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Review

Incorporating energy justice throughout clean-energy R&D[5] in the United States: A review of outcomes and opportunities

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SUMMARY

It is widely acknowledged that a successful clean-energy transition is instrumental to climate change mitigation. However, clean-energy researchers and engineers rarely address the degree to which the success and consequences of the transition depend on its incorporation of equity and justice principles. In this review, we draw on inter-related literatures to discuss failures resulting from equity-myopic approaches to clean-energy research, development, demonstration, deployment, dispatch, and disposal (R&D[5]) and explore opportunities, tools, and frameworks for energy practitioners to employ when attempting to incorporate justice into their work. We find that opportunities to incorporate energy justice are greatest at the earliest stages of the R&D[5] continuum. As inequities persist into later stages of R&D[5], they may lead to maladaptive technology development and the inequitable impacts thereof. We thereby articulate how embedding principles of energy justice throughout R&D[5] not only enables a successful clean-energy transition but also ensures that the transition is sustainable.

INTRODUCTION

In response to the Intergovernmental Panel on Climate Change's clarion calls regarding the pressing impacts of global warming,[1] governments and institutions worldwide have announced historic decarbonization goals, including achieving a carbon pollution-free power sector by 2035 and a net zero emissions economy by 2050.[2,3] To reach these targets, a major transformation of our energy infrastructure, technology, and built environment is required.[4,5] In their Net Zero by 2050 Roadmap, the International Energy Agency (IEA) calls for an unprecedented push for clean technology by 2030, comprising increasing global solar photovoltaic (PV) capacity 20-fold, wind power 11-fold, biogas and hydrogen production each 6-fold, zero-carbon-ready buildings 85-fold, and electric vehicle diffusion 20-fold between 2020 and 2050.[5]

Although each of these technologies has significantly lower life-cycle carbon emissions than incumbent fossil fuel technologies, reduced emissions alone do not make the technologies inherently just nor equitable.[6–8] A rich literature has emerged documenting where the development and deployment of clean-energy technologies have perpetuated existing inequalities or introduced new ones[9] and the ways in which these inequalities have slowed the progress of the clean-energy transition. For example, Baker chronicles how market-based wind farm development in Oaxaca,[10] one of the windiest places in the world, has resulted in conflict and displacement of Indigenous communities. Sunter et al. reveals that racial disparities in rooftop PV adoption persist even after accounting for differences in income and home ownership status,[11] limiting the benefits of this technology to the most advantaged groups. Further literature demonstrates that the disproportionate burdens borne by vulnerable communities are not merely confined to one or two aspects of the energy system, or to only specific technologies, but are present throughout.[12] In other words, burdens and injustices are persistent and systemic. This is not to say the existing fossil fuel-based energy system is equivalent to the future clean-energy system, although there have been attempts to co-opt calls for a just transition to justify continued use of fossil fuels,[13] but rather that systemic injustices have persisted over time. The clean-energy transition provides a unique opportunity to consider reimagining a more equitable and sustainable energy system.[14,15]

This review article terms approaches to clean-energy technologies that do not actively internalize energy equity or justice, such as the aforementioned examples from Baker[10] and Sunter et al.,[11] "equity-myopic approaches." Here, equity-myopic approaches rely on an assertion that purely technological or economic approaches to developing clean-energy technologies and pursuing a clean-energy system are sufficient for achieving

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Box 1.

*Here, "complete" refers to efforts required to achieve net-zero emissions by 2050 outlined by the aforementioned IEA report, which has the goal of limiting global temperature rise to 1.5°C. IEA milestones include (1) "from today, no investment in new fossil fuel supply projects, and no further final investment decisions for new unabated coal plants." (2) By 2035, no sales of new internal combustion engine passenger cars. (3) By 2040, the global electricity sector has already reached net-zero emissions.

** "Sustainable" refers not only to "clean" and "renewable" energy production and usage on a life-cycle basis, but also in a manner that is able to be sustained. As defined by the UN Brundtland Commission in 1987, sustainable development "meets the needs of the present without compromising the ability of future generations to meet their own needs."

a complete* and sustainable** (Box 1) energy transition. Here, we highlight that equity-myopic approaches are insufficient. By passively overlooking equity, equity-myopic approaches do not consider the real, persistent, and systemic biases that limit clean-energy access, affordability, and realization of the full benefits of the energy transition for those in poverty, the marginalized, and communities of color.

