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Justice considerations in climate research

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Climate change and decarbonization raise complex justice questions that researchers and policymakers must address. The distributions of greenhouse gas emissions rights and mitigation efforts have dominated justice discourses within scenario research, an integrative element of the IPCC. However, the space of justice considerations is much larger. At present, there is no consistent approach to comprehensively incorporate and examine justice considerations. Here we propose a conceptual framework grounded in philosophical theory for this purpose. We apply this framework to climate mitigation scenarios literature as proof of concept, enabling a more holistic and multidimensional investigation of justice. We identify areas of future research, including new metrics of service provisioning essential for human well-being.

The urgently required changes in human activity to tackle climate change and stay below 1.5 °C come with many justice implications[1]. This has led to vivid public and scientific debates on the design of just transitions[2–4], differentiated impacts and responsibilities[5,6].

Different terms and indicators are used in the climate discourse to reflect diverse interpretations of justice. 'Justice', 'equity' and 'fairness' are often used interchangeably even though they pertain to different conceptual levels[7]. This leads to a lack of clarity, consistency and comparability. The absence of a broad shared understanding of justice makes communication among researchers and between researchers and users of research challenging[8,9], and can result in misinterpretation and misunderstandings between researchers and users, who might focus on different challenges and scales[10].

To help researchers and policymakers navigate the justice landscape, we introduce a justice framework that clarifies key concepts and terminology grounded in philosophical theory. The novelty does not predominantly consist in the philosophical structure, but in the cross-disciplinary translation, the clarity of exposition and ease of application. We aim to bridge disciplinary boundaries, introduce shared terminology and raise awareness of justice considerations that have not gained sufficient attention thus far.

As a proof of concept, we apply the framework to mitigation scenario research that has informed and influenced global climate policymaking and target-setting[11]. Scenarios are an integrative element across all working groups of the IPCC research domains and a way to explore plausible futures. This is a vital and influential literature to which we apply our justice framework. We explore the extent to which existing literature captures key concepts and has contributed insights on diverse justice considerations. Implicit and explicit justice considerations underpinning mitigation scenarios call for such a framework[12]. Justice is a moral issue important in and of itself. Furthermore, justice has been recognized as being conducive to more ambitious climate policy and its acceptability[13–16]. It is thus an urgent moral and practical concern for different disciplines working on decarbonization to explicitly consider it.

A justice framework to guide climate research and policy discussions

We propose a conceptual justice framework (Fig. 1 and Table 1) that is rooted in philosophical theory[17,18] for the interface of human well-being and climate change. Its purpose is to help researchers systematically identify which justice considerations are explicitly or implicitly invoked, but it does not aim to evaluate what is just or unjust.

