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# Mitigation justice

Peter B. Reich[a,b,1], Kathryn Grace[c], Arun Agrawal[a,d], and Harini Nagendra[e]

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**Mitigating climate change and social injustice are critical, interwoven challenges. Climate change is driven by grossly unequal contributions to elevated greenhouse gas emissions among individuals, socioeconomic groups, and nations. Yet, its deleterious impacts disproportionately affect poor and less powerful nations, and the poor and the less powerful within each nation. This climate injustice prompts a call for mitigation strategies that buffer the poorest and the most vulnerable against climate change impacts. Unfortunately, all emissions mitigation strategies also reshape social, economic, political, and ecological processes in ways that may create climate change mitigation injustices—i.e., a unique set of injustices not caused by climate change, but by the strategies designed to stem it. Failing to stop climate change is not an answer—this will swamp all adverse impacts of even unjust mitigation in terms of the scope and scale of disastrous consequences. However, mitigation without justice will create uniquely negative consequences for the more vulnerable. The ensuing analysis systematically assesses how climate change mitigation strategies can generate or ameliorate injustices. We first examine how climate science and social justice interact within and among countries. We then ask what there is to learn from the available evidence on how emissions reductions, well-being, and equity have unfolded in a set of countries. Finally, we discuss the intersection between emissions reduction and mitigation justice through actions in important domains including energy, technology, transport, and food systems; nature-based solutions; and policy and governance.**

climate change | climate change mitigation | justice | climate justice | climate mitigation justice

Climate change and social injustice are critical challenges facing humankind. They are inextricably linked; those least responsible for climate change are most adversely affected by it and would benefit the most from mitigation. Yet, many actions to mitigate climate change will exacerbate climate injustices (1–10). A large literature documents these connections, often with a focus on individual countries, locations, and/or social groups; particular aspects of climate change and related injustices (e.g., sea level rise and flooding, droughts, and food insecurity); specific climate mitigation efforts (e.g., carbon sequestration, solar energy); or with a comprehensive, but sprawling coverage. These approaches expand knowledge in important ways. But by providing a synthesizing overview herein of mitigation justice (*SI Appendix*, Fig. S1), we hope to inform specialists and general readers alike.

This Perspective illuminates connections among disparate aspects of the climate change mitigation and justice nexus, allowing us to explore how climate change mitigation-related justice outcomes unfold in different settings and at different scales (3–8). We first examine how climate change and social justice interact (2, 11, 12), including how various dimensions of equity and justice intersect (*SI Appendix*, Table S1) with climate impacts and mitigation within and among countries (Figs. 1 and 2 and *SI Appendix*, Figs. S1 and S2). Second, we show how emissions reductions, well-being, and equity have unfolded in a set of countries (Figs. 3 and 4) and ask what may account for the trajectories of these changing relationships and decoupling. Third, we explore the intersection between emissions reduction and mitigation justice, especially relevant in the context of the potential uncoupling of emissions and well-being (Fig. 4). In particular, we assess the mitigation justice implications of actions related to demography; food, energy, and technology systems; nature-based solutions; and policy and governance (2, 6, 11–15).

## Current and Future Challenges for Climate Change Mitigation and Social Justice

Both climate change and climate mitigation strategies can exacerbate social injustice (5–7, 16, 44, 45). Greenhouse gas emissions drive climate change, and their historic (*SI Appendix*, Fig. S2) and current (Fig. 2) levels are related to wealth, consumption, and governance. If current global trends in energy use and land management continue along business-as-usual trajectories, climate will warm by 2 to 4 °C during this century, and impacts of warming will accelerate (16, 20, 31, 46–49). Poorer countries that contribute negligibly to climate change will be most adversely and disproportionately affected (12–14, 16, 47, 50, 51) (Fig. 2). For example, impacts of future climate

Author affiliations: [a]Institute for Global Change Biology and School for Environment and Sustainability, University of Michigan, Ann Arbor, MI 48109; [b]Department of Forest Resources, University of Minnesota, St. Paul, MN 55108; [c]Department of Geography, Environment and Society, University of Minnesota, Minneapolis, MN 55455; [d]Keough School of Global Affairs, Just Transformations to Sustainability Initiative, University of Notre Dame, Notre Dame, IN 46556; and [e]School of Climate Change and Sustainability, Azim Premji University, Bengaluru 562125, India

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[1]To whom correspondence may be addressed. Email: preich@umich.edu.

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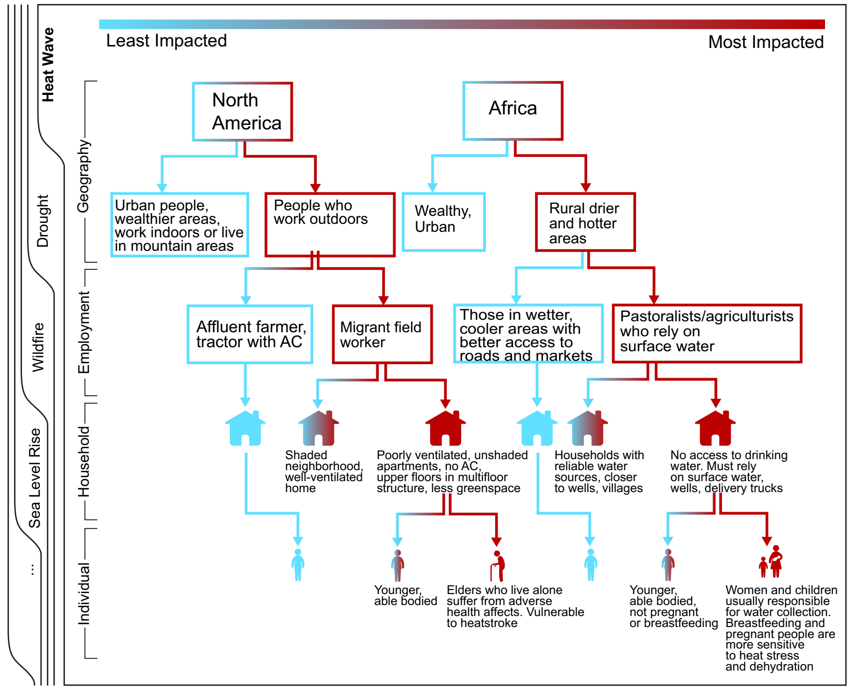


