Mitigating Climate Change and Climate Injustice Simultaneously

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Abstract:

Mitigating climate change and social injustice are critical, interwoven challenges facing humankind. Climate change is the result of grossly unequal greenhouse gas emissions by different societies and groups. Its impacts are also unjust, disproportionately affecting poor and less powerful nations, and the poor and the less powerful within each nation. While climate mitigation is essential, it reshapes the interacting socio-cultural, economic, political, physical and ecological processes that cause climate change, often with adverse outcomes for the most vulnerable. Answering the challenge of how to achieve climate mitigation alongside social justice mitigation and enhanced wellbeing will require improved understanding of the tradeoffs of alternative climate mitigation options with demonstrably different social justice outcomes. Herein, we present a broad framework to illustrate the interface between climate change and social justice, examining how economic, health, governance, social and policy dimensions interrelate both as cause and consequence of climate change, related emissions, and associated injustices. We then assess how specific mitigation interventions can address or exacerbate climate injustice, or more complexly, simultaneously worsen climate injustice for some and improve justice outcomes for others. In sorting through these possibilities, we identify a set of interventions that can both reduce emissions and enhance justice more broadly. These solutions highlight a range of possible ways forward, and include demographic choices, technology, a suite of natural solutions, and policy and governance. We also discuss political-economic obstacles to adoption and possible mechanisms that may support broader deployment. Addressing such possibilities has the potential to generate new ways of thinking about and mitigating inequity and power imbalance in the context of mitigating climate change.

One Sentence Summary: Mitigating climate change and social injustice requires systemic attention to political, cultural, economic, and technical pathways.

Main Text:

Climate change and social injustice are arguably the most critical challenges facing humankind in the 21st century. They are inextricably linked: those least responsible for climate change are most adversely affected by it and many actions taken to mitigate climate change will exacerbate climate injustice for many of the world's people (1–12). Much has been written about these connections, but typically with a focus on particular aspects of climate change and related injustices (e.g., sea level rise and flooding, droughts and food insecurity, wildfires and health), specific places or social groups (within a given country or region), specific climate adaptations (e.g., levees, air conditioning, wildfire management), and/or specific climate mitigation efforts (e.g., forest carbon sequestration, solar energy). In this paper, we attempt to provide a synthetic overview of potential climate mitigation strategies and associated justice consequences across a range of contexts (Figure 1). We build on a large literature that assesses social changes and climate impacts and mitigations through a justice lens (see Table S1 for key definitions), and examines stakeholder tensions (13–15). Choices over pathways and interventions depend on clearer scientific and policy understandings of the relationships between mitigating climate change and ameliorating social injustice (4, 16–18). To support multi-disciplinary discussion of pathways and trade-offs, we present a framework that highlights how climate change drivers and impacts ripple through spatial, temporal, and social dimensions.

Issues of climate change adaptation, mitigation and justice can be examined by telescoping out to the global scale or focusing in to gain insights into specific issues or spatio-temporal contexts. Telescoping out gives the 'big picture' - essential when contemplating climate mitigation - but

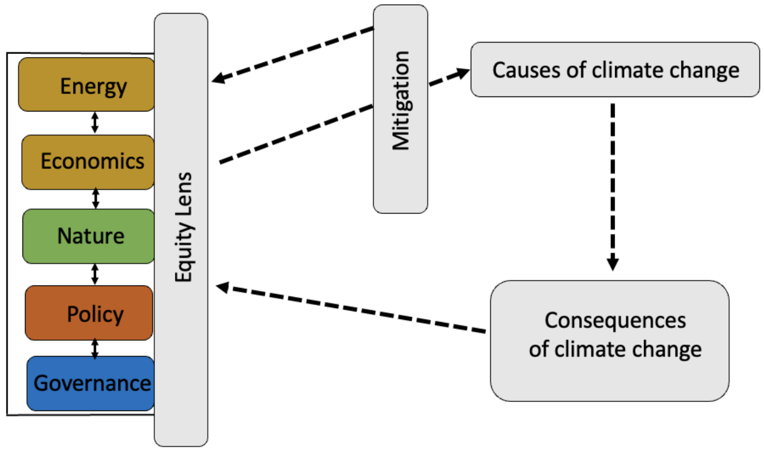

Figure 1. Overview of the architecture of this review. Social processes and structures, represented by the coloured boxes on the left, lead to emissions that cause climate change. In turn climate change influences social structures and processes. We assess these relationships through an equity or justice lens. Mitigation is overlaid on these relationships and reduces further warming through a variety of means, but also directly affects justice, often exacerbating justice outcomes for the most vulnerable even as climate change impacts may decrease overall. Our goal is to highlight opportunities to improve social justice while also rapidly and expansively mitigating climate change.

glosses over the complexities and context dependencies illuminated with a focused look at place-based or single-issue contexts. Additionally, although adaptive management can be planned at large scales, whether or not any particular action is in fact adaptive will tend to be local, while local mitigation efforts only matter if in the aggregate they slow or stop climate change globally. This duality is 'baked' into climate change reality and made more complex because it is the global climate that impacts local areas, adaptively managed or not, and the sum of activities in local areas that determine whether, how fast, and in what direction, global climate will change.

The framework guiding our argument (Fig. 2) represents the challenges at the interface between climate change science and social justice. It links climate impacts with key components of inequality and injustice in multiple dimensions (Figs. 3-5). Our framework distinguishes between inequality and injustice conceptually while recognizing their relatedness and the difficulties of empirical measures of injustice across spatio-temporal contexts. Inequality refers to differences between and within groups in distribution of resources, capabilities, benefits, and harms (19, 20).