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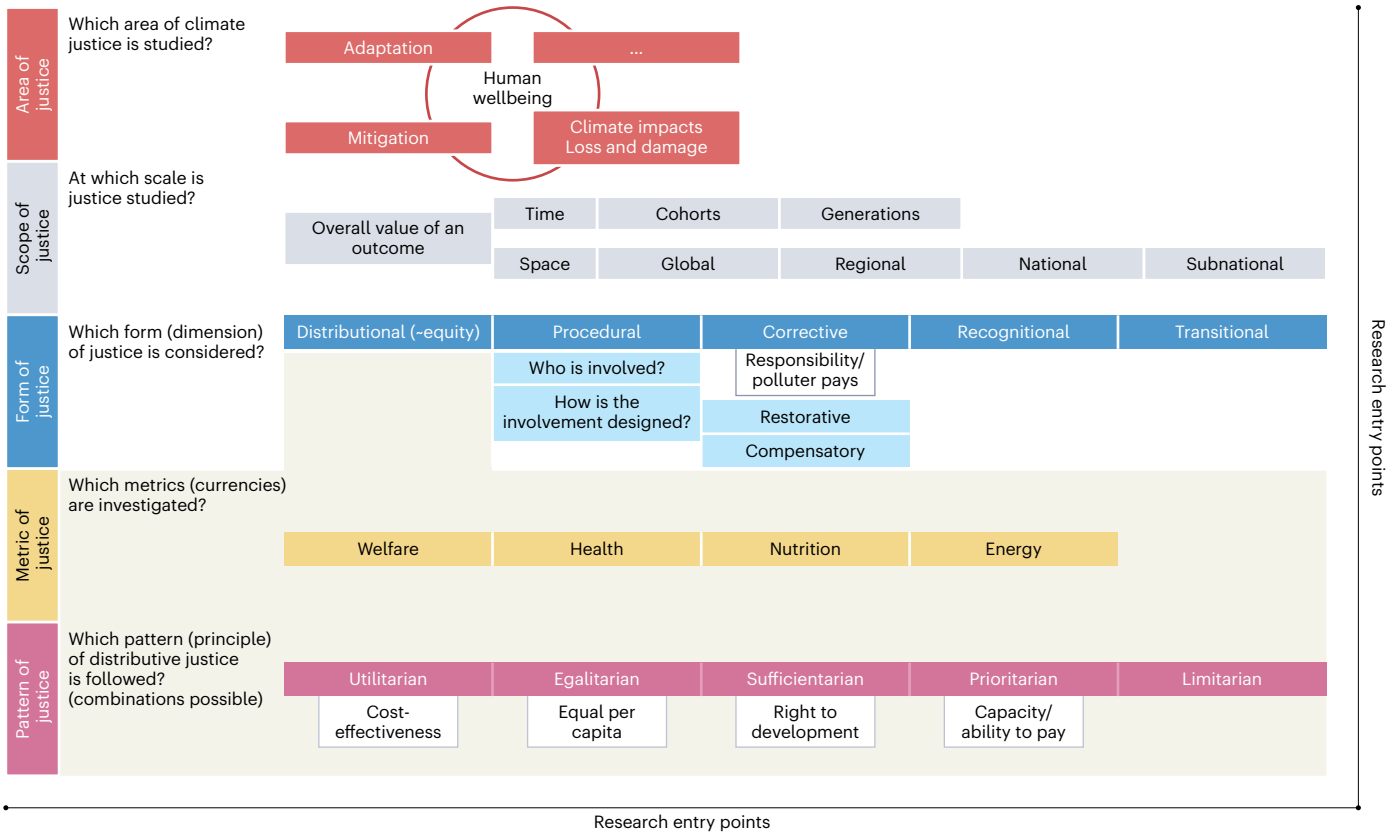

Fig. 1 | A justice framework to guide climate research and policy discussions. The area of climate justice is shown (red), followed by the scope of justice (space and time, grey) and the form of justice (blue), as described in more detail in Table 1. Within distributional justice, different metrics (yellow) and patterns (pink) can be combined for which examples are given. We have added the principles of equity (white) used in IPCC reports by the IPCC[13] to study mitigation effort sharing and remaining emissions quota to illustrate where most of the equity discourse in mitigation scenarios has happened so far. Depending on the research question, the entry point to the framework and focus of the study may differ, and additional elements may be investigated.

When considering how to study climate justice, there are various policy contexts that are worth evaluating. Justice concerns have been highlighted, inter alia, as relevant to actions on climate mitigation, adaptation, and loss and damage. We call such domains of application the areas of justice (similar to what have been called 'faces' 'types' or 'dimensions'[6]). In the climate literature, justice has been invoked to some extent regarding the scope of climate impacts and also the appropriate actors for mitigation, but we believe that explicating climate justice concepts will allow us to move beyond these familiar burden-sharing discussions. The importance of a development space for climate justice has been highlighted by many[19], foremost by scholars from low- and middle-income countries[3].

This framework contains five forms (also called 'dimensions' or 'pillars'[10]) of justice (lower panel Fig. 1): (1) distributional justice, applied to the sharing of scarce resources; (2) procedural justice, regarding who is involved and how decision-making and research are done; (3) corrective justice, involving responses, such as restoration or compensation, where restoration means setting a situation back to status quo and compensation means providing alternative means for achieving ends ('means displacement') or addressing the losses involved in adopting new ends ('ends displacement')[20], to address or ameliorate historical wrongdoing; (4) recognitional justice, responding to the historical or cultural identity of a particular group, with consideration of these differences reflected in choices and policy[21,22]; and we add (5) transitional justice[23,24], used to discuss the dynamics of pathways. We follow Rawls's theory of justice in transitions[17], but note that this is a distinct use of the term from how it is sometimes used in terms of responding to massive social historical harms.

To whom, or how far, our duties of justice extend determines the scope of justice, both temporally and spatially, which is relevant to all forms of justice. Temporally, a key question relates to the time span of investigation (for example, across generations or cohorts) and how welfare should be compared over time. For modelled scenarios, this includes whether or how much the future should be weighted (for example, through discounting). Temporal scope also relates to debates about how sustainability is linked with intergenerational justice[25].