**Fig. 1.** Hierarchical framework. Examples of hierarchies showing additional injustices at neighborhood and individual scales, within populations that experience contrasting levels of climate injustices. Herein we show as an example hierarchical injustices for heat waves; visualizations of this kind could be made for every other element of climate change (e.g., other tabs).

change on per capita GDP will likely be higher in countries with higher internal income inequality, lower life expectancy, and lower overall well-being (Fig. 2), in part because many such countries will also find it harder to adapt to or recover from climate change impacts (6). By 2050, India, Indonesia, Malaysia, the Philippines, and Thailand, with per capita GDPs 5 to 25% of those in rich countries and home to one in five people on earth, may experience reductions of as much as 35 to 46% in their GDP under 3.2 °C warming. Considerable but much lower GDP reductions of 5 to 10% are projected for richer countries such as Canada, Finland, Poland, and the United States (16). Per capita GDP is an imperfect metric (5), but its variation across countries is strongly associated with well-being indicators of poverty, health, and education (8), including those shown in Fig. 2, making it useful as a proxy for multidimensional well-being.

## Conceptual Frameworks and Dimensions of Climate Change Mitigation and Social Justice

Many diverse but related definitions of climate justice exist (3–8, 10). We largely follow the IPCC which emphasizes three principles: distributive justice (referring to the allocation of burdens and benefits among individuals, countries, and generations); inclusion (i.e., where all are included and have equal access to justice) and its narrower sister concept, procedural justice (regarding who participates in, and ultimately controls, decision-making); and recognition (concerning respect for, engagement with and fair consideration of diverse cultures and perspectives) (14). The ensuing arguments touch upon all these dimensions of justice, but we focus primarily on distributive justice in this analysis.

Climate change mitigation interventions and related justice outcomes span multiple dimensions and social hierarchies (2, 3, 11–13). For example, climate negotiations and policies invoke diverse justice concerns (52), consider multiple rationales to allocate responsibility for historical emissions (2), and deploy distinct principles of future carbon budgets (53) to evaluate compensation claims (54) and adaptation financing commitments (55). These complexities also exist in interventions that address intertemporal and intergenerational inequities (4–6, 56).

Fig. 2 depicts variations across countries. Additionally, economic inequalities related to climate impacts influence justice outcomes within countries (as illustrated in Fig. 1). For example, poorer and less powerful individuals experience greater air pollution within cities and in their homes (57, 58); exposure to heatwaves while at work (e.g., outdoor labor) and at home (lower likelihood of air conditioning and tree cover) (49, 59); likelihood of inundation from sea level rise, flooding, or both (60); likelihood of catastrophic wildfire impacts (61); and vulnerability to adverse effects of droughts or nondrought drivers (e.g., social unrest) leading to food system disruptions (62). Gender inequalities regarding resources and power leave women facing additional higher risks within households and communities (56, 63). Children and pregnant women face unique health vulnerabilities because of increased risks of malnutrition, food insecurity, adverse birth outcomes, vector-borne disease risk, and constrained educational opportunities (49, 57, 64), all of which are compounded by in-country and between-country climate-induced distress migration. In other words, those who are less powerful within any country, socioeconomic, or cultural system (e.g., women and children; caste, ethnic, and religious minorities; indigenous communities; people with disabilities; and the elderly) are more likely to experience greater adverse impacts of climate change (49, 57–61), while having contributed less to causing it (2, 12, 13, 49, 56–58, 65).

In total, adverse climate change impacts will be worse for the most vulnerable in low-income nations (3–6, 12). First,