This review focuses on the six stages of clean-energy technology research, development, demonstration, deployment, dispatch, and disposal (R&D[5]) requisite for the clean-energy transition. This broad continuum is considered because without identifying and overcoming barriers to incorporation of equity and justice considerations throughout R&D[5], we run the risk of developing and deploying maladaptive technologies that, by definition, inadvertently increase greenhouse gas (GHG) emissions, shift vulnerabilities, diminish welfare, and adversely impact marginalized and vulnerable groups by reinforcing inequities.[16] Manifesting in a similar fashion to Unruh's description of carbon lock-in,[17] maladaptive technologies and equity-myopic approaches lend themselves to "inequity lock-in"—the entrenchment and propagation of inequities in the energy system that must be addressed later on.

In this review, we enumerate the present and tangible ways that equity-myopic approaches to clean-energy technologies have perpetuated inequity lock-in and harms that ultimately limit the transition overall. We then offer opportunities for further embedding equity and justice considerations throughout R&D[5] to enable an accelerated, more sustainable, and more just energy transition. Given that landmark legislative actions in the United States, such as the Inflation Reduction Act,[18] will mobilize over a trillion dollars in the coming decade to enhance climate mitigation and adaptation efforts, the reviewed literature and implications of this article center the US. Although this review primarily focuses on the United States and mostly draws on literature from the Global North, we recognize the global nature of the energy transition and its equity implications, given that our global atmosphere and international supply chains demand the impacts of domestic decisions be evaluated beyond the restrictions of domestic borders.

The literature selected for this article was first identified through keyword searches on Scopus, the Web of Science, and Google Scholar using keywords such as "energy justice," "energy equity," "energy justice impacts," and "technology design," oftentimes in combination. The main challenge with identifying articles to investigate the impacts of integrating justice in early-stage energy research, development, design, and demonstration literature, particularly, was the latent nature of such topics.[19] For example, topics such as "justice" and "impact" or "effect" are polysemous (one word with multiple meanings) and synonymous (different words describe same idea)—making classic keyword searches on their own insufficient to identify literature for our purposes.[19] Therefore, tools such as ConnectedPapers.com and the Bibliometrix package in R were also used in tandem with forward and backward citation methods to aid in identifying relevant articles. Here, selected articles were based on the following criteria: the article either (1) speaks to the outcomes of equity-myopic approaches to clean-energy technology investigation, creation, or implementation or (2) provides resources or frameworks for technical energy researchers, engineers, and practitioners to better embed justice and equity in their work.

The analytic approach and structure of our review reverses the standard technology creation, implementation, and disposal timeline by beginning with the end of a technology's life and working backward toward early-stage research. In this manner, we highlight the equity impacts of prior stages. We find that opportunities to incorporate energy justice are greatest at the earliest stages of R&D[5] while inequities at these early stages lock-in and persist into subsequent phases. Incorporating equity and justice considerations in technological pursuits can have substantial implications on the course of the energy transition that we are just beginning to understand. More research is needed to understand the impacts of equity on both energy technology innovation and its outcomes, especially in different geographical, social, and political contexts.

CONTEXT

Although the literature does not yet offer a single definition of energy equity and energy justice, this article employs the following: energy equity refers to "the fair distribution of (social, economic, and health) benefits and burdens of energy production, distribution, and consumption and fair engagement in this system's decision-making processes."[20] Energy justice goes a step beyond to include retributive and corrective elements.[21] Energy justice is defined as "the goal of achieving equity in both the social and economic participation in the energy system, while also remediating social, economic, and health burdens on those historically harmed by the energy system."[22] Energy justice is often conceptualized as encompassing distributive, procedural, and recognition tenets[23] and touching upon principles such as availability, affordability, sustainability, and inter-/intra-generational equity.[24] The literature's conceptualization of energy justice was built upon the more established fields of environmental and climate justice,[22] none of which exist in isolation.

Given the speed, depth, and breadth required for a successful energy transition,[25] it is especially important for us to better understand the trade-offs and tensions that arise between equity-centered approaches to technology development and historical and existing technical approaches and constraints.

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As decision-makers attempt to juggle a multitude of priorities in the transition to a clean-energy system, considering equity and justice can appear as yet another task capable of ultimately slowing the transition down.[13,26] For instance, Heffron and McCauley highlight the ways in which particular just transition policy initiatives have been used to continue financing and prioritizing the fossil fuel industry.[13] These policy initiatives can act as an excuse to derail the energy transition by investing primarily in carbon-intensive regions. Additionally, Newell et al. discuss tensions policymakers face in pursuit of both a just and rapid low-carbon transition, especially given large, influential incumbent actors in the energy system.[26] These powerful incumbent actors have structural and financial resources to push forth large-scale change, despite potentially entrenching injustices.[26] Such resources have historically not been provided to support more grassroots decarbonization efforts and innovations. Both Heffron and McCauley and Newell et al. highlight the inefficiency of time-intensive, ''for-show'' participatory processes that tend to be ineffective and can act as delay tactics in the face of an urgent climate crisis.[13,26]

