Justice considerations in climate research

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Climate change and decarbonization raise complex justice questions researchers and policymakers must address. Distribution of greenhouse gas emissions rights and mitigation efforts have dominated justice discourses within scenario research, an integrative element of the Intergovernmental Panel on Climate Change. However, the space of justice considerations is much larger. Currently, there is not a 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 wellbeing.

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 between 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 so far have not gained sufficient attention.

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 Intergovernmental Panel on Climate Change 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 to what extent 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 (Figure 1) that is rooted in philosophical theory[17,18] for the interface of human wellbeing and climate change. Its purpose is to help researchers systematically identify which justice considerations are explicitly or implicitly invoked but does not aim at evaluating what is just or unjust.

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 & 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 about the scope of climate impacts and also about 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 scholars from low- and middle-income countries[3].

This framework contains five *forms* (also called "dimensions" or "pillars"[10]) of justice (lower panel Figure 1): *Distributional justice*, applied to the sharing of scarce resources; *Procedural justice*, regarding who is involved and how decision-making and research is done; *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;

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 *Transitional justice,*[23,24] used to discuss the dynamics of pathways. We follow Rawls'[17] theory of justice in transitions, 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 (e.g., 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 weighed (e.g., 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 a) metrics and b) patterns.

The first key aspect of distributional justice is the *metric* (or *currency*) of justice, i.e., which goods or services one analyses the 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, e.g. 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 which 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 ways that it can be defended[33,34]. Furthermore, utilitarianism is not always seen by philosophers as a pattern of justice, but we do here, because it is a distributional shape (also it is unmotivated that it is not always seen as a pattern of justice, since most philosophers see prioritarianism as a pattern of justice, and utilitarianism is structurally similar to prioritarianism). *Egalitarian* patterns strive to minimize differences among people by making sure that everyone receives the same quantity (e.g., 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[34–36]. Other recent philosophical debates include new patterns. The first is a *sufficientarian* pattern[37–39] where priority is given to providing some threshold of goods or services in order to meet some minimum, basic, or decent level of human needs, for instance as indicated by decent living standards[40]. The second is a *limitarian* pattern[41], where limiting a metric below an upper limit (e.g., of consumption) is argued to be morally preferable. Initially justified for income or wealth[41], this pattern could also potentially apply to other metrics of justice. This list of patterns is not exhaustive; neither are they necessarily mutually

exclusive as we will show in our application. All act as a potential guideline 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 policy-making, we extend these ideas to apply to the scientific process in order to explore how research could become procedurally just. In the context of research, some important ways that this form of justice could apply involve which tools and models scientists select and the ways that their conclusions are communicated, i.e., 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 socio-economic 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-public, this will require packaging claims in ways that are accessible; when communicating science to policymakers, this will require explaining the limitations of conclusions 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 issues may arise even amongst scientists, especially in interdisciplinary collaboration.