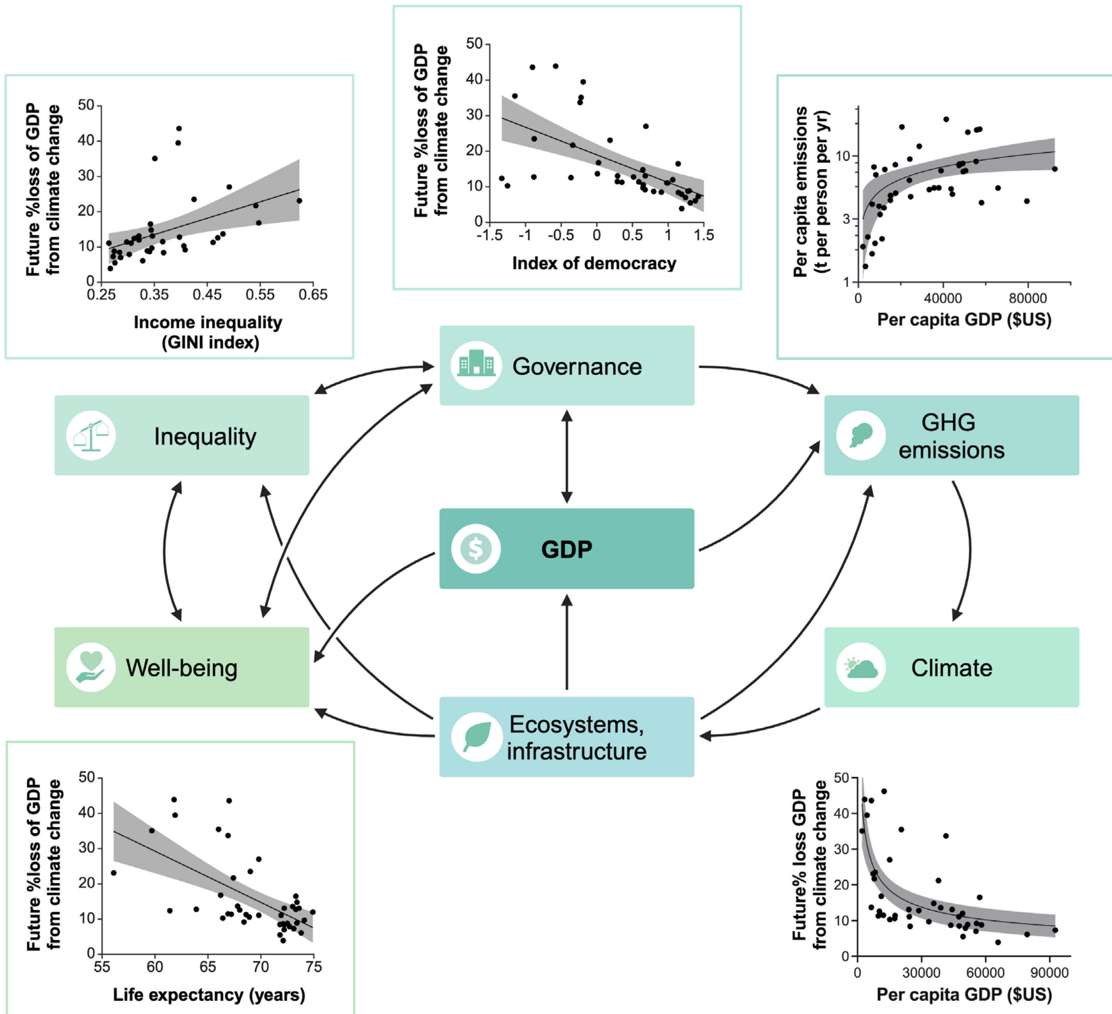


**Fig. 2.** Relationships among economics, emissions, governance, climate impacts, and inequality. Estimates of percent loss in GDP due to climate change for 42 nations (16) in relation to per capita emissions [tons $CO_2$ per person per year, in 2019, (17)], per capita GDP [GDPpc, 2017, (18)], healthy life expectancy at birth (19), the GINI index (2000 to 2016 average) of within-country income inequality (18), and an index of governmental democratic quality (19). Percent loss in GDP estimated for a RCP 8.5 Scenario with anticipated increase of 3.2 °C warming by midcentury, which best matches current trajectory of greenhouse gas emissions and atmospheric concentrations (16), using estimates of severe outcomes from a set of quantified and proxied risks. Statistics for the five embedded relationships are in *SI Appendix*, Table S3.

impacts are likely to be higher in countries with higher internal income inequality, higher levels of corruption, challenges to democratic governance, low state capacity, and high state fragility (6). These country characteristics occur together with lower per capita incomes (see arrows and connections, Fig. 2), constraining climate policies that may buffer marginal populations via investments in resilient infrastructure, or safety nets and social assistance programs (47, 66, 67). Second, climate and geography in poorer tropical countries make people particularly vulnerable to climate change impacts such as sea level rise, heatwaves, droughts, biodiversity loss, and disease spread because of the ways they interact with the local setting (9, 51) (*SI Appendix*, Fig. S1) (68). As an example, smallholder farmers in sub-Saharan Africa will experience many negative climate impacts, in part because of widespread reliance on rainfed farming for food and income. Limited market access, lack of storage infrastructure, and weak crop insurance programs will compound the negative effects of climate change on household-level availability of food and resources, while predisposing factors such as stunting due to childhood nutritional stress may further decrease household capacity to deal with stressors (62).

The above evidence highlights how unchecked climate change will disproportionately affect vulnerable peoples everywhere in an accelerating fashion (Figs. 1 and 2) (5–7, 11–13, 46, 48, 57). Additionally, alleviating injustice, especially in terms of economic development, without considering climate change mitigation, can also eventually feedback to reduce climate justice through accelerating climate change impacts. For example, although increases in incomes that shift the very poorest out of extreme poverty have a low carbon cost, business-as-usual consumption that would accompany shifts to even slightly higher income levels (≈$US 3 to 8 PPP per day) could cause as much as an additional 0.6 °C warming by 2100 (66).

Overall, climate change impacts under a business-as-usual emissions scenario will likely consign an additional 80 to 120 million people to extreme poverty (68). They will cause increasingly large health, economic, environmental, and infrastructural damages, amplifying climate-related injustices (13, 16, 20, 31, 46–49). These inequities in climate impacts are already in evidence. Exposure to extreme heat in 2021 caused 0.7% loss of global economic output but 5.6%