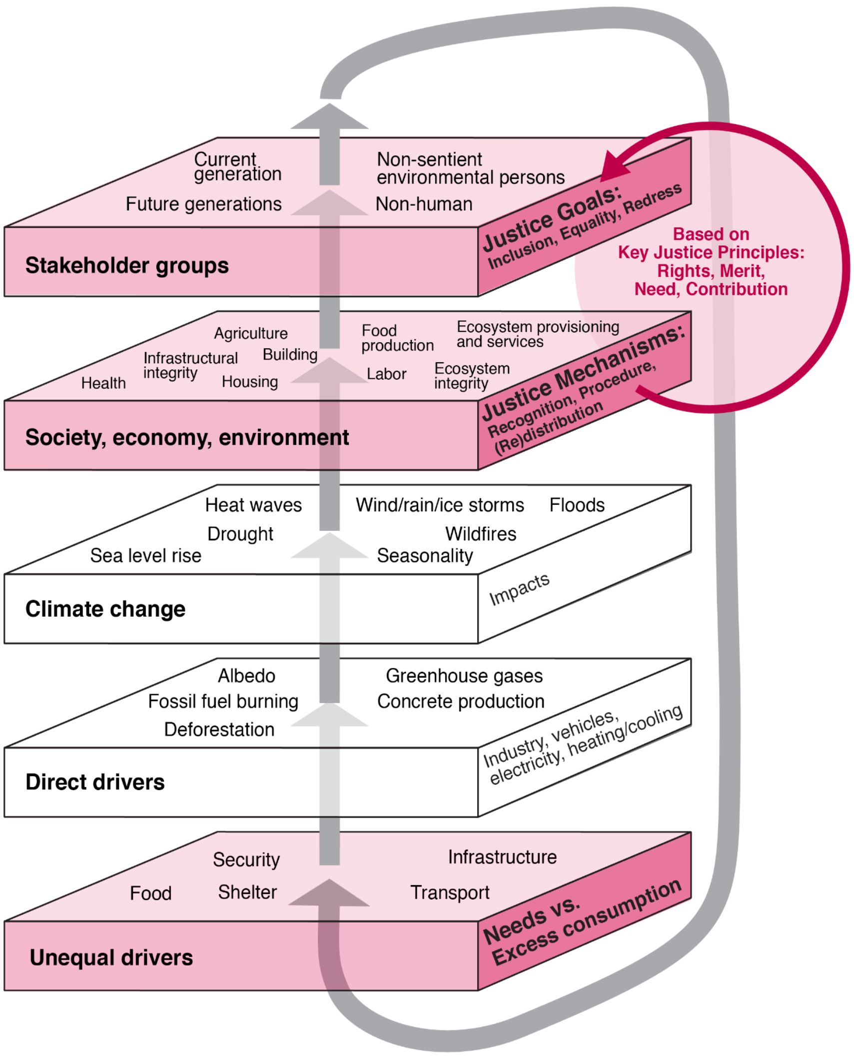

Figure 2. Climate Justice Framework. A thematic representation of the links between varying domains of climate change drivers and impacts as they relate to social justice. A key link involves the potential for climate change mitigation strategies to either exacerbate or dampen inequalities.

Injustice denotes principles-based assessments of inequalities (21, 22). We then examine current challenges at the interface of climate change science and social justice, providing a context, baseline and benchmark for future directions, before discussing real-world examples where emissions reduction and wellbeing improvements have occurred together. We further connect real-world complexities to the framework to highlight a suite of approaches and interventions that center justice-based mitigation of climate change.

Core objectives of justice include inclusion, equity, and redress. These goals can be advanced by a wide range of distributional, recognitional and procedural mechanisms. Existing research on climate-justice outcomes is typically concerned with three types of stakeholders: distinct social groups in the current generation, generations yet to come, and non-human subjects such as animals, plants, and landscapes (Fig. 2). Intra-generational equity and justice concerns have perhaps received the greatest attention in writings on climate justice, because climate change injustices are borne by specific groups depending on impact type, geography, nationality, context, identity, and history (Figs 2-4). But the long time horizons over which climate change has unfolded and will unfold, means that climate justice must be attentive to questions of historical and future injustices - including the interests of those yet to be born (3–7, 23, 24). In addition, a growing movement claims the rights (environmental personhood) for other species, landscapes, and rivers. Some of these advocacy efforts have been successfully codified in law, such as in Ecuador, Bolivia, Bangladesh, and New Zealand (25), but whether and how these developments will influence international policy and economic decisions remains unclear.

Inclusion is a fundamental component of climate justice. Ongoing efforts to create and develop inclusive climate science, policy, and interventions are promising, and must consider dimensions related to power and influence (8, 26–28). A vital step forward would focus on scaling across local-to-global levels (e.g. (8, 27, 29–31). For example, discussions of energy-related interventions often aim at reducing country-level emissions, but for success, such interventions will require that individuals, households, and communities make fundamental changes to their everyday behaviors (e.g., how food is stored and prepared, what energy sources power lighting and heating, what means of transport are deployed)(Fig. 2). Indeed, some argue that concrete shifts towards inclusive climate justice must be built around the concerns and experiences of those whose daily lives will be affected by climate change (27, 32). In this view, taking the time and investing scientific and policy resources to communicate and interact with marginalized population groups, like the impoverished, the elderly, the disabled, and the disadvantaged is a necessary step in developing inclusive climate justice.

Climate negotiations and policies have often sought to address justice concerns (33), including through rights to a stable climate (34); allocation of responsibility for historical emissions (5); support for compensation for emissions reduction (35); and commitments for financing adaptation (36). These approaches demonstrate the complexities in designing interventions that address intertemporal inequities (8, 10, 27, 37, 38), including in debates over allocation of future carbon budgets (39, 40) and discussions of loss and damage (41, 42). Regardless, these diverse justice principles and mechanisms have had only limited effects on climate action to date because of ongoing resistance to policies that benefit marginalized populations but impose costs on wealthy and powerful constituents.

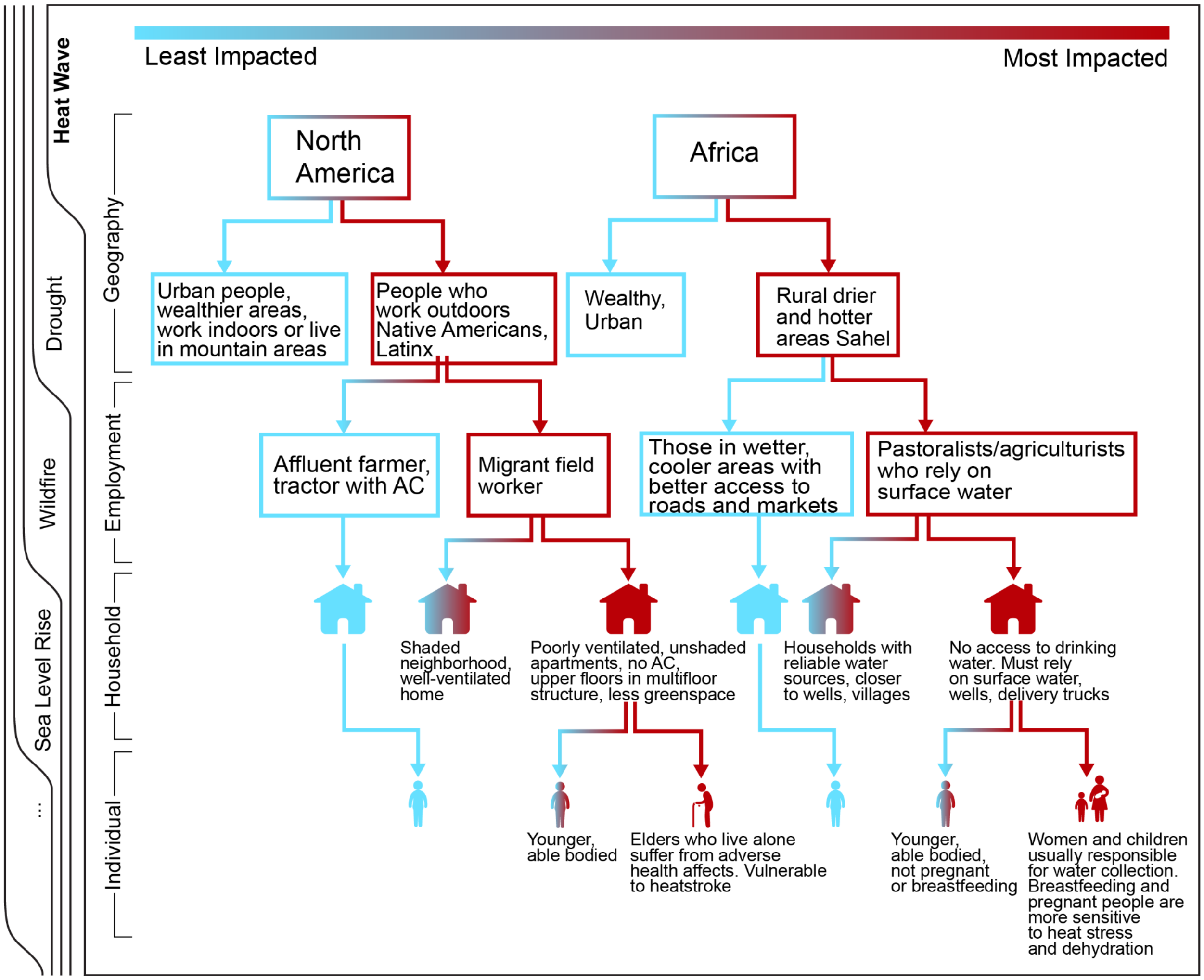

Figure 3. Hierarchies. Examples of hierarchies showing sub-group level additional injustices at neighborhood and individual scales, within populations that experience contrasting levels of climate injustices. Herein we show as an example hierarchical injustices for heat waves; visualizations of this kind could be made for every other element of climate change (see other tabs for example).