Spatially, the question is how far the commitments of justice extend. A large spatial scope, for instance, would be cosmopolitan (with global scope or where justice applies to all humans); in contrast, a small spatial scope might be domestic or regional. While less commonly integrated into climate decision-making, many utilitarians have argued that the scope of justice should include non-humans[26]. Indeed, this reinforces our general point: climate models tend to make similar justice assumptions and not explore the space of justice options. In fact, the common anthropocentric scope assumption in climate research is actually rejected by the vast majority of utilitarian philosophers. The scope could be widened to all beings capable of suffering (sentientism) or all living beings (biocentrism), instead of just human beings (anthropocentrism).

We begin with distributional justice, which quantitative scenarios are most concerned with. Distributional justice considerations are implicitly invoked across climate policy, but often not explicitly discussed[17,26–28]. To explicate different accounts of distributional justice, we consider their (1) metrics and (2) patterns.

The first key aspect of distributional justice is the metric (or currency) of justice—that is, which goods or services one analyses the

Table 1 | Explanations for forms of justice

Form of justice	Description and context for climate justice
Distributional	How should scarce resources be distributed? Distributive justice is forward-looking, concerned with patterns of distributions of goods (metrics) and how they can be reached from current distributions, but without necessarily reflecting their origins. Metrics can reflect all areas of justice, for example climate impacts or energy use.
Procedural	Is the process fair? Procedures used to make decisions, whether political or scientific, should be fair and accessible, involving relevant stakeholders (for example, vulnerable or impacted groups such as Indigenous peoples or representative citizens) in both decision-making and the scientific processes, while decisions should be informed by an understanding of differentiated implications.
Corrective	How can we address those who have been wronged? Corrective justice responds to historical moral wrongdoing (backward-looking). If no one has been wronged, there is nothing to correct. Corrective responses range from symbolic (for example, apologies) via restorative actions to compensation (such as transfers to undo the effects). Some believe that historical greenhouse gas emissions constitute wrongdoing.
Recognitional	What sensitivities are relevant to climate policy? How and which climate policies are enacted should be sensitive to historical, cultural and regional factors.
Transitional	How should policies be sequenced to make them bring us overall closer to an ideally just state? How to reach an intended endpoint, such as net-zero emissions, is underdetermined. Given a choice, it might be more just to sequence policies in such a way that we continuously get closer to the ideally just society or that later policies build on previous ones. If the process fails, societies are not left in less just outcomes than before, making the transitional process (more) just.

distribution of. The metric is the morally relevant (set of) thing(s), but these might not be directly empirically observable, so indicators are often invoked as (imperfect) proxies. The term 'metric' is used differently across disciplines, sometimes interchangeably with 'indicators'. For instance, utility, welfare or energy services might be morally relevant (metrics), but we may only be able to observe prices or consumption (indicators)[9,29].

We also focus on five influential patterns (also called 'shapes' or 'principles'[30]) of justice that reflect how a metric is distributed: a utilitarian pattern maximizes total welfare, for example by selecting economically optimal pathways with assumptions about consumption's contribution to welfare. Utilitarianism, following the tradition of neoclassical economics, is often the default in climate policymaking and research, a default that is not always recognized or questioned. However, there may be good reasons to question it in this context[31]. The form of utilitarianism implicit in many climate contexts is discounted utilitarianism. While many philosophers reject discounted utilitarianism, there are multiple reasons that it can be defended[32,33]. Furthermore, utilitarianism is not always seen by philosophers as a pattern of justice, but we do here, because it is a distributional shape (also, since most philosophers see prioritarianism as a pattern of justice, it is logical to include utilitarianism as a pattern, as utilitarianism is structurally similar to prioritarianism). Egalitarian patterns strive to minimize differences among people by making sure that everyone receives the same quantity (for example, caloric intake per capita, income or even utility). In a prioritarian pattern, priority is given to those who are worst off. This priority could be absolute or gradual by adding weights to the metric that increase the moral importance of gains to less-well-off individuals[33–35]. Other recent philosophical debates include new patterns. The first is a sufficientarian pattern[36–38] where priority is given to providing some threshold of goods or services to meet some minimum, basic or decent level of human needs—for instance, as indicated by decent living standards[39]. The second is a limitarian pattern[40], where limiting a metric below an upper limit (for example, of consumption) is argued to be morally preferable. Initially justified for income or wealth[40], this pattern could also potentially apply to other metrics of justice. This list of patterns is not exhaustive, nor are they necessarily mutually exclusive, as we will show in our application. All act as potential guidelines for a just distribution, but there is reasonable disagreement about which is morally preferable and why.