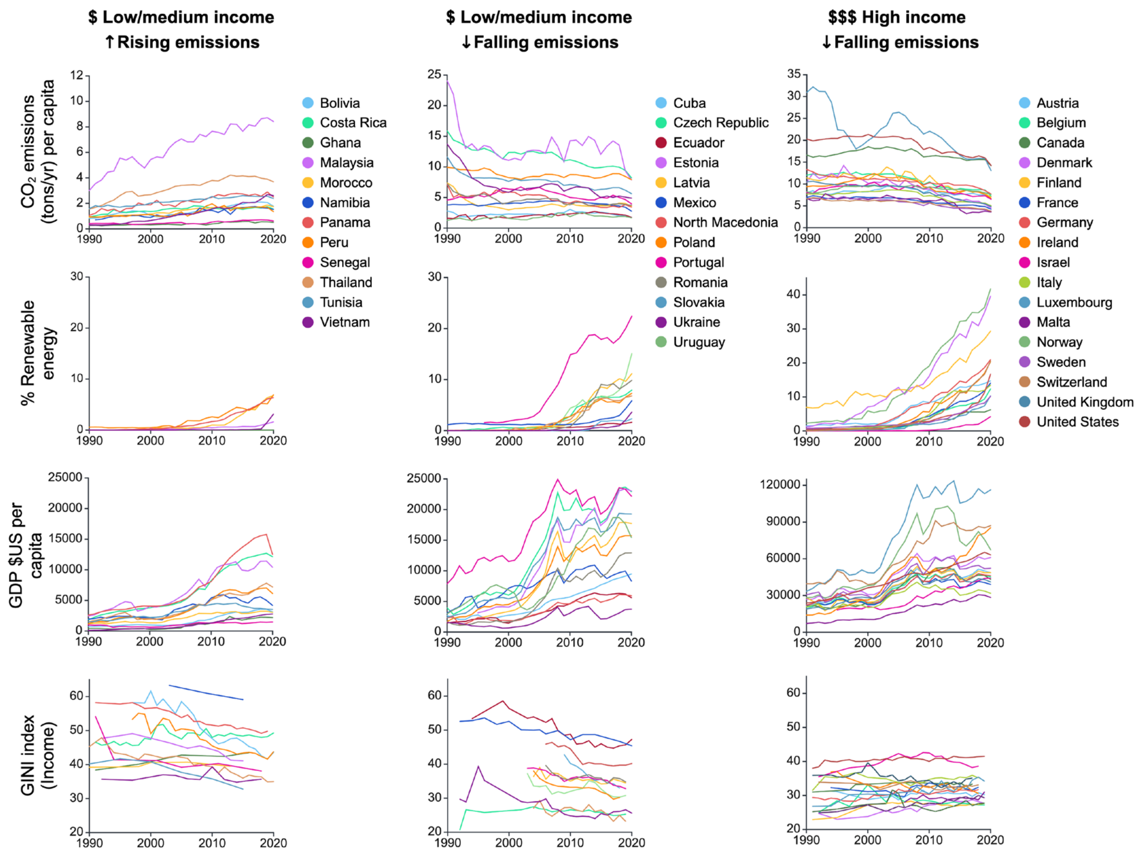


**Fig. 3.** Interannual trends. Trends in average greenhouse gas emissions per capita, GDP per capita, and income inequality (Gini coefficient), (data from refs. 17, and 18), and per cent renewable energy (https://www.energyinst.org/statistical-review), for three representative country groups. Group 1 is 12 low-to-middle-income countries with increasing greenhouse gas emissions, Group 2 is 13 low-to-middle-income countries with decreasing greenhouse gas emissions, and Group 3 is 18 high-income countries with decreasing greenhouse gas emissions. Emissions are shown in tons $CO_2$ equivalent per year, % of total energy from renewable sources, GDP per capita in 2022 $US, and the Gini income equality (×100). GDP, emissions data, and % renewable data were available for most countries in most years. Gini data were available for a subset of all countries in each group, with more data missing for earlier (1990 to 2004) than later years (2004 to 2020). Axes are scaled differently among some panels to maintain visual resolution.

loss of GDP in low Human Development Index countries (69). Future climate change and land use change will combine as codominant drivers of species extinctions and ecosystem integrity losses, furthering climate injustice impacts directly and indirectly (15). Those excluded from contemporary mitigation planning—for example, future generations and nonliving entities—will face even greater injustices compared to those alive today and in the near term future (16, 31). The frameworks and dimensions we highlight (Fig. 1 and *SI Appendix*, Fig. S1) help to graphically demonstrate the complexity of linkages across disciplinary boundaries, scales, and hierarchies.

## Opportunities to Simultaneously Mitigate Climate Change and Injustice by Decoupling Emissions and Economic Well-Being

Climate change mitigation strategies often disfavor vulnerable peoples economically, political, and/or culturally (3–6, 12, 21, 32) compromising justice benefits of climate mitigation itself. How can we minimize this tendency? An immediate challenge is that fossil fuel emissions have generally increased in parallel with economic development and well-being. There has been much discussion regarding whether encouraging renewable energy and energy efficiency in developing economies is unjust, because it will reduce economic growth: i.e., higher incomes and associated measures of well-being in high-income countries were built on high fossil energy use and emissions, and depriving poorer countries of that opportunity would exacerbate historical injustice. Questions remain, however, about the extent to which energy consumption and economic output are causally related (70).

Nations have often followed development pathways in which energy consumption and fossil fuel emissions rise rapidly as GDP rises, but with advanced industrialization and the growth of services as a share of the economy, emissions (which fall), and GDP (which increases) decouple (70). Whether asking low-income countries to mitigate climate is unjust thus depends on whether heavily polluting strategies during early economic development are required or not. Is substantial investment in efficient production and use of renewable energy a significant detriment to economic growth? Despite decades of analysis, there is no clear answer, as evidence both supports and refutes this hypothesis (8, 70–73). Additionally, economic suppression due to mitigation will weaken beyond 2050 (8), whereas negative effects of climate change on economic performance will grow exponentially (8, 16), hence concerns about adverse economic consequences of mitigation are likely also short-sighted. As poorer countries are vastly more vulnerable to climate change, any collective mitigation investment will in aggregate benefit emerging nations more than developed ones; hence rapid decarbonization may be a