Current challenges of climate change science and social justice

Both energy consumption leading to climate change and strategies used to mitigate it often exacerbate issues of social justice (43–45), suggesting that we could better co-address these problems with an integrated climate justice framework. Wealth, consumption, governance, and inequality are related to historic (Fig. 4) and current (Fig. 5) greenhouse gas emissions and their consequences, and likely also to their capacity to uncouple wellbeing from future emissions (Fig. 6). At present, per capita emissions and carbon footprints (including embedded emissions) remain higher on average in more well-to-do nations (Fig. 5) and among the wealthier within every nation; moreover, a greater fraction of total global inequality of carbon emissions now occurs within rather than among nations (46, 47). If current global trends in energy use, land management, and socio-political systems continue along business-as-usual trajectories, the goals of the Paris Climate Agreement will not be reached. Climate will warm by another 2-4 ℃ (or more) during this century, and the impacts of our changing climate on nature and human societies and economies will grow larger, leading to multiple and cascading tipping points (45, 48–58). There will be stark contrasts at the national level in relative contributions to greenhouse emissions versus level of anticipated adverse climate impacts (Fig. 5) and poorer countries will experience much more negative proportional reductions to their already low per capita GDP from such climate impacts (Fig. 5). For example, and for a variety of reasons (see below), India, Indonesia, Malaysia, the Philippines and Thailand may experience enormous reductions of 35-46% in their GDP under 3℃ warming, compared with reductions of 5-10% for countries such as Canada, Finland, Poland, and the U.S. (45). We recognize that per capita GDP is an incomplete and flawed metric, but argue that it is useful in macro-scale comparison among nations, as well as within nations when coupled with income inequality data and health or other well-being metrics.

Many nations that contribute negligibly to climate change (especially on a per capita basis) will be among those most adversely affected, including African, Southeast Asian, and Caribbean and Pacific Island nations (7, 8, 15, 16, 49, 51, 52, 54, 55, 59–61). Overall, estimates of likely impacts of future climate change on per capita GDP are not only higher in countries with lower current per capita GDP, but also in countries with higher internal income inequality, lower life expectancy and lower overall well-being (Fig 5). Climate change impacts will likely exacerbate those inequities in the future.

Within all countries, groups less responsible for climate change will experience more of its adverse effects (Fig. 3) (4, 5, 7, 10, 15, 16, 27, 28, 58, 62, 63). Figure 5 depicts variations across countries using readily available metrics but does not present how economic inequality plays out within countries when gender, race, or rural/urban residence are also considered. It also does not present the effects of large-scale migration from more- to less-affected countries, a dynamic that is already happening. Including additional layers of inequality would dramatically complicate Fig 5 but would highlight how varied, complex, and important it is to consider layers of inequality (as in Fig 3). For example the poorer and less powerful experience greater air pollution within cities (62, 64); greater exposure to heatwaves while at work (e.g., outdoor labor) and at home (lower likelihood of air conditioning and tree cover in urban settings) (58, 65, 66); greater likelihood of inundation from sea level rise, event flooding or both (67, 68); greater likelihood of catastrophic wildfire impacts (69), and greater vulnerability to adverse effects of droughts or non-drought drivers (e.g. social unrest) on either crop failure or food system dysfunction (70, 71). Gender inequalities in command over resources and power leaves women facing additional higher risks within households and communities (27, 72, 73). Additionally, those from households with more resources may be better equipped to leave afflicted or risky areas (74).

Children and pregnant women also face unique health vulnerabilities because of increased risks of malnutrition, food insecurity, adverse birth outcomes, vector-borne disease risk, and constrained educational opportunities (58, 64, 75–77), 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 socio-economic 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 (58, 62, 64, 66, 68, 69), while having contributed less to its development. Intersectionalities of multiple vulnerabilities further exacerbate social injustice - for e.g. the situation of elderly or pregnant women from minority communities may be especially precarious.

Two additional factors could make these adverse impacts even worse for the vulnerable in many mid- to low-income nations. First, future impacts may be higher in countries with higher levels of corruption, challenges to democratic governance, and low state capacity (Fig. 5). Climate policy-making in many such countries also ignores or downplays the need to buffer vulnerable populations through investments in resilient infrastructure, responsive decision making, and comprehensive safety nets and social assistance programs (55, 78–81). Second, even apart from governmental factors, because of climatic and geographic differences, people in poorer tropical countries are likely the most vulnerable to climate change impacts such as sea level rise, heatwaves, droughts and climate-change related spread of diseases because of the ways they interact with the local landscape for food and income production (Fig. 4) (82). 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, or poor soil due to repeated wildfires, may further decrease household capacity to deal with stressors (70).

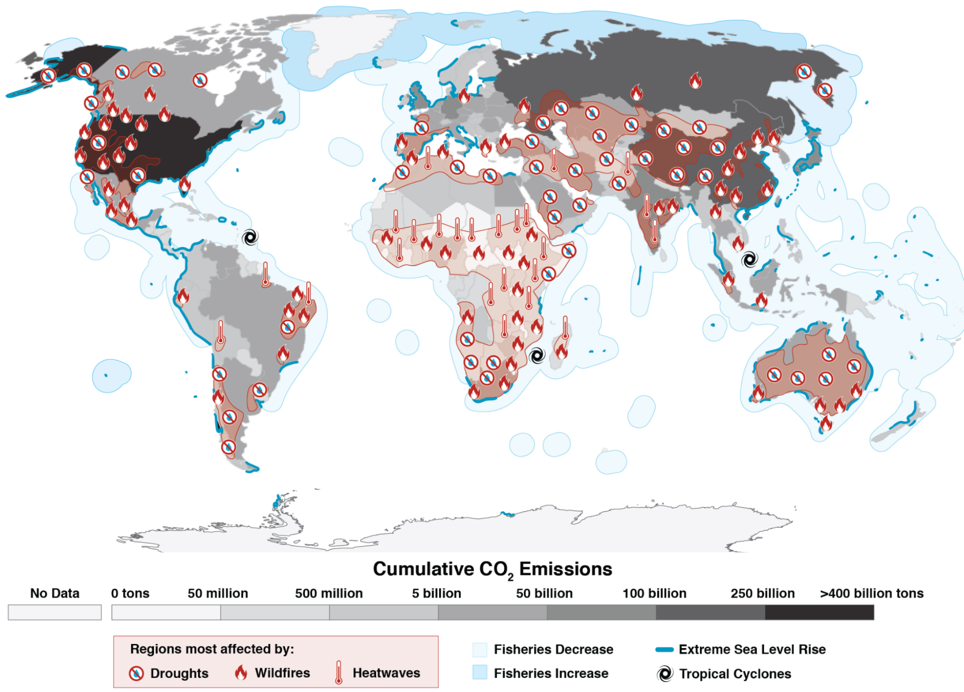

Figure 4 Map of cumulative greenhouse gas emissions by country and areas of highest projected risks of climate change impacts (49, 52, 54, 55, 58–60, 83, 84). Communities that have produced the fewest emissions will bear the greatest impacts of future climate change; this will also occur at a series of subnational scales (regions, cities, neighborhoods).