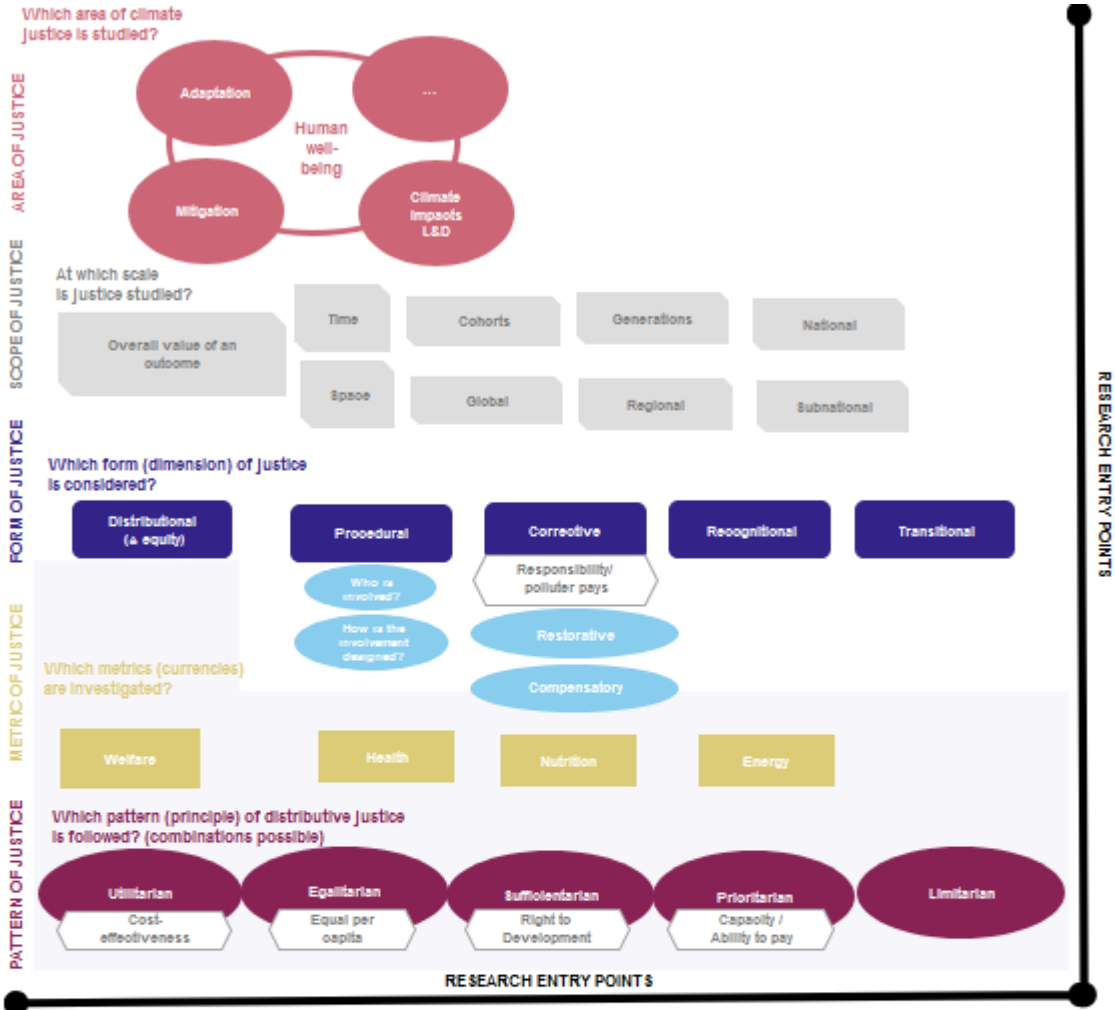
Recognitional justice[22] can occur at many points, but most relevantly here, both at the research stage and at the policy implementation stage. At the research stage, recognitional justice relates to whether the

145 research reflects scientists, literature, and goals that connect with the contexts and particularities of
146 stakeholder groups. Just as democratic processes ideally reflect the heterogeneity of the public, science
147 should ideally cultivate diversity[43]. There may be epistemic benefits, in the sense that diverse backgrounds
148 can lead people to recognize different issues in research[42]; more directly, there is symbolic value in having
149 more of society feel ownership of or inclusion in the scientific process. At the policy implementation stage,
150 recognitional justice requires that implementation of policies is sensitive to the specifics of those affected.
151 For instance, can policies be communicated or coordinated by locally recognized leaders? Are variations
152 in policy needed to reflect traditional ways of life or geographic needs? These contexts and specifics might
153 be contemporary or historical but should be appropriately recognized and acknowledged.

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

162 The framework is not exhaustive but is flexible and can incorporate many issues of (in)justice. For instance,
163 when some use the term "social justice", they might be concerned with demographic and socioeconomic
164 characteristics such as age[44], gender[45], race[46], or income or the intersectional or overlapping nature of
165 (in)justices. These can be considered through appeals to historic wrongs or repression (corrective justice),
166 current vulnerability or limitations on political power (procedural justice), or because a candidate
167 distribution might be objectionable (distributional justice). While discussions of "social (in)justice" are
168 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.