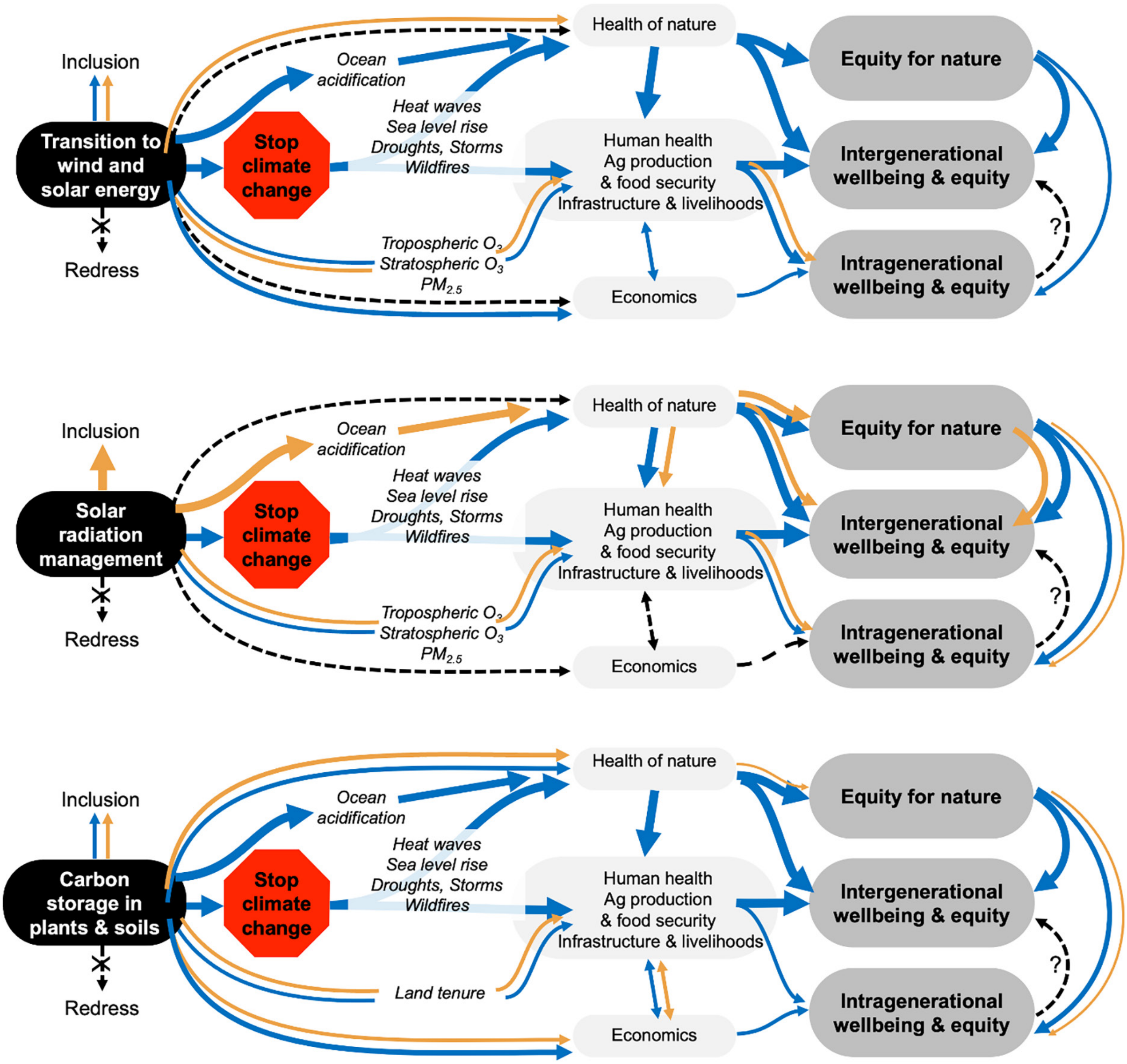


**Fig. 4.** Pathways. Hypothesized pathways by which transition to (*Top*) low-carbon energy sources (e.g., wind, solar), (*Middle*) solar radiation management, and (*Bottom*) enhanced carbon storage in plants and soils might influence climate change and other environmental conditions, with consequences for well-being and various aspects of inequity and injustice. These represent a subset of possible pathways for a subset of possible mitigation interventions. Blue color is used for pathways that reduce inequity, orange those that increase inequity, and black dashed lines "uncertain" or context dependent; line thickness indicates the magnitude of the impacts. Based on refs. 16 and 20–27 (*Top*), 28–30 (*Middle*), and 31–43 (*Bottom*).

wise rather than unjust choice for emerging economies from both climate and economic perspectives. The challenge however is to transition to greater efficiency and renewable energy in a way that does not disadvantage the poor farmer or poor elder living in a poor country who are the least likely to have direct access to the near-term benefits of decarbonization.

A central question for mitigation justice, therefore, is how to uncouple emissions and societal well-being without harming the vulnerable (74), while also considering effects of leakage due to trade that displace harm to poorer countries. Between 1995 and 2019, most low-to-middle income countries increased national and per capita incomes (17, 18, 75), with accompanying increases in emissions. In contrast, a smaller number of low-to-middle income countries (including Cuba, Portugal, Thailand, and Uruguay) increased their fractional reliance on renewable low-C energy and reduced or stabilized their emissions while increasing per capita GDP and reducing or stabilizing income inequality (Fig. 3). Many high-income countries have also maintained low income inequality and increased GDP (e.g., Denmark, Finland, Germany, UK) while increasing reliance on renewable energy sources and reducing emissions (Fig. 3). Over a shorter period (2015 to 2018), a larger fraction of countries uncoupled GDP from emissions, although carbon leakage and emissions displacement have been insufficiently considered in analyses, and few consumption-based emissions were included (74, 75).

Moreover, countries with greater reliance on renewable energy have lower income inequality on average, and as renewable energy has become a larger fraction of total energy, income inequality has decreased in most nations (Fig. 3). We do not argue that these relationships are causal; however, they argue against the widespread belief that accelerating decarbonization in low- and middle- income countries will be associated inevitably with increases in within-country inequality. However, reductions in per capita emissions since 1990 have been highly uneven among economic strata—with emissions reduced in lower and middle-income groups but increasing among the wealthy and especially the ultrawealthy (44, 45).

Common features mark how low-to-middle and high-income countries have reduced emissions, including less carbon-intensive and more efficient residential, business, transport, and industrial sectors, recourse to nuclear energy, and, in some cases, carbon taxes (74). However, for the countries that decoupled emissions trends and economic well-being, the speed and extent of emissions reductions are insufficient to meet national commitments aligned with keeping warming below 1.5 °C; thus, decarbonization must be accelerated. Moreover, the mechanisms for decoupling emissions and well-being are not necessarily transferable from one place to another, although they serve as lessons with general relevance. Nonetheless, the multinational trajectories of decoupling provide evidence to suggest that reducing GHG emissions is not always incompatible with economic well-being and justice. In the aggregate, the countries discussed above—home to hundreds of millions of people—point toward the importance of making well-considered policy, technology, and social choices to reduce emissions and achieve improved economic well-being while promoting economic and climate justice. Admittedly, we have above used coarse, cross country-comparisons in a simplified manner to illustrate the potential for simultaneously mitigating emissions, enhancing economic well-being, and reducing injustices.