This evidence highlights how unchecked climate change will disproportionately affect vulnerable peoples everywhere and in an accelerating fashion (Fig. 2-5) (49, 52, 54, 55, 59, 60). This acceleration of inequity will occur because the adverse climate change-related effects of global economic development would grow exponentially larger with time due to the non-linear and compounding interactive effects of an increasingly altered climate, whereas their social benefits to vulnerable communities and societies will grow at best linearly (and perhaps decelerate due to feedback from climate change itself) (15).

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 modest income levels (≈$US 3-8 PPP per day) could cause warming of as much as an additional 0.6 ℃ by the end of the century, according to one estimate (78). In turn, climate change impacts under a business-as-usual emission scenario will likely lead to an additional 80-120 million people in extreme poverty, perhaps within decades (82) and cause increasingly large health, economic, environmental and infrastructural damages, amplifying climate-related injustices (50, 51, 56, 85). For example, exposure to extreme heat in 2021 already caused 0.7% loss of global economic output, but 5.6% loss of GDP in low Human Development Index (HDI) countries (86). Moreover, climate change and land use change will combine as co-dominant drivers of species extinctions and ecosystem integrity losses, furthering climate injustice impacts both directly and indirectly (Fig. 5)(87). Those excluded from contemporary mitigation planning - for example, future generations and non-living entities - will face even greater injustices compared to those alive today and in the near term future (45, 56, 85, 88). The framework we propose (Fig. 2) helps to graphically demonstrate the complexity of the linkages across disciplinary boundaries and can serve as a useful tool for supporting scientifically based mitigation strategies that considers issues of injustice across scales and hierarchies.

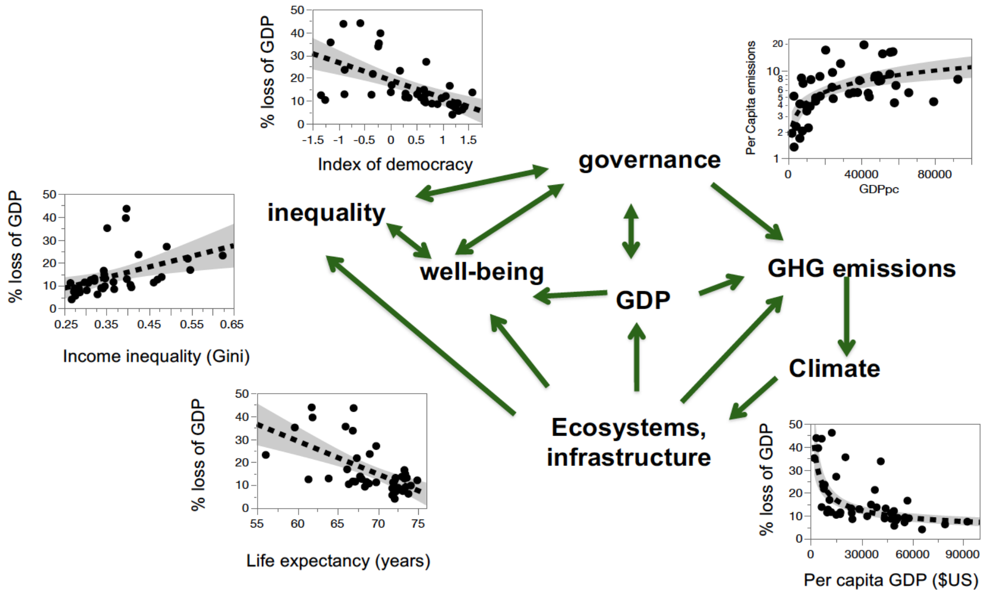

Figure 5. **Relationships among economics, emissions, governance, climate impacts, and inequality.** Estimates of percent loss in GDP due to climate change for 42 nations (45) in relation to per capita emission (in 2019, (83)), per capita GDP (GDPpc, 2017, (89)), healthy life expectancy at birth (90), the GINI index of within country (2000-2016 average) income inequality (89), and indices of governmental democratic quality (90). Lines and confidence intervals shown for linear or non-linear fits (all P<0.01) for illustrative purposes.

The framework in action: opportunities to simultaneously mitigate climate change and injustice

Climate emissions have generally increased in parallel with efforts to enhance wellbeing. A central question, therefore, is how to uncouple them. Between 1995 and 2019, most low-to-middle income countries saw increases in national and per capita incomes (83, 89), accompanied by increases in emissions (e.g., Fig. 6). The BRIC (Brazil, Russia, India, China) countries also experienced rising emissions and incomes, although with more variability in some cases. In contrast, a smaller number of low-to-middle income countries increased per capita GDP and reduced income inequality (including Cuba, Czech Republic, Portugal, Slovakia, Uruguay) while reducing greenhouse gas emissions over periods ranging from the past 8-25 years. Many high income countries have also maintained stable, low income inequality and increased GDP (e.g., Belgium, Denmark, Finland, Germany, Sweden, UK) while reducing emissions over the past 25 years. However, reductions in per capita emissions since 1990 have been highly uneven among economic strata within high income countries - with emissions reductions noted in lower and middle income groups but rapid increases among the wealthy and especially among the ultra-wealthy (47) who already are responsible for the greatest per capita emissions and have the greatest financial wherewithal to reduce their emissions if desired or required.

For the approximately 25 countries that decoupled emissions trends and average economic well-being, some of the cases likely reflect accidents of geopolitical and technological change, whereas others are products of intentional policy choices (as discussed below). While these reductions are insufficient to meet national commitments aligned with keeping warming below 1.5C and may not be transferable from one place to another, they provide some signs for optimism that reducing GHG emissions may be compatible with increasing average economic well-being and justice. In the aggregate, these countries - home to hundreds of millions of people - point towards policy, technology, and social choices that can reduce emissions and achieve improved economic well-being while promoting economic and climate justice.

To illustrate potential mechanisms, we examine the experience of four of the middle-to-high income countries that reduced emissions concomitantly with improvements in economic well-being: Denmark, the United Kingdom, the Czech Republic, and Uruguay (Figure 6). Common features mark the paths these countries pursued, including a less carbon-intensive national energy portfolio, greater energy efficiency in residential, business, and industrial sectors, recourse to nuclear energy, more efficient vehicles, and, in some cases, carbon taxes. These carbon management policies have neutral to modestly positive effects on equality and equity in the near term, and strong positive effects for nature and for future generations of people through emissions reduction (e.g., Fig. 7A).

