertainties must be kept in view. Heightened challenges include planning and managing grids amid new disruptions, improving and expanding repair of existing grids, and rebuilding these infrastructures after more frequent disasters. These dilemmas risk openings for new forms of disaster capitalism, as in the recent case of Puerto Rico. Conversely, as worsened risks become a new norm, they may prove a more profound obstacle to speculative for-profit grid ownership models, if the costs and risks of grid ownership become too high for private owners to bear or displace to broader publics (and see Schmidt 2024). Such grid resilience considerations must direct particular attention to environmental justice communities—those historically first and most likely to be disconnected from grids in a disaster, and last to be reconnected afterwards.

Together, these justice questions shape a need for alternative visions, of varying scales and kinds, which plan for climate mitigation and adaptation needs together, and which put these needs first in imagining future energy system infrastructures.

Data availability statement

All data that support the findings of this study are included within the article (and any supplementary information files).

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