## Intersections between Emissions Reduction and Mitigation Justice

Our objective is less to applaud policies in specific nations, more to highlight that effects of climate change mitigation on different peoples' lives need consideration alongside aggregate-level indicators at different spatial scales. What works in Thailand or Denmark may not work across Africa or South America, and what works for the well-to-do may not work for others. But available examples provide evidence both for experimentation and some cautious optimism. In the remaining sections, we illustrate promises and potential pitfalls of particular interventions within social/health, economic, energy, technology, nature-based, and political systems (Figs. 1 and 4, see *SI Appendix*, Table S2 for a fuller range of potential interventions).

**Demographic Dimensions.** There is substantial debate over whether a focus on population and demography will yield consequential reductions in emissions; such debates concern the ethics and efficacy of recommendations to control either the population or the consumption of the poor and vulnerable (65). In contrast, there is clear need to limit the overconsumption of the superrich, who emit many times more emissions than the average person (44, 45). While hotly debated, a move away from a focus on population control (including family planning) aimed at low-income countries and marginalized communities (and towards human and reproductive rights) could help to redirect attention toward the complex system-level economic, societal, and governance aspects that shape vastly unequal consumption footprints. Shifting away from a populationist narrative (76) will also allow for more systematic discussions of consumption and climate equity, including considering different dimensions of well-being, reproduction, and connections between people and family/kin systems, caregiving practices, and aging (77). More broadly, despite the importance of shifts in individual behaviors and findings from innovative programs targeting behaviors, it also remains the case that a focus on individual behaviors can have the unintended effect of downplaying the critical need to address larger systemic and structural drivers of emissions and the complexities of social injustices.

**Energy Choices.** A rapid global energy transition is necessary to mitigate future fossil-fuel emissions and related climate change (21, 22). However, renewable energy might have near-term positive, neutral, or negative impacts on social justice (5, 22, 78), depending on scale, context, and pathway (Fig. 4).

Decision-making driving energy transitions often excludes communities home to new infrastructure, despite evidence that public participation can secure relevant local knowledge and support for policy (22). This trade-off arises from tensions that challenge the ability to simultaneously achieve both rapid and just low-carbon transitions (23). For example, participatory processes may increase justice but slow the speed of action. In contrast, mobilizing businesses, banks, and financiers to invest in low-carbon transitions is accelerated when those actors benefit, which can sustain existing injustices.

Whether decarbonization of energy systems (including agriculture, see below) has positive or negative effects on environmental justice in the near term will vary depending on technology, process, scale, and context (24)—as demonstrated by impacts from solar, wind, hydro, and nuclear energy that differ in scope and kind (21, 22, 25, 26). Low-carbon energy technologies can produce negative externalities (e.g., wind turbine shadow flicker, pollution from methane generating landfills, and exacerbation of local inequality due to differing accessibility to sustainable products and services). Some such effects are substantial, as with creation of large reservoirs for hydropower that flood well established communities (27) and disproportionately impact those who live nearby, who are likely to be rural, less educated, and less wealthy (22).

Renewable energy expansion can also influence biodiversity and pollution, indirectly affecting livelihoods and exacerbating poverty (25). Land needed to completely source global energy demand (i.e., from solar and wind) would however require only ≈0.2% of Earth's land area (79) (less than the current global urban area) and thus almost certainly be a minor cause of net injustice compared to losses from unchecked climate change. Moreover, land needed for mining associated with renewable energy will likely impact an area as large or larger than that needed to harvest energy, and there are considerable concerns for justice in this realm (80, 81).

In the long run, inequities associated with low-carbon energy development will likely be smaller compared to inequities ameliorated by dampening the disproportionate direct effects of fossil fuel operations, as well as the disproportionate indirect effects of climate change, on underserved, poorer communities in countries rich and poor (8, 12, 13, 20, 21) (Fig. 4*A*). Moreover, even high cost estimates of major investment in renewable energy pale in comparison to the anticipated costs of damages from unchecked climate change (16), indicating a strong economic logic for such future investments (21, 22).

**Technology and Integrated Systems.** Although technological innovation is likely required for emissions reduction (26, 78, 82) its justice implications should be considered as part of climate resilient development, which addresses integrated mitigation, adaptation, and justice (3, 5–8). For example, advances in transportation technology have historically been least available to lower-income underserved populations. Policymakers need to prioritize equal access to new technologies and services like private and public electric and automated transit, if the underserved are not to be left behind. Increased implementation of decarbonized mass and shared transit will do more to mitigate climate change and injustice than current policy and market emphasis on individually owned EV cars (83). To do so, countries could amplify congestion pricing, compact cities, cycling, and electric public transit, while also promoting EVs.

Many strategies for the built environment could, but often do not, reduce inequity (78). Programs to insulate homes and buildings, transition to LED lights, and incorporate smart thermostats, especially if targeted to those who cannot afford upfront costs of adoption, are low cost strategies with positive impacts for both climate change mitigation and social injustice (78). Replacing traditional biomass or kerosene cooking stoves with cleaner cookstoves could mitigate adverse health effects, experienced disproportionately by women and the poor, reduce greenhouse gas emissions (78), and reduce the labor burden of women.

Given the enormous contributions of agriculture to global emissions, reducing those are key (14, 74), but some food systems interventions might impact justice (6, 14). As one example, life cycle analyses illustrate how improving food cold supply chains and reducing their length could reduce food waste and improve food security and nutrition for vulnerable populations in lower income countries, while resulting in considerable emissions reductions, with a majority of these from lower income nations (84). Many strategies exist to ameliorate either climate change or food systems injustice; it should be possible to prioritize those that do both (6, 33).