Form of justice	Explanation 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 e.g., 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 (e.g., 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 (e.g., apologies), via restorative actions to compensation (e.g., 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 either sequence policies in such a way that (a) we continuously get closer to the ideally just society or (b) 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.

Figure 1. A justice framework to guide climate research and policy discussions. Area of climate justice (magenta) studied, followed by the scope of justice (space & time, grey) and the form of justice (blue), as described in more detail in the table below (linked by an arrow). Within distributional justice, different metrics (yellow) and patterns (burgundy) can be combined for which examples are given. We have added the principles of equity (white) used in IPCC reports by the Intergovernmental Panel on Climate Change (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.

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[47–49], as well as to details on the applied tools, their design and underlying assumptions[12,30,49–52]. The Representative Concentration Pathway (RCP) and Shared Socioeconomic Pathway (SSP) frameworks[53–55] 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[56,57]. While these studies do not explicitly cover several justice considerations, recent calls do include moving towards more diverse accounts of justice[58]. Since the SSPs have been used in a large number of studies[56,59,60], 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 for 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 that justice considerations have been addressed, we elucidate which parts of the justice framework existing mitigation scenario literature has covered and to what extent.

Justice in Shared Socioeconomic Pathway narratives

Our framework helps bring attention to justice-relevant considerations embedded in the SSPs. The SSP narratives[61] describe various internally consistent socioeconomic development trajectories using diverse elements (see SI Table S1) and how they might relate to different levels of mitigation and adaptation challenges in view of climate change within the 21st century. We highlight here the SSP elements that speak most directly to our framework and are not discussing the design and content of individual SSPs for which more detailed narratives and marker quantifications are available[54].

The SSPs followed in the footsteps of the IPCC's Special Report on Emission Scenarios[62], which featured different socioeconomic development pathways.

The SSP narratives show that, from early in the SSP development process, justice considerations feature in narrative elements. Justice is however not considered in the SSPs in a systematic and explicit way. Applications based on the SSPs consider justice in different ways and only a limited set of studies have attempted to quantify justice considerations explicitly as our literature review below found. Several SSP narrative elements have received less attention[56], such as gender equality, perhaps because they went unquantified (see information SSP databases[59,60] and the literature review below). That an element is addressed in the SSP narratives does not necessarily mean i) that the full plausible outcome space is covered in the current set of SSPs; ii) that it has (so far) been considered in a scenario study in more detail; or iii) that it can be quantified with currently 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 (e.g., "societal participation"). Also, the SSP framework and narratives development were 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[63].

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, since 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 (i.e., food, energy, water, sanitation, education, health). *Sufficientarian* and *limitarian* patterns are implicit, for example, with regards to meat consumption. Population trends, including level of educational attainment[64], are another important input SSP element. In this context, differential investment in education results in diverse population composition and size 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 just being entirely omitted within 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 which are summarized and studied in scenarios in line with different SSP trajectories.[65] The spatial scope of justice in the narrative elements generally

remains at 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 our framework covers, subsequent developments and applications have neglected many of these considerations—especially the considerations which 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 mitigation scenario literature

Next, to get a sense of how much of the justice landscape has been covered, we dive 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 base our review on the two publicly available SSP literature databases[56,59,60]. 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 (e.g., 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[56]. Numerous articles investigate other justice-relevant considerations, such as poverty and living standards (47), SDGs (67), or health (167).

Around 320 mitigation studies investigate trade-offs and synergies across different regional trajectories for human wellbeing and tackling climate change. In some of these studies, justice-related assumptions are implied but not discussed. For instance, a study might adopt a particular SSP/RCP combination which suggests a particular pattern of justice, e.g., a scenario that uses exogenous inputs with converging GDP

per capita such 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 focus on studies that explicitly refer to justice in our review.