Procedural justice relates to the way that policies, research and decision-making are done and who is involved. While the philosophical literature has predominantly focused on procedural justice in terms of governance and policymaking, we extend these ideas to apply to the scientific process to explore how research could become procedurally just. In the context of research, some important ways that this form of justice could apply involve the tools and models scientists select and the ways that their conclusions are communicated—that is, the science–policy and science–public interfaces.

The first question is whether the tools or models used allow us to recognize morally important implications. For instance, representative agent models might be too coarse grained to understand the implications of policies on different socioeconomic classes or sectors, leading to opacity of injustice. In this example, these conclusions have implications for distributional justice; the ways researchers investigate or the tools they select have implications for procedural justice.

The second question is whether the scientific contributions are effectively communicated. For instance, when communicating science to the public, claims will need to be packaged in ways that are accessible; when communicating science to policymakers, the limitations of conclusions will need to be explained, while giving enough information to inform decision-making. This is important for procedural justice because social decisions and understanding ultimately depend on the methods or quality of communication. In both cases, scientists hold a position of trust and that should be reflected in these communication processes. Indeed, these kinds of issue may arise even amongst scientists, especially in interdisciplinary collaboration.

Recognitional justice[22] can occur at many points, but most relevantly here both at the research stage and at the policy implementation stage. At the research stage, recognitional justice relates to whether the research reflects scientists, literature and goals that connect with the contexts and particularities of stakeholder groups. Just as democratic processes ideally reflect the heterogeneity of the public, science should ideally cultivate diversity[41]. There may be epistemic benefits, in the sense that diverse backgrounds can lead people to recognize different issues in research[42]; more directly, there is symbolic value in having more of society feel ownership of or inclusion in the scientific process. At the policy implementation stage, recognitional justice requires that implementation of policies is sensitive to the specifics of those affected. For instance, can policies be communicated or coordinated by locally recognized leaders? Are variations in policy needed to reflect traditional ways of life or geographic needs? These contexts and specifics might be contemporary or historical but should be appropriately recognized and acknowledged.

Transitional justice builds on a thread of the justice literature involving how policies or actions can be sequenced; for example, how unjust policies might be effective ways to promote overall just outcomes[17,24]. Unlike the historically focused use of the term in the literature (where transitional justice denotes ways in which societies can overcome historical trauma or atrocities), we use the term to indicate dynamic questions about approaching ideally just (or 'end-state') goals. For instance, if a policy can be sequenced to take advantage of previous policy, this can be an area where transitional justice can be applied. More theoretically, we might be interested in how quickly a trajectory gets to a (distributively) just outcome or whether that trajectory goes through unjust states to ultimately arrive at a (distributively) just outcome.

The framework is not exhaustive but is flexible and can incorporate many issues of (in)justice. For instance, when some use the term 'social justice', they might be concerned with demographic and socioeconomic characteristics such as age[43], gender[44], race[45] or income or on the intersectional or overlapping nature of (in)justices. These can be considered through appeals to historic wrongs or repression (corrective justice), current vulnerability or limitations on political power (procedural justice) or because a candidate distribution might be objectionable (distributional justice). While discussions of social (in)justice are pervasive in public policy, philosophers use this term less commonly because it is too diffuse. However, once the meanings are disentangled, we believe many uses of the term align with these different forms of justice.

Applying the framework to mitigation scenarios

Applying the justice framework to mitigation scenarios as a proof of concept raises several moral and scientific questions related to the research process[46–48], as well as to details of the applied tools, their design and underlying assumptions[12,30,48–51]. The Representative Concentration Pathway (RCP) and Shared Socioeconomic Pathway (SSP) frameworks[52–54] were designed inter alia to increase comparability across the diverse models used by the scenario community. They permit an integrated analysis of climate change. Several studies have reflected on whether this combined RCP–SSP framework is fit for purpose and assessed the needs for further development[55,56]. While these studies do not explicitly cover several justice considerations, some have called for a move towards more diverse accounts of justice[57]. Since the SSPs have been used in a large number of studies[55,58,59], and notably played a vital role in the Sixth Assessment Report of the IPCC[1], it is fundamental to understand how well they capture the breadth of justice accounts, what they are lacking and how they can be improved for the next generation of scenarios to enable better climate research.