More generally, reduced demand can not only reduce emissions but do so more cheaply than switching to low carbon energy sources (78). Reduced demand could be achieved via policy instruments (see below), increased energy efficiency (6, 14, 74), switching to plant-based diets and reduced food waste (78), and other behavioral changes (78); all with a range of justice implications (8, 78).

Technological solutions to remove carbon from the air or reduce incoming solar radiation have also been proposed. Direct carbon capture and sequestration remains far from operational at scale and is difficult to assess from a justice perspective (85). The justice effects of others, such as solar radiation management through stratospheric aerosol injection, are likely profound and complex (28, 29) (Fig. 4*B*). The dampening of climate change from solar radiation management would reduce some adverse impacts (e.g., from excess heat, drought, etc.) that disproportionately fall on the poor and the powerless. However, increases in excess mortality due to increasing surface-level concentrations of PM2.5 and exposure to UV-B radiation would exacerbate inequities (28). Additionally, stratospheric aerosol injection would do nothing to mitigate ocean acidification, whose adverse impacts heavily affect poor communities that rely directly on healthy marine and ocean ecosystems. Further, the decision to deploy stratospheric atmospheric injection might be made noninclusively, further concentrating power within a small group of technologically and politically powerful nations (29, 30). Finally, solar radiation management is an example of "kicking the can down the road" because it leaves the underlying problem (of excess greenhouse gas concentrations) untouched and in fact would worsen it, leaving future generations with a worse pollution load to resolve.

**Natural Solutions: Nature, Agriculture, and Forests.** Multiple nature-based solutions (e.g., afforestation, protecting peatlands, restoring grasslands, precision and regenerative agriculture, and conservation grazing) have been proposed to reduce emissions and sequester more carbon (9, 34). The proposed solutions have promise and potential pitfalls from climate mitigation justice perspectives (Fig. 4), including those related to biodiversity (14, 51, 86).

Afforestation, a popular mitigation strategy, requires suitable land, where people often are already living. Large-scale tree planting campaigns often fail to consider the social and ecological complexities of the landscapes they aim to transform (32) or other adverse climate-related feedbacks (87). Using agricultural land for biofuel production and carbon sequestration can exacerbate food price increases, leading to increased food insecurity and malnutrition (35), with negative consequences for social justice (36). Agricultural intensification, coupled with associated land sparing to protect forests as carbon sinks, has been proposed as an approach to achieve climate mitigation without sacrificing global food security (37). However, such agricultural intensification could lead to unequal outcomes in terms of biodiversity, food security, and sovereignty (6, 14, 15, 38). Impacts on rural people (through land tenure) and nature (e.g., biodiversity) will depend on socially and ecologically appropriate policy, land management, and carbon sequestration choices (9, 86).

Despite concerns about potential nonalignment with social justice of many nature-based solutions, they remain a key tool in climate change mitigation, as they have surprisingly high collective mitigation potential. For example, agricultural and forest lands alone could in theory mitigate 50% of climate-altering emissions (33, 35), and there is belief that many such interventions could be implemented without furthering injustice (Fig. 4*C*) (33, 34). Such high mitigation potential exists because soils and land plants exchange 10x more carbon with the atmosphere each year than we emit in burning fossil fuels, and they hold 3 to 4× more carbon than the atmosphere; thus, modest percent changes in soil and plant carbon stores at the global scale are large relative to emissions.

Recent analyses agree that there is sufficient area of degraded, nonagricultural forest land that forest restoration alone has considerable potential from a carbon storage perspective (39). Similarly, access to resources (improved varieties, including perennials) and sustainable practices can simultaneously reduce agricultural greenhouse gas emissions and enhance soil carbon sequestration through judicious fertilizer use and fire management (37). Overall, modified agricultural practices (75% through enhancing soil carbon through a variety of pathways and 25% transforming pastures to silvopastures by planting trees) could provide additional sinks of 2.8 $GtCO_2e$ per year by 2050, costing less than half as much annually as the gain in global GDP derived from dampening climate change, and providing considerable economic gain to small-holder farmers (assuming well-off countries and consumers were paying for these carbon benefits) (33). To be sure, legitimate concerns exist about biophysical, political, and justice dimensions of proposed land-based climate mitigations, with a particular focus on offset markets (40, 41). We agree that strategies to restore the plant and soil carbon debt should not merely be used as an opportunity to greenwash direct emissions (41). However, the existence of poorly imagined and/or implemented nature-based solutions does not mean that more effective ones cannot be developed (9): realizing even a fraction of the mitigation benefits from nature-based strategies that address both climate and justice would help slow the pace of climate change and could potentially avoid triggering multiple critical tipping points of climate system collapse (88).

More generally, many of the strategies to store carbon in forests and agricultural lands can include cobenefits for climate adaptation for local communities (86). For example, maintaining and restoring diverse plant communities can reduce local riverine or coastal flooding, increase carbon storage, and provide environmental (safety) and economic benefits to local residents (32, 34). The selection of end-user is critical however to justice impacts of such practices (9). For example, industrial scale methane digesters will likely benefit wealthier business owners, whereas on-farm digesters might benefit small-holders.

Nature-based solutions that engage communities and incorporate procedural and distributional equity in implementation have substantial potential for reducing emissions and injustices, as illustrated by examples in India and Ethiopia (42, 43). Such approaches can help mitigate climate change while mitigating social injustice if adapted by local farmers (31, 34, 36–38). If these and other strategies are deployed, it may be possible to feed 10 billion people while maintaining sustainable ecosystems (34, 36) that help cool the planet. These efforts will take shape in different ways depending on the setting, food preferences, connectivity, and environmental conditions. Forward-looking efforts can and must simultaneously achieve land sparing goals for mitigation without sacrificing food sovereignty or local equity (77).