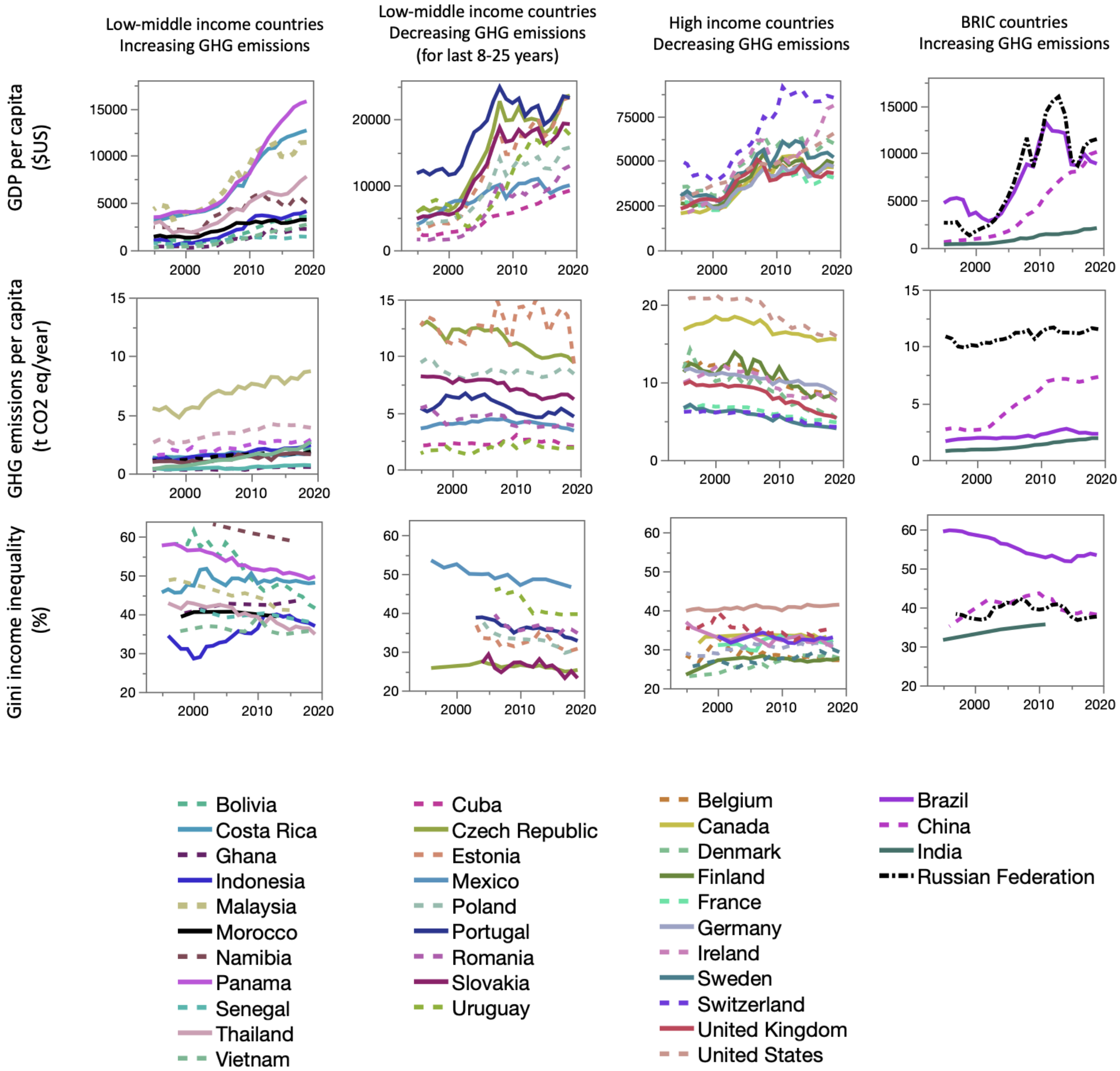

Figure 6. Intraannual trends. Illustration of recent trends in GDP per capita, greenhouse gas emissions per capita, and income inequality for countries representing four groups with different income and emissions trajectories (83, 89). Axes are scaled differently among some panels to maintain sufficient resolution.

Denmark's manufacturing sector cut emissions by 65% between 1990 and 2020 while improving productivity and GDP by 35% (44). Beyond deployment of renewable energy – especially via offshore wind generation – the Danish government supported changes in agriculture and transport, coupled with a carbon tax that led to additional emissions reductions. In the United Kingdom, emissions fell by 38% between 1990 and 2017, while GDP rose by more than 50%. These changes can be attributed to shifts away from coal and towards renewable energy; lower energy consumption by residential, business, and industrial sectors; lower transport emissions due to fewer kilometers driven; and more efficient vehicles (91). In the Czech Republic, emissions reduction of 35% between 1990-2017 - a period during which per capita GDP nearly doubled - resulted from a shift to a market economy, with movement away from heavy industry, reduced dependence on coal, and greater emphasis on nuclear energy (89, 92, 93). Finally, Uruguay's greenhouse gas emissions mirrored GDP between 1990 and 2008. Thereafter, as GDP continued to rise, fossil carbon emissions decreased by ≈20% (83, 94) largely a result of renewable energy development (hydropower, wind, solar, biomass) which accounted for 97% of electricity generation in 2017. Uruguay has mainstreamed climate change policy, established institutions necessary to implement such policies, and engaged its citizens in the process (94), serving as a useful example for other nations across the income and development spectrum. A recent example of addressing climate change and equality while considering important cultural shifts was recently presented in the New York Times in the case of Uruguay https://www.nytimes.com/2022/10/05/magazine/uruguay-renewable-energy.html. In particular, this case study describes how the country has identified and prioritized values and tradeoffs around food (e.g. raising cattle) and consumption as part of a vision of culturally embedded sustainable development. Future emissions reduction in these countries will likely require greater investments in efficiency, a stronger commitment to renewables, and more widespread adoption of equitable and thus politically palatable carbon taxes (46, 47) that tend towards positive justice consequences.

The metrics we have used above are simple, national level annual indicators of emissions, economic well-being, and inequality. Richer empirical analysis that reflects the sophistication of conceptual discussions of climate justice and equity would be contextualized at a finer spatio-temporal resolution with indicators validated by stakeholders affected by climate change threats. (Figs. 2 and 3).   Such indicators and data remain scarce, especially at scale. We therefore use coarse, cross country-comparisons to highlight the potential for simultaneously mitigating emissions, enhancing economic well-being, and reducing injustices. What works in Uruguay or Denmark may not work across Africa or Asia. Pursuing these joint goals, therefore, will likely require a broad range of promising interventions at multiple scales and dimensions.

In the remaining sections we focus on promises and potential pitfalls of interventions within social/health, economic, energy, technology, agricultural/nature-based, and political systems that connect to the framework we propose. These are important to examine critically, as the consequences of a wide variety of climate mitigations may include injustices in many cases (11).

Demographic Dimensions. It is tempting to say that limiting global population and per capita emissions under individual control are key pathways for mitigating climate change. Indeed, in some wealthy country settings when college students are exposed to specific types of climate education through courses tailored to educate on carbon emissions, the students make notable behavioral shifts years after the completion of the course (95). While innovative programs targeting individual behaviors exist, a focus on individual behaviors ignores the inadequacies of individual action in the face of larger systemic drivers and the complexities of social justice and creates a situation ripe for coercive and potentially marginalizing interventions (Fig. 1-5). In fact, noting the unequal burden these recommendations can place on marginalized populations, there is growing debate over the efficacy and morality of controlling either population or consumption, especially of those who are vulnerable (28, 96) - contrasting this against the need to limit the over-consumption of the super-rich, some of whom emit tens to hundreds of thousands of times more emissions than the majority of the world does (46, 47).

While hotly debated, a move away from a focus on population control (including family planning and migration) aimed at low-income countries and marginalized communities, helps to redirect attention towards the complex system-level economic, societal and governance aspects that shape vastly unequal consumption footprints in different parts of the world. Shifting away from a narrow populationist narrative (97, 98), makes way for more diverse and inclusive discussions of climate change, consumption, and equity including considering different dimensions of well-being and reproduction, relations and connections between people and systems, family/kin systems, caregiving practices, and aging (99).

A separate, but related issue at the nexus of demography and climate change is food security. Beyond simply ensuring supply of and access to adequate calories for each person, progressive global food security requires strategies to feed a growing population under a changing climate in culturally relevant and sustainable ways (100, 101). These efforts will take shape in different ways depending on the setting, local food preferences, connectivity, and environmental conditions (among other factors). Forward-looking efforts can and must simultaneously achieve land sparing goals for mitigation without sacrificing food sovereignty or local equity (e.g. (102, 103).