First we scan the SSP narratives to identify which justice considerations they addressed. The narratives underpin the quantification of specific parameters that serve as inputs to the models. Second, to understand the extent to which justice considerations have been addressed, we elucidate which parts of the justice framework the existing mitigation scenario literature has covered and in which ways.

Justice in the narratives of mitigation scenarios

Our framework helps bring attention to justice-relevant considerations embedded in the SSPs. The SSP narratives[60] describe various internally consistent socioeconomic development trajectories using diverse elements (Supplementary Table 1) and how they might relate to different levels of mitigation and adaptation challenges in view of climate change within the twenty-first century. We highlight here the SSP elements that speak most directly to our framework and do not discuss the design and content of individual SSPs for which more detailed narratives and marker quantifications are available[53].

The SSPs followed in the footsteps of the IPCC's *Special Report on Emission Scenarios*[61], which featured different socioeconomic development pathways.

The SSP narratives show that, from early in the SSP development process, justice considerations feature in narrative elements. However, justice is not considered in the SSPs in a systematic and explicit way. Applications based on the SSPs consider justice in different ways and our literature review found that only a limited set of studies have attempted to quantify justice considerations explicitly. Several SSP narrative elements have received less attention[55], such as gender equality, perhaps because such elements went unquantified (see the SSP databases[58,59] and the literature review below). An element being addressed in the SSP narratives does not necessarily mean that (1) the full plausible outcome space is covered in the current set of SSPs; (2) it has (so far) been considered in a scenario study in more detail; or (3) it can be quantified with available tools or data.

The SSP narratives include several elements that match considerations of our justice framework, such as reflections of procedural or recognitional justice (for example, societal participation). The SSP framework and narratives development were also accompanied by an inclusive process, which consisted of several workshops involving the broader research community and users of scenarios, as well as a public review of the narratives and initial quantifications[62].

Distributional justice in economic and human development is the most prominent form of justice in the SSP narratives: 'equity' and 'inequality' are stand-alone SSP elements, where the former is generally not discussed in detail. Economic inequality is an indicator and SSP element that is related to a pattern of justice described in our framework, as describing changes in inequality seems to reflect progress towards or deterioration from an egalitarian pattern. Economic growth and income level are also important SSP elements used by many interpretations as both a proxy for utility and as a modelling variable to derive production and consumption patterns.

For human development, SSP narratives speak to access to services for decent living (that is, food, energy, water, sanitation, education and health). Sufficientarian and limitarian patterns are implicit, for example, with regards to meat consumption. Population trends, including the level of educational attainment[63], are another important input SSP element. In this context, differential investment in education results in diverse population compositions and sizes, which in turn yield different levels of mitigation and adaptation challenges.

Several justice considerations from our framework are not further specified or discussed, leaving room for misinterpretation, or are entirely omitted from the SSP narratives. Corrective justice is not mentioned in the narratives, which was a design choice. Different policy approaches could reflect corrective and transitional justice considerations in ways that are summarized and studied in scenarios in line with different SSP trajectories[64]. The spatial scope of justice in the narrative elements generally remains at the country or regional level. The temporal scope is not addressed explicitly beyond the potential period of investigation, which originally extended to 2100.

We conclude that although the SSP narrative design may have begun by considering justice considerations that our framework covers, subsequent developments and applications have neglected many of these considerations—especially those that remain unquantified. The goal of our framework is to make it easier to tell which of these considerations have been neglected, and how alternative justice assumptions could be adopted.

Existing efforts to include justice considerations in the mitigation scenario literature

Next, to get a sense of how much of the justice landscape has been covered, we dived into the wealth of SSP literature. Our intention was to see which considerations of justice are highlighted and which are neglected, as well as which predominate in the literature. We based our review on the two publicly available SSP literature databases[55,58,59]. These contain around 2,500 articles that detail various SSP applications. They were published between 2014 and 2021 and have been coded using a range of criteria (for example, covered indicators, timelines). SSP1, with rapid improvements in social and economic equity, is used in more than half (>1,300) of the articles. The continuation of current trends of SSP2 (~2,000) is used most (often as a baseline), while SSP3 (~1,200) and SSP5 (~1,300), which depict development of worsening inequality, are used equally often. SSP4 (~650), with its change towards high inequality, is used less frequently. More than 1,400 studies deal with climate impacts and vulnerability[55]. Numerous articles investigate other justice-relevant considerations, such as poverty and living standards (47), the Sustainable Development Goals (67) or health (167).