**Policy and Governance, and Nongovernmental Actors.** Generally, policy interventions are at the core of efforts to shift away from business-as-usual trajectories of higher emissions and injustices (74, 78). Among means of spurring such change are tax and cap-and-trade policies, net-zero plans, shifts in subsidies, policy choices over discount rates, and international climate agreements. Although we focus on the country-scale herein, actions can be taken by cities and regional governments. Additionally, nongovernmental actors, including cultural and institutional players, NGOs and philanthropic and business organizations, can also play critical roles in spurring change (78, 86). Collectively, these agents all influence climate mitigation finance; but at present, inequities in access to finance, as well as its terms and conditions, contribute to a poor outlook for a just global decarbonization (89).

Carbon taxes, renewable energy portfolios, subsidies, emissions trading schemes, and efficiency standards are among the policy instruments for reducing emissions and can have differing impacts on emissions and inequities depending on instrument-specific design choices and time horizons (21, 90, 91). Carbon taxes and cap-and-trade already generate substantial revenues and are considered key mechanisms to meet national and global emissions reduction goals (92–94). Taxation levels, complementarity with other policies, and political and public acceptance, are key levers (64). Carbon taxes can have a modest positive effect both on GDP growth and employment (95), but effects of taxes on equity, macrolevel growth, and household-level well-being will likely depend on design and enforcement because of their differing effects on commodity prices (96, 97). Their equity effects also depend on who pays the majority of the taxes (45) and how and how much of tax revenues are redistributed (94). Carbon taxes, subsidies, and offsets could be designed in light of the ethical principle of universal coownership of gifts of nature (89). However, we have far to go in this policy direction, because as of 2019, 69 (80%) of 86 countries reviewed had net-negative carbon prices; in short, they provided a subsidy to fossil fuels for a net total of US$400 billion (69).

The pricing of carbon taxes and valuation of other mitigation interventions and policies should be linked to the social cost of carbon; which itself reflects estimated future damages from climate change and the discount rate chosen to weigh the value of costs today to benefits in the future. Estimates of damages from climate change range widely; prior estimates corresponded to a roughly 3 to 6% decrease in global GDP for a 3 °C warming (48). In contrast, a report by SwissRe, the world's largest reinsurance company, suggests an enormous 9 to 18% reduction in global GDP for a 3.2 °C warming (16); with the range depending on whether impacts on a comprehensive set of risk channels are moderate or severe, respectively. Discount rates used to estimate the social cost of carbon rely on the presumed relative wealth of future generations, the opportunity cost of investing to mitigate climate change, and social time preference, all of which are highly uncertain and/or arbitrary. Low discount rates highlight the interests of future generations and intergenerational equity. In contrast, high discount rates valorize present generations and lead to greater intergenerational inequity (98, 99).

Some claim that when investments to slow climate change compete with investments in other areas, a discount rate of ≈5% per year is appropriate (98). Others argue that such a high discount rate appears rational only when future climate change impacts are underestimated; moreover, high discount rates that delay climate change mitigation will leave future generations with a much more damaged world (biodiversity and infrastructure loss, higher rates of catastrophic climate events) and lay higher costs on future generations than those alive today; all represent strong intergenerational inequity (46, 99).

The influence of discount rate on how we, today, value future impacts of mitigation provides a useful illustration of its importance. Under the 3% discount rate used in the 2021 US government estimate of the social cost of carbon, climate damages in 2122 count only 5% as much as those in 2022 (and those in 2150 by 2% as much). Discount rates ranging from 2 to 5% for all practical purposes ignore damages experienced beyond this century, which will likely be extreme and perhaps chronically catastrophic. Thus, the range of discount rates typically considered in current policy discussions indicates that we alive today take virtually no responsibility for climate change damages we will cause to generations, non-human life forms, and ecosystems in the 22nd and 23rd century. Recognizing the rights of future generations by choosing very low (≪1%), zero, or even negative discount rates to value the social cost of carbon could accelerate climate change mitigation and enhance future climate justice.

## Conclusions

Climate change both creates and amplifies social injustices. Those who unfairly bear the brunt of negative consequences of specific mitigation actions are often agriculturalists, the poor, indigenous peoples and ethnic minorities, and aging populations that live within the footprint of the climate mitigation activity (3, 5–7, 10). The alleviation of climate injustices that result from specific mitigation actions are however distributed among peoples across the planet. Difficulty in and disagreement about how to predict which interventions will result in good versus bad adaptation and/or mitigation should not stall policy, practice and implementation, however, because unintended negative consequences of failure to act will fall on those most vulnerable (100). In essence, it will be necessary to balance any negative and localized injustice consequences of climate mitigation interventions from positive justice consequences that would occur globally from reduced climate change.

Some countries, including low–middle-income countries, have grown their economies and reduced income inequality while increasing reliance on renewable energy and reducing fossil fuel emissions. Their experience demonstrates that improvements in human well-being and social justice concurrent with reductions in emissions are feasible. Selected countries show common shifts to less carbon-intensive fossil fuels and from fossil fuels to renewable energy; an emphasis on efficiency in business, industry, and residential energy use; strategic use of carbon taxes; and reforms in the transportation and agricultural sectors. Such transitions could be made in poorer countries as well; for example, a shift to renewal energy and full decarbonization in Bangladesh can be technically feasible from economic cost efficiency, land availability, and justice considerations (24), but will require substantial international and national investment. More broadly, national commitments to emissions reductions and culturally embedded conversations about climate mitigation and justice (2, 5, 6, 8, 12, 78) will remain key elements in advancing climate policies with positive justice and well-being effects.

Just because humankind could mitigate climate change and ameliorate climate injustices and reduce suffering, sustain biodiversity and save money in the long term by doing so, does not mean we will. To date we simply have not figured out how to find the political will to make this happen (5). Hopefully, the existence of a plethora of possible pathways that collectively could contribute to a sustainable and just future will inspire people across all walks of all societies to figure out how to turn that potential into a reality.

**Data, Materials, and Software Availability.** All data in the article and/or *SI Appendix* are publicly available in Zenodo (101).

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