About a quarter (77) of the studies explicitly use justice-related terms, which we analyze in detail (Figure 2, details in S2. Literature Review in the SI). In response to calls for insights about climate justice, the term "justice" has been used more recently, whereas the terms "distribution", "equity" and "(in)equality" have been in use for longer (Figure S2 in SI). 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 GDP[66,67] or greenhouse gas emissions (rights or mitigation effort), based on different equity principles[12,13,68–70]. Fundamentally important metrics for wellbeing, such as energy services[71], health or nutrition[72] are explored less often, and only recently and infrequently for multiple indicators together.[73,74]. Different patterns of distributional justice have been discussed recently[75,76]. Utilitarian, prioritarian[77,78] and egalitarian[79,80] patterns dominate in the reviewed papers, with utilitarian assumptions often adopted as baselines or without recognition of these normative commitments[81]. Patterns are also mixed[82]; whereas sufficientarian[83,84] and limitarian[85,86] patterns[73] are less well-explored, but some recent literature has started to address them[87,88].

The justice-relevant analyses are undertaken at different stages within the scenario modeling process from data input, modelling choices and highlighted model outputs, to scenario evaluation and post-processing methods (Figure S2). 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[89,90] 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[91]. Notions of corrective justice are captured by differentiated investment flows for mitigation based on historical responsibility[92].

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

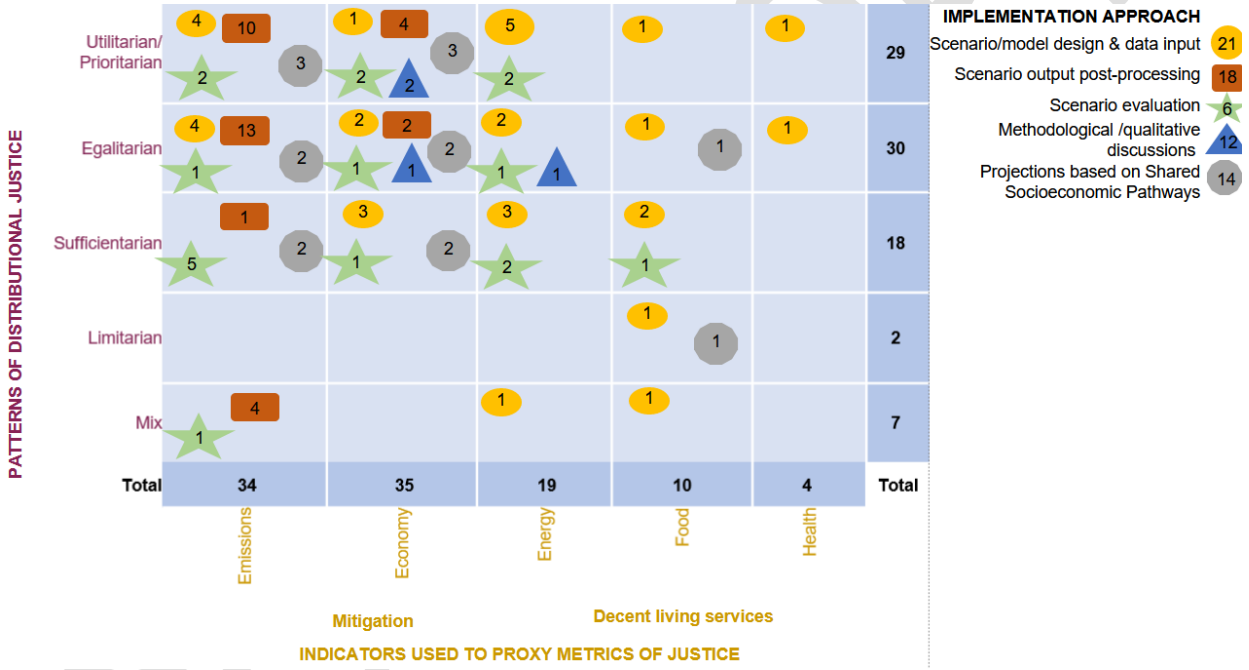


Figure 2. Summary of patterns, indicators, and implementation approaches of distributional justice of the review on articles with justice terms in their title or abstract (N=77). Note: the number of unique studies does not match the total as some studies involved several patterns (for different metrics), and some studies involved patterns that were not easily defined. Details in Supplementary Information.