Around 320 mitigation studies investigate trade-offs and synergies across different regional trajectories for human well-being and tackling climate change. In some of these studies, justice-related assumptions

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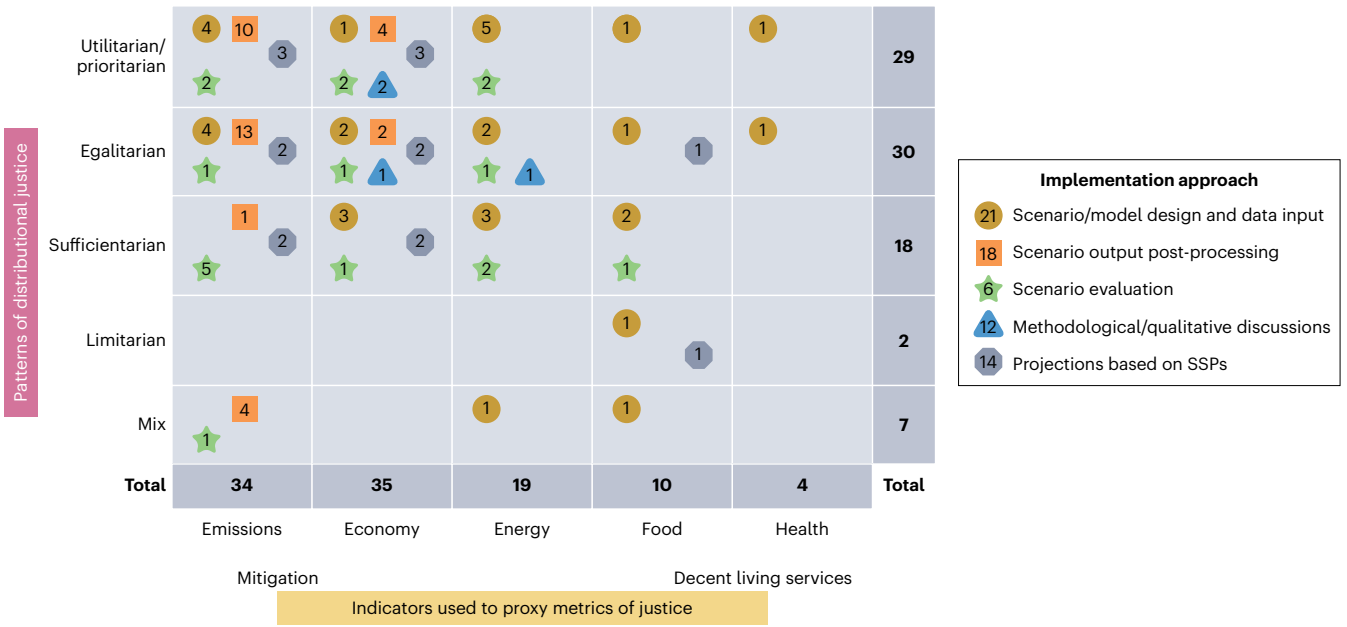

Fig. 2 | Distributional justice patterns, indicators and implementation approaches in the SSP literature. The literature review included articles with explicit justice terms in their titles or abstracts ($N = 77$). The number of unique studies does not match the total, as some studies involved several patterns (for different metrics) and some involved patterns that were not easily defined. See the Supplementary Information for more details.

are implied but not discussed. For instance, a study might adopt a particular SSP/RCP combination that suggests a particular pattern of justice, such as a scenario that uses exogenous inputs with converging gross domestic product per capita, as in SSP1, reflecting the move towards a more egalitarian distribution pattern with low adaptation and mitigation challenges, and RCP2.6 which translates to lower climate impacts. However, many such assumptions are not undertaken from a justice motivation, which is why we focused on studies that explicitly refer to justice in our review.

About one-quarter (77) of the studies explicitly use justice-related terms, which we analysed in detail (Fig. 2, see the Supplementary Information for more details). In response to calls for insights into climate justice, the term justice has been used more recently, whereas the terms distribution, equity and (in)equality have been in use for longer (Supplementary Fig. 2). Studies without an explicit justice focus still retain implicit commitments about justice, be it through the choice of SSPs, model set-up, mitigation objectives or metrics and patterns.