Energy Choices. A rapid and accelerating global energy transition is necessary to mitigate future fossil-fuel emissions and related climate change (17, 104). Macro vs. meso vs. micro-scale renewable energy might have differing positive, neutral or negative impacts on social justice. Examining the equity and justice outcomes of energy transitions across scales and contexts is therefore necessary (104).

Decision-making processes driving energy transitions often exclude communities home to new infrastructure, despite evidence that public participation can secure relevant local knowledge and support for policy (104). This trade-off arises from tensions that challenge the ability to simultaneously achieve both rapid and just low-carbon transitions (105). For example, participatory processes may increase justice but slow the speed of action, sometimes markedly. In contrast, mobilizing businesses, banks, and financiers to invest in low-carbon transitions is accelerated when those actors benefit, which can sustain existing injustices. Renewable energy expansion can also influence biodiversity, indirectly affecting livelihoods and exacerbating poverty (106).

Whether decarbonization of energy systems has positive or negative effects on environmental justice in the near term will vary depending on technology, process, scale and context– as demonstrated by impacts from solar, wind, hydro, and nuclear energy that differ in scope and kind (17, 104, 106–109). Low-carbon energy technologies can produce negative externalities (e.g., wind turbine shadow flicker, pollution from methane generating landfills, 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 (110) and disproportionately impact those who live nearby, who are likely to be rural, less educated and less wealthy (104). Nonetheless, in the long run, inequities associated with low-carbon energy development will be small 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 at every stage on the wealth continuum (6, 50) (Fig. 7a). Moreover, even high cost estimates of major investment in renewable energy pale in comparison to the anticipated costs of damages from unchecked climate change (45), indicating a strong economic logic for such future investments (17, 92, 104).

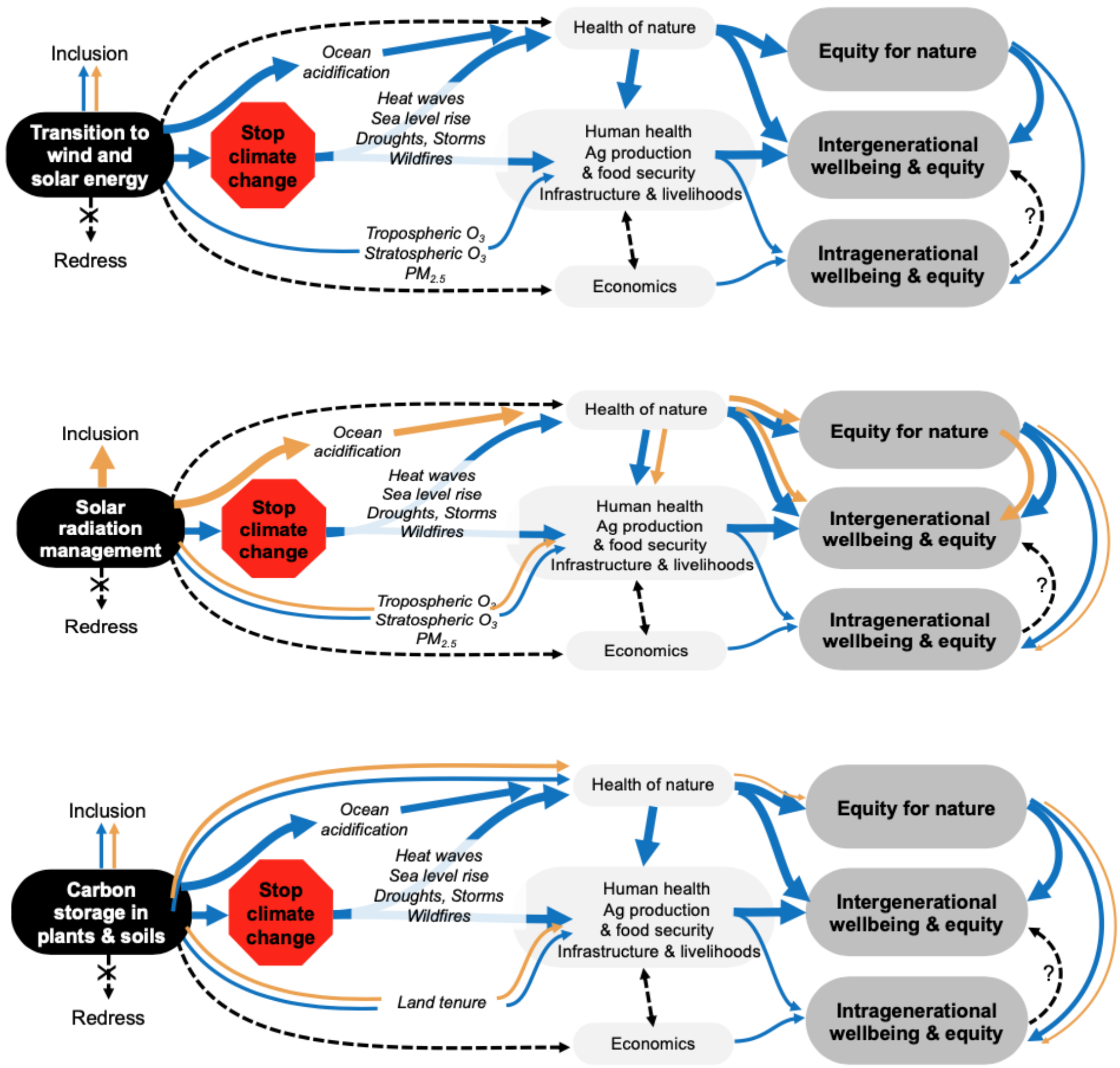

Figure 7. Pathways. Hypothesized pathways by which transition to (A) low-carbon energy sources (e.g. wind, solar), (B) solar radiation management and (C) enhanced carbon storage in plants and soils might influence climate change and other environmental conditions, with consequences for well-being and various aspects of inequity and injustice. These represent a subset of possible pathways. Blue color used for pathways that **reduce** inequity, orange those that **increase** inequity, black dashed lines 'uncertain' or context dependent; line thickness indicates the magnitude of the impacts. Based on the literature cited in the text.

Technology. Technological innovation is broadly viewed as a core requirement for emissions reduction (107, 108). But the justice implications of technological innovation require greater attention than has been the case (111). For example, advances in transportation technology have historically been least available to lower-income and 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 (112). 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 (113). Countries should amplify congestion pricing, compact cities, cycling and electric public transit, while also promoting EVs.

Many strategies for the built environment can reduce inequity, if applied equitably. Programs to insulate homes and buildings, transition to LED lights, and incorporate smart thermostats, especially if targeted to those who can not afford upfront costs of adoption, are low cost strategies with positive impacts for both climate change mitigation and social injustice (114). Replacing traditional biomass or kerosene cooking stoves with clean cookstoves or those fueled by solar or locally-generated biogas mitigates adverse health effects, experienced disproportionately by women and the poor, reduces greenhouse gas emissions (114), and reduces the labor burden of women.