With energy justice literature concentrated in the social sciences and focused on later-stage technologies and interventions,[27] members of the technical workforce may be unclear to what degree, how, and when to apply energy justice to their work and if pursuing a just energy transition is, indeed, a responsibility to consider. Given the wealth of literature surrounding the need for equitable energy policymaking, we center our focus on the creation, use, and disposal of clean-energy technologies and the researchers, engineers, and other members of the technical energy workforce who study, create, build, use, and maintain these technologies and the resultant system. Here, we apply a perspective of systems justice[28] to elucidate the role of energy justice in successful clean-energy technology creation and implementation—seeing each energy scientist, engineer, and researcher as an actor in the larger energy system who has the potential to effect positive systemic change in the creation of a more just energy system. The utility of this cross-disciplinary review lies in its articulation of impacts associated with equity-myopic approaches to each stage of technology R&D[5] and its presentation of existing opportunities, tools, and frameworks for energy practitioners to employ for building a more just energy future.

WASTE GENERATION AND DISPOSAL

Research and development strategies do not always consider disposal; however, the development and selection of materials, establishment of manufacturing and recycling processes, and the ultimate disposal of waste products often drive the justice implications of a technology. Siting of waste facilities, lack of inspections,[29] toxicity of manufacturing and disposal processes, and mishandling of waste result in adverse impacts that have historically disproportionately affected low-income communities, communities of color, and immigrant communities.[30–32]

In 1987, Dr. Robert Bullard and the United Church of Christ Commission for Racial Justice published their seminal report exposing that toxic waste landfills were sited primarily in communities of color throughout the nation.[30,31] Their follow-up report in 2007 showed that race continued to be a stronger predictor of hazardous waste siting than income, education, and other socioeconomic indicators.[31] Although there exist policies, governing bodies, and programs dedicated to hazardous waste assessment,[33] cleanup,[34] waste site maintenance,[35] and enforcement of environmental justice laws,[36] research has found evidence that counties with larger populations of Black residents and counties with higher residential instability, higher population densities, and larger populations of foreign-born residents have disproportionately fewer inspections under federal waste handling laws.[29]

A 2020 US Environmental Protection Agency (EPA) report indicated that 21 million people in the US live within 1 mile of a Superfund site—a location contaminated by hazardous waste that has been designated by EPA for management and clean up—and that they are disproportionately minority, living below the poverty level, and linguistically isolated.[32] Further studies show that the presence of a nearby Superfund site is associated with reduced life expectancy, elevated cancer risk, and increased congenital anomalies.[37–39] In 2019, the Government Accountability Office found that 60% of Superfund sites may be impacted by climate change effects including flooding, storm surges, wildfires, and sea level rise, potentially leading to releases of contaminants that could pose even greater risks to the health of the surrounding communities.[40]

Clean-energy technologies and processes are not immune from these issues. For example, some solar panels contain lead and cadmium, which, when present in high enough quantities, can be considered hazardous waste under the EPA's Resource Conservation and Recovery Act (RCRA) at end-of-life disposal.[41] The IEA projects that there will be 10 million metric tons of cumulative PV waste in the US and 78 million metric tons worldwide by 2050. Although this is a small fraction of the waste produced by fossil fuels,[42] it still points to a need for end-of-life management approaches, including regulations, research into methods of materials recovery, and increasing capabilities for reuse and recycling.[43,44] Similarly, a predicted 4 million metric tons of lithium-ion electric vehicle batteries will reach the end of their useful life annually by 2040 in the US.[45] Lithium-ion batteries are often regulated as hazardous waste under RCRA because they contain flammable electrolytes and can exhibit hazardous characteristics of reactivity.

Research into new processes for hard-to-recycle materials, such as thermoset epoxy resins in wind turbines,[46] and early-stage design interventions, such as ''design for recycling,''[47] seek to address the need for more effective reuse and recycling of energy technologies and their associated materials. Consideration of waste and disposal at the earliest stages of research and development can impact material selection, future manufacturing processes, waste handling, and the effects of disposal, all of which impact the energy equity and justice implications of the technology through all phases of R&D[5]. Designing for a circular economy—which includes developing novel, low-emissions materials, creating design architectures to increase recyclability, designing manufacturing processes that reduce materials use, increasing technology lifetimes, and developing end-of-life material recovery strategies[47]—reduces the potential impacts of waste and disposal on low-income communities and

communities of color, while also potentially addressing the supply-chain stress that is anticipated with the unprecedented global scale-up of clean-energy technology deployment.[45,47,48]

DISPATCH

Although dispatch—instructions to generators, transmission facilities, or other electricity market participants to start up, shut down, raise, or lower generation—is a concept most familiar in electricity grid operations, here, it also encompasses how energy systems are operated during their working lifetimes. In between the deployment of technologies in specific locations and their decommissioning and disposal, many energy technologies have lifetimes of 30–100 years (e.g., solar and hydropower, respectively).[49] During these long technical lifetimes, energy systems can be operated in alternate ways that can mitigate or magnify potential harms.[50] Early incorporation of equity and justice principles into dispatch decision-making could lead to different determinations that not only enable more just outcomes but also reduce social and health costs, overall.