Distributional justice accounts dominated in our review. The predominant indicators are gross domestic product[65,66] or greenhouse gas emissions (rights or mitigation effort), based on different equity principles[12,13,67–69]. Fundamentally important metrics of well-being, such as energy services[70], health or nutrition[71] are explored less often, and only recently and infrequently for multiple indicators together[72,73]. Different patterns of distributional justice have been discussed recently[74,75]. Utilitarian, prioritarian[76,77] and egalitarian[78,79] patterns dominate in the reviewed papers, with utilitarian assumptions often adopted as baselines or without recognition of these normative commitments[80]. Patterns are also mixed[81]; sufficientarian[82,83] and limitarian[84,85] patterns[72] are less well explored, but some recent literature has started to address them[86,87].

The justice-relevant analyses are undertaken at different stages within the scenario modelling process from data input, modelling choices and highlighted model outputs to scenario evaluation and post-processing methods (Supplementary Fig. 2). Clear reporting and reflections on the implications of when in the research design justice is considered are lacking.

Procedural justice through stakeholder engagement occurs especially at regional and local levels[88,89] and for narrative development. Some of the studies coded for procedural justice could also apply for recognitional justice, such as those accounting for Indigenous knowledge[90]. Notions of corrective justice are captured by differentiated investment flows for mitigation based on historical responsibility[91].

This review highlights gaps in research with regards to indicators and patterns of distributional justice. Other forms of justice also provide research opportunities, as would investigating different justice considerations and their roles during the scenario research process.

Expanding the justice space in mitigation scenarios

Our framework provides a systematic guide to engage with different justice considerations and to highlight current gaps in climate change research. We believe that this could help scientists reflect on their work in an ethically coherent way[92]. Philosophers of climate science have increasingly noted the role of values[93]. The first step for any researcher to improve their approach to justice is to realize that research is not free of justice[12,49] and having a framework to understand what justice considerations might be applicable is crucial. Depending on the tools and research processes, different challenges exist as certain justice considerations, such as corrective justice, are more difficult to cover in scenario research than in others.

Using our framework, we identified avenues for future justice-related research to enhance the scenario space (Table 2). These are our suggestions, and other researchers applying the framework might identify others. Awareness and reporting of underlying assumptions, motivations and scenario choices is key. For instance, the utilitarian pattern of total (global) welfare maximization, for example, through minimizing overall mitigation costs (or the assumption that highest utility comes from mitigation where it has the lowest costs[65]), which has dominated previous work, is an example of an implicit assumption that is not commonly recognized by scientists as a substantive pattern of justice[48]. Some integrated assessment models (IAMs) use utility or welfare as the core metric, often proxied by consumption or sometimes even by emissions[75]. Efficiency concerns justify the pursuit of lowest cost, but (independent) distributional concerns might advocate sensitivity to where the costs fall[13]. The models generally do not represent the actors who mobilize the investments, however.

Table 2 | Avenues for future work on justice in mitigation scenarios

Form of justice		Options for expansion	Examples of implementation approaches
Distributional	Utilitarian	• Expand domain coverage • Investigate different patterns and combinations of patterns • For different metrics and indicators at more granular scopes and with different regional configurations • Include in narratives	Expand utility/welfare to include different aspects of human well-being (for example, the application of specific social welfare functions in ref. 107)
	Prioritarian		Different groups being served beyond efficiency considerations
	Egalitarian		Per capita and Gini coefficient (reductions in Gini) of different indicators (beyond gross domestic product and greenhouse gases)
	Sufficientarian		Minimum levels of different indicators
	Limitarian		Caps/upper limits of different indicators
Procedural	Model design	• Transparency about objectives and underlying assumptions • More and broader stakeholder involvement • Greater diversity in research teams	Share underlying assumptions and their potentially different impacts with regard to justice questions
	Scenario development		Discuss regional/national choice and preference for metrics and patterns with stakeholders
	Scenario selection		Share of population living in democratic regimes
Corrective	Restorative	• Include in individual scenario application narrative	Combined with distributional justice (modify patterns considering historical contributions or inclusion of compensatory payments[101])
	Compensatory	• Inclusion of compensatory payments	Adjust patterns and metrics reflecting historical responsibility
Recognitional		• Acknowledgement of issues	Using trusted locals to communicate climate policy or suggest contextually sensitive ways to implement policy or design scenarios[90]
Transitional		• Different policy sequencing options for different metrics and patterns	Introducing initial rebate cheques before fully implementing carbon pricing[108]