In addition to carbon-neutral energy, transport, building and manufacturing, many technological mitigation solutions have been proposed. Some, such as direct carbon capture and sequestration, remain far from operational at scale and it is difficult to assess potential climate injustice connections (115). The environmental and justice effects of others, such as solar radiation management through stratospheric aerosol injection to block radiation and reduce further warming, are likely profound and complex (116–118)(Fig. 7b). The dampening of climate change from solar radiation management would reduce adverse impacts (e.g. from excess heat, drought, crop loss, etc.) that disproportionately fall on the poor and the powerless; and thus would reduce inequities. Exacerbations of inequities would include increases in excess mortality due to increasing surface-level concentrations of PM2.5 and excessive exposure to UV-B radiation (117). Additionally, stratospheric aerosol injection would do nothing to mitigate ocean acidification, the adverse impacts of which heavily affect poor communities that rely directly on healthy marine and ocean ecosystems. Further, deploying stratospheric atmospheric injection as a unilateral or global strategy would be non-inclusive, and would exacerbate inequities by further concentrating power over climate and environmental quality within a small group of technologically and politically powerful nations (118). Finally, solar radiation management is an egregious 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. silvopastoralism, agroforestry, afforestation, protecting peatlands, restored grasslands, perennial crops, regenerative agriculture, conservation grazing) have been proposed and are being implemented to both reduce emissions and sequester more carbon (2, 119, 120). The proposed ‘solutions’ have both promise and potential pitfalls. Afforestation, a popular strategy for mitigation, requires suitable land, where typically people are already living. Large-scale tree planting campaigns often fail to consider the social and ecological complexities of the landscapes they aim to transform (121) or other adverse climate-related feedbacks (122). Using agricultural land for biofuel production and other climate mitigation policies can exacerbate food price increases, leading to increased food insecurity and malnutrition (123). Some suggest that biomass-based negative emissions via bioenergy with carbon capture and storage may be incompatible with sustainability of freshwater resources and biosphere integrity, with likely negative consequences for social justice (2, 124). The global food system itself needs transformation to meet caloric needs of all people without creating emissions that on their own would result in a 1.5 ℃ warmer world this century (48). 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 (e.g. (125). However, such an optimization of agricultural production at a global scale can lead to unequal outcomes, in terms of biodiversity, food security and sovereignty (126, 127). Impacts on rural people (through land tenure) and nature (e.g. biodiversity) will depend on socially and ecologically appropriate land management and carbon sequestration choices.

Despite concerns (such as raised above) about potential non-alignment with social justice of nature-based climate solutions, some suggest they can mitigate as much as 20-30% of climate-altering emissions (but others disagree, e.g. (122)) while also mitigating climate injustice (Fig. 6c)(119). Many of these strategies include co-benefits for climate adaptation for local communities (2). 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 (2, 119, 121, 128). Similarly, access to agricultural resources (improved varieties, including perennials) and practices of both high and low-tech nature can simultaneously reduce greenhouse gas emissions and enhance soil carbon sequestration through judicious fertilizer use and fire management. Nature-based solutions that engage communities and incorporate procedural and distributional equity in implementation have substantial potential for reducing emissions and injustices, as experience from nation-wide programs in India and Ethiopia demonstrates (129–131). The selection of end-user is critical. For example, industrial scale methane digesters will likely benefit wealthier business owners, whereas on-farm digesters might benefit small-holders. Such approaches can collectively help mitigate climate change while mitigating social injustice if adapted by local farmers (56, 119, 124–126, 132). If these and other strategies are deployed it may be possible to feed 10 billion people while maintaining sustainable ecosystems (119, 124) that contribute decreasingly to greenhouse gas emissions and albedo changes that would warm the planet.

Policy and Governance. In a general sense, policy and governance interventions are at the core of efforts to shift away from business-as-usual trajectories of higher emissions and injustices (Figs 1-5). Changes in behavioral patterns, adoption of renewable energy, technological innovations, and natural solutions all require cascading and connected interventions to become feasible and achieve change.

Among means of spurring such change are governance and policy interventions including taxes and cap and trade policies, policy choices over discount rates for multi-temporal initiatives, and international climate agreements. Carbon taxes, renewable energy portfolios, emission trading schemes and efficiency standards are among the available policy instruments for reducing emissions (133) and can have differing impacts on emissions and inequities depending on instrument-specific design choices and time horizons (17, 29). Carbon taxes and cap-and-trade already generate substantial revenues and are considered key mechanisms to meet national and global emissions reduction goals (134–137). Taxation levels, complementarity with other policies, and political and public acceptance are key levers (77, 138, 139). Carbon taxes can have a modest positive effect both on GDP growth and employment (140), but effects of taxes on equity, macro-level growth, and household-level well-being will likely depend on design and enforcement because of their differing effects on factor and commodity prices (141–144). Their equity effects also depend on who pays the majority of the taxes (46) and how and how much of tax revenues are redistributed (136). Carbon taxes can also be designed to be responsive to the ethical principle of universal co-ownership of gifts of nature (145).

The pricing of carbon taxes and valuation of other possible mitigation interventions and policies should logically be linked to the social cost of carbon, estimates of which vary widely. The social cost of carbon is related to the 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 economic damages from climate change range widely; prior estimates correspond to a roughly 3-6% decrease in global GDP for a 3℃ warming (57). In contrast, a report by SwissRe, the world's largest re-insurance company, suggests an enormous 18% reduction in global GDP for a 3℃ warming (45), which as noted above would fall disproportionately on those least responsible for climate change. 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, and are biased in favor of those alive today over future generations. 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 (146–148); although it can be argued that this will be true, and largely only for the wealthy, only in the short run until climate change impacts become much larger. Some claim that when investments to slow climate change compete with investments in other areas a discount rate of ≈5% per year is appropriate (146). Others argue that such a high discount rate only emerges 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 (loss of biodiversity, damaged infrastructure, higher annual rates of catastrophic climate events) and lay higher costs on future generations than those alive today; all represent strong intergenerational inequity (53, 148).

The influence of discount rate on how we today value future impacts provides a useful illustration of its importance. With a 5% discount rate (146) climate change damages in 2071, 2101 and 2121 would have 9%, 2% and <1% as much impact on the social cost of carbon as those from 2021. Under the 3% discount rate used in the 2021 U.S. government estimate of the social cost of carbon, climate damages in 2121 count only 5% as much as those in 2021. Even low discount rates (e.g. 1.4%) (148) mean that future damages count little; discount rates ranging from 1 to 5% for all practical purposes ignore damages experienced beyond this century, which will likely be extreme and perhaps chronically catastrophic. In essence 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 - they will simply be on their own. Recognizing the rights of future generations by choosing very low (<<1%), zero or even negative discount rates to value the social cost of carbon would accelerate climate change mitigation, and enhance climate justice, especially in the more distant future.

Governance among nations is also a lever that can theoretically be used to advance joint mitigation of climate change and associated injustice (149–151). For example, game theory suggests that complex overlapping multiple coalitions and considerations can stabilize and advance a more singular goal (such as mitigating climate change) than attempting a singular policy (149). Thus, the more flexible and complex Paris Climate agreement may represent a useful step towards achieving multiple objectives including mitigation of climate changes and associated injustice. In a related fashion, emissions reductions commitments by nations could be made conditional on the commitments of others (so-called matching commitments), helping ameliorate undesirable aggregate outcomes of sound strategies by nation states that result from the 'tragedy of the commons' (151). Other policy innovations to help nations agree voluntarily to cooperate to jointly mitigate climate change and climate injustice could similarly be developed. Analyses modeling the relationship between economic growth and emissions suggest that more equitable growth, over time, will lead to a reduction in emissions rates (152). Policy and governance, thus, offer a range of tools to jointly mitigate climate change and associated climate injustices (see also see Table S2 for a fuller range of potential interventions). However, we have a very long way 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 net subsidy to fossil fuels for a net total of US$400 billion (86).