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 this can help scientists reflect on their work in an ethically coherent way[93]. Philosophers of climate science have increasingly noted the role of values[94]. The first step for any researcher to improve their approach to justice is to realize that research is not free of justice[12,50] and having a framework to understand what justice considerations might be applicable. Depending on the tools and research processes, different challenges exist as certain justice considerations, such as corrective justice, are more difficult to cover, for example, in scenario research than in others.

Based on our framework, we identify avenues for justice-related future research to enhance the scenario space (Table 1). 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, e.g., through minimizing overall mitigation costs [or the assumption that highest utility comes from mitigation where it has the lowest costs[66]], 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[49]. Utility or welfare is the core metric in some IAMs, often proxied by consumption or sometimes even by emissions[76]. 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, though.

A variety of objections to the assumptions and underpinnings of IAMs have been made[12,30,49–52], but exploration of these goes beyond our goals and the scope of this paper. Often, due to lack of awareness and structured thinking, critical assumptions with justice implications (e.g., discount rate[95]) and description of how narratives and constraints are translated in developing scenarios and their

quantifications are not[95]—or not in sufficient detail—described in method sections or supplementary information, let alone discussed in the context of justice[81] There are also surveys of ethical assumptions in IAMs from a moral perspective[96,97]. This is particularly relevant when modeled policies are strongly affected by the assumption of a certain baseline or when scenarios are compared to each other[98]. A lack in sharing 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 (e.g., with representative agent models), it may be hard to detect effects on vulnerable sectors or socio-economic groups. Thus, smaller units of investigation relating to the number of units or scope of aggregation[49] to include, for example, granular quantifications of national level distributions could be considered. Since these outcomes might have distributional implications, it is important for procedurally just research to be aware of these dependencies. Further, 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, e.g., best practices[89]). 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[99]. 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[100]. Another aspect of recognitional justice, which has proved challenging, relates to the diversity in research teams[30,48,49].

Corrective justice can be incorporated in several ways, but one way is to combine it with distributional justice. How to incorporate historical responsibility is a debated issue[101], 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 inclusion of compensatory payments[102], also 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[103], including just transitions[104], the broader climate justice discourse[5,7] and safe and just corridors for humanity[105].

The proposed framework advances interdisciplinary understanding of climate justice and can help prevent justice from being mischaracterized or used to justify delayed mitigation[106]. 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 i) clarity by using terminology shared with justice scholarship, ii) consistency in looking at justice considerations within a coherent whole, and iii) comparability across scenarios and modeling 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 AR6 scenarios and models. 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[107], to use the proposed framework and deepen collaboration to study justice, to engage with stakeholders, to reflect on their roles, research and tools, share insights and report on them.

Table 1. Avenues for future work on justice in mitigation scenarios.

Form of Justice		Options	Exemplary 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 wellbeing (e.g., the application of specific social welfare functions by[108])
	Prioritarian		Different groups being served beyond efficiency considerations
	Egalitarian		Per capita and Gini coefficient (reductions in Ginis) of different indicators (beyond GDP, GHG)
	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 assumption and their potentially different impacts with regards to justice questions
	Scenario development		Discuss regional/national choice and preference for metrics and patterns with stakeholders
	Scenario		Share of population living in democratic regimes

	selection		
Corrective	*Restorative*	• Include in individual scenario application narrative	Combined with distributional justice (modify patterns considering historical contributions or inclusion of compensatory payments (e.g., [102])
	Compensatory	• Inclusion of compensatory payments	Adjust patterns and metrics reflecting historical responsibility
Recognitional		• Acknowledgement of issue	Using trusted locals to communicate climate policy or suggest contextually sensitive ways to implement policy or design scenarios (e.g.,[91])
Transitional		• Different policy sequencing options for different metrics & patterns	Introducing initial rebate cheques before fully implementing carbon pricing (e.g., [109])

383 **Competing interests statement**

384 The authors declare no competing interests.

385 Supplementary Information is available for this paper.

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