A variety of objections to the assumptions and underpinnings of IAMs have been made[12,30,48–51], but exploration of these goes beyond our goals and the scope of this Perspective. Often, due to lack of awareness and structured thinking, critical assumptions with justice implications (for example, discount rate[94]) and descriptions of how narratives and constraints are translated in developing scenarios and their quantifications are not[94] described—or not in sufficient detail—in method sections or supplementary information, let alone discussed in the context of justice[80] There are also surveys of ethical assumptions in IAMs from a moral perspective[95,96]. This is particularly relevant when modelled policies are strongly affected by the assumption of a certain baseline, or when scenarios are compared with each other[97]. A lack of sharing of such information is also relevant in further post-processing studies, which look at different development and distributive outcomes. It is also important to discriminate clearly between model input and output variables and any post-processing work. Open and understandable communication and reflection on these issues can help users of scenarios classify and better understand relevant insights. This can also benefit procedural justice with regards to the science–policy interface.

Distributional analyses can be extended to a broader set of (1) metrics that are reflective of the currently unequal development status of nations and populations, such as indicators of multidimensional deprivation and decent living standards and (2) patterns of justice to study different ways metrics are distributed.

Procedural justice in research contexts can apply to selection of tools and models. For instance, if models are overly aggregated (for example, with representative agent models), it may be hard to detect effects on vulnerable sectors or socioeconomic groups. Thus, smaller units of investigation relating to the number of units or scope of aggregation[48] to include, for example, granular quantifications of national level distributions could be considered. Given that these outcomes might have distributional implications, it is important for procedurally just research to be aware of these dependencies. Furthermore, model set-ups that allow the researcher to detect morally important outcomes may better reflect procedural justice in research practices. While it is difficult to predict the evolution of political and social processes, thinking through how scenarios reflect issues of procedural justice is an important open topic.

For recognitional justice, consideration of stakeholder values and contexts may be relevant in many ways. First, the research design should draw on literature, with attention paid, if possible, to those affected. Relatedly, stakeholder engagement should be extended (following, for example, best practices[88]). As a next step, our framework could be used for engagement with stakeholders to elicit systematic input on which patterns of justice are perceived as fair and why for different metrics and regions. Such processes could contribute to increasing recognitional justice and enhancing scenario space and impact[98]. A variety of speeds, thresholds and pattern configurations can be considered in studies and consultation exercises to understand perceptions of justice from different stakeholders. Stakeholder processes can also be useful in exploring other forms of justice and how they are reflected in scenarios' transitional justice: for example, determining practically feasible policy sequences to be considered in scenario narratives and designs[99]. Another aspect of recognitional justice that has proved challenging relates to diversity in research teams[30,47,48].

Corrective justice can be incorporated in several ways, but one such way is to combine it with distributional justice. How to incorporate historical responsibility is a debated issue[100], with corrective justice approaches assuming historical emitters had both control over and knowledge of the consequences of their emissions. While the extent that historical responsibility is the correct paradigm is contested[20], potentially justifiable ways of addressing responsibility include adjusting carbon budgets considering historical emissions or the inclusion of compensatory payments[101], in combination with stakeholder processes. Corrective justice could also be included in the narratives, given its prominence in climate negotiations. This could inform discussions on sustainable and alternative development concepts[102], including just

transitions[103], the broader climate justice discourse[5,7] and safe and just corridors for humanity[104].

The proposed framework advances interdisciplinary understanding of climate justice and can help prevent justice from being mischaracterized or used to justify delayed mitigation[105]. With justice being both a potential enabler and barrier for decarbonization, more justice-related research is needed for the next IPCC cycle[1]. The SSPs were developed to facilitate model intercomparison. Similarly, our framework aims to contribute to improve (1) clarity, by using terminology shared with justice scholarship, (2) consistency, by looking at justice considerations within a coherent whole and (3) comparability across scenarios and modelling contexts when discussing the same issues.

To systematically do so, we propose a Justice Model Intercomparison Project (JUSTMIP) for mitigation scenarios that builds on our framework and guidance: a JUSTMIP could provide reporting templates for deep dives into different research steps, sectors or comparing models that run the same scenarios to facilitate a comprehensive study of all scenarios and models in the Sixth Assessment Report of the IPCC. This will help create awareness about what can or cannot be done with regards to different justice considerations in scenarios and will increase transparency. Scenarios are one of many approaches in climate research. Several of the justice considerations, especially of more granular nature, can more suitably be tackled with other approaches and policy participation. We thus invite researchers from the diverse disciplines working in this realm[106] to use the proposed framework and deepen collaboration to study justice, engage with stakeholders, reflect on their roles, research and tools, share insights and report on them.

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Competing interests

The authors declare no competing interests.

Additional information

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