Conclusions

Climate change negatively affects social justice. It is also increasingly clear that some actions taken in order to mitigate climate change can exacerbate social injustice – often directly and substantially for local peoples – at the same time as the climate mitigation outcomes of those same actions ameliorate social injustice globally. In such cases we must balance those negative and positive justice consequences that occur at very different scales. Those who unfairly bear the brunt of negative consequences of any specific mitigation action are often agriculturalists, the poor, aboriginal peoples and ethnic minorities, and aging populations that live within the footprint of the climate mitigation activity (43); whereas the alleviation of climate injustice that results from that mitigation action is distributed among peoples all across the planet. Knowing enough about adverse justice impacts of specific climate mitigations on local peoples – and their counterbalancing and broadly distributed positive impacts on justice via climate mitigation – to conclude that on balance a specific policy choice is for the greater good or not will often be a highly imperfect calculus.

However, the fact that some countries have grown their economies and reduced income inequality while reducing fossil fuel emissions demonstrates that improvements in human wellbeing and social justice concurrent with reductions in emissions are feasible at the country level. The example countries show a common shift 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. These changes have been achieved through shifts in the policy environment, with national commitments to both emissions reductions and culturally and socially embedded conversations about climate mitigation and justice (94). These represent examples of a broader set of interventions with demonstrated potential to reduce emissions and enhance justice, that include behavioral changes and cultural shifts, energy transitions and technological innovations, and a range of natural solutions. These examples, and those related to policy and governance, embody a movement away from business-as-usual that must be accelerated, as continuing along business-as-usual trajectories of economic growth, emissions increases, and worsening inequalities is environmentally unsustainable and ethically indefensible. Youth-led climate movements and protests, combined with calls for systemic reform in light of police violence and unequal mortality rates during the COVID-19 pandemic, have also increased the sense of urgency around building justice-focused systems. They also point to the necessity of inspired and dynamic political leadership to address the extraordinary twin challenges of achieving greater climate security and climate justice.

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Supplementary Materials

Table S1. Key equity and justice-related concepts

Goals of equity and justice	Inclusion, equality, and redress (reparation, or restoration) are three common goals of efforts to advance equity and justice.
Inclusion	Inclusion refers to removal of barriers and promotion of access, participation, and engagement in social and decision making processes in different domains (151–153).
Equality	Equality can refer to similarity in treatment, capacity, participation, or distribution of benefits and harms, even as it is evident that these different dimensions of equality are associated with different conceptions of justice (19, 154–156). The Gini Index, focusing on material endowments, is the most common measure of inequality (157, 158).
Redress	Redress and restorative justice are allied approaches that focus on those who have suffered harms. They aim to repair historical harms and wrongs through reparative actions (159, 160).
Means to advance equity and justice	Equity and justice goals can be advanced through recognition of different groups, through their inclusion in decision-making processes, or through allocation of resources and capacities.
Justice in Recognition	Recognition justice refers to the acknowledgment of the existence and presence of specific groups and their members by virtue of their identities and respect for their values, rights, and needs (161–164).

Procedural justice	Procedural justice refers to efforts that support participation for those suffering discrimination in institutional, organizational, and decision making processes (165, 166).
Distributive justice	Approaches to achieve justice through allocation of resources, benefits, harms, or capacities are one of the most common means to advance justice goals, and often emphasize redistribution (167–169)
Equity and justice-related principles	Although rights, need, merit, and contribution are often used as principles of distributive justice (170), they are also relevant for recognition and procedural justice
Rights	Rights are entitlements based in legal, ethical, or sociopolitical foundations as in property or human rights or right to health or food (22). Rights-based approaches encompass diverse justice principles because of the range of entitlements that rights reference
Contribution	Contribution-based justice approaches link allocation, participation, or recognition to the levels of contribution made by groups and households, and are often emphasized when economic and efficiency goals are prized (170).
Merit	Merit (and contribution) based justice stands in some contrast to ideas of equality in consideration (156) as justice, and focuses on allocation of rewards in accordance and proportion to the merit of recipients (171).
Need	Need directs attention to the circumstances of agents and calls for a consideration of these circumstances in determining the justice outcomes of decisions and choices (170).

Note: This table provides summary definitions of how our paper uses key equity and justice concepts. While scholarship on fairness, equity, and justice typically distinguishes among them, they are often used interchangeably in everyday conversations.

Table S2. List of potential interventions, their type (demographic choices, DC; technology, T; natural solutions, NS; and policy and governance, P&G), impact on emissions and social justice and material well-being; and feasibility and constraints. Interventions ordered roughly from high to low emissions relative to the scale of emissions reductions potential.

Intervention	**Type**	**Emissions reduction**	**Equity and justice**	**Material well being**	**Feasibility, challenges, constraints**
Reduced food waste	DC	Improve	Improve	Improve	Limited evidence on large scale shifts, will require major food systems and cultural shifts
Plant-based diets	DC	Improve	Improve	Improve	Limited evidence on large scale shifts, will require major cultural shift

Renewable energy technologies (solar, wind)	T, P&G	Improve	Mixed	Improve	Key for emissions mitigation at scale. Enabling policy and economic incentives needed for rapid change. Community and small holder rights need consideration for climate justice; Incorporate concerns about negative biodiversity impacts.
Carbon taxes	P&G	Improve	Improve, largely indirectly through climate mitigation	Mixed, but largely positive through climate mitigation	Potential for large-scale impacts, but consistency needed across countries; Will require attention to historical emissions and equity across countries for more equitable outcomes.
Energy Efficiency mandates and technologies	P&G	Improve	Mixed	Improve	Strong potential to scale up, providing benefits for both climate mitigation and climate justice

Tropical afforestation, reforestation, restoration, terrestrial biodiversity conservation	NS, DC P&G	Improve	Mixed (can reduce access to pastoralists)	Mixed (can reduce wellbeing by restricting grazing access	Potential to work at scale. Needs implementation in conjunction with secure land rights for communities, and local and indigenous groups for improved wellbeing and equity outcomes.
Public transport and mobility initiatives	T, P&G	Improve	Improve	Improve	Potential to scale quickly and consistently; potential behavioral change obstacles in rich countries
Promote regenerative agriculture on large farms	P&G, DC	Improve	Improve largely indirectly and long-term through climate mitigation	Mixed, but largely positive through climate mitigation	Substantial potential, but will require shifts in loans, subsidies, price supports, and/or carbon payments to accelerate wellbeing and equity outcomes.

Permaculture and small farm agriculture (e.g. multi-cropping, assistance programs)	NS P&G DC	Improve	Improve directly	Improve directly	Local scale positive impacts on climate justice. Will need shifts in global supply chains for substantial mitigation effects at scale
Smart cities	T, P&G	Improve	Mixed	Mixed	Potential for both positive and negative impacts at scale. Needs to be carefully adapted to local social, political, technological context
Social assistance	P&G, DC	Mixed	Improve directly	Improve directly	Substantial evidence on improved wellbeing and equality outcomes across contexts. Greater attention needed on mitigation and adaptation effects.
Agricultural insurance	P&G	Worsen	Improve	Improve	Will enhance ability of farmers to manage longer-term sustainability practices

Timely and local weather information to support planting/harvesting decisions	T	Mixed	Improve, especially by targeting women's needs	Improve	Local scale. Needs to be devised carefully so as not to exclude groups without access to technology.
Biofuels	NS	Improve	Mixed	Mixed	Modest potential for climate mitigation and reducing climate injustice