Energy planners can include a carbon price in modeling efforts as a first step toward reducing emissions, but equity also requires understanding for whom emissions are reduced.[51] Studies in North America find that adding a carbon price to least-cost capacity expansion and operation modeling induces changes to the optimal technology deployment types, timing, and capacity installed, in addition to dispatch patterns.[52] However, even where models incorporate a price for GHGs, rarely is it comparable to the $185 USD per metric ton CO_2 estimate for the social cost of carbon—the total monetized value of the damages to society caused by an incremental metric ton of CO_2 emissions—recommended by Rennert et al.,[53] or the $120–$340 USD per ton CO_2 estimated by the EPA.[54] Yet, the social cost of carbon itself does not address other air pollutants, such as particulate matter, sulfur oxides, nitrogen oxides, volatile organic compounds, and ozone, which have more direct health impacts on local populations and, because of historical siting decisions, are more likely to negatively impact disadvantaged groups.[55,56] For example, one study found that reducing transportation-related emissions in Los Angeles would disproportionately benefit disadvantaged communities because those communities were located closest to the pollution sources.[57]

Kerl et al. modified the traditional approach to optimal electricity planning and dispatching by incorporating air quality modeling, fluctuating pollutant emissions, and the resultant health impacts that are locationally and temporally specific. They found that incorporating health externalities beyond the global pollutant of CO_2 on a life-cycle basis changes technology choices and dispatching, resulting in a lower overall social cost.[58] The case study primarily replaced coal with gas-powered generation in the state of Georgia. Since their study period, coal-fired electricity generation has dropped precipitously nationwide, and there is increasing interest in retrofitting retired coal infrastructure; however, less-polluting resources, such as biomass and wood combustion, are not exempt from mortality impacts. As of 2018, the projected mortality impacts of particulate matter-related wood and biomass combustion in energy consuming sectors—residential buildings, commercial buildings, industry, and electricity—are higher than the impacts of coal or gas combustion,[59] thereby necessitating the continued inclusion of health equity even in clean electricity dispatch decisions.

Beyond day-to-day operations, decisions on dispatch, load shedding, and selective restoration made during extreme events reveal both disparities and opportunities to further embed equity principles. Recent literature on grid operations during climate emergencies has revealed significant inequities in whose power gets shut off first and whose power is restored last. These patterns have been documented during hurricanes in Puerto Rico,[60] heat waves in California,[61] and winter storms in Texas.[62] The increased number and duration of outages for low-income and minority groups during climate emergencies compound with issues of lower resilience resulting in worse health and economic outcomes, including increased risk of mortality. Integrating equity considerations into dispatch decisions during power shutoffs and restoration can help address this discrepancy by adjusting the location of load shedding and order of restoration to ensure disadvantaged communities do not unduly experience more frequent or longer power disruptions.[63]

Clark et al. present a novel, theoretically grounded, framework to quantify the social burden of infrastructure disruptions.[64] Utilizing a Capabilities Approach theory to human development, their metric focuses on "estimating the burden of post-event adaptations taken by households to maintain their basic capabilities (e.g., ability to access food and water) and fulfill important household functionings (e.g., maintaining health and well-being)." Such a metric allows for clean-energy dispatch decision-makers to internalize not only the social cost of carbon and air pollution, but also differential resource access and vulnerability into their prioritization decisions. Furthermore, studies on hidden energy poverty explore the adaptations taken by lower-income households every day (not only during infrastructure disruptions) to limit their energy consumption to reduce financial stress.[65] Decision-makers can work with communities to understand how these behaviors, along with disparities in other indicators of well-being,[66] may impact dispatch and load shedding decisions. Ensuring more equitable dispatch decision-making and system controls inevitably relies on the existing infrastructure and choices made during technology deployment, particularly choices during siting processes, ultimate siting locations, and the distributional impacts thereof.

DEPLOYMENT

The enormity of the net zero challenge relies on large-scale clean-energy technology deployment, entailing siting and construction of infrastructure and widespread adoption of end-user technologies. For instance, the IEA estimates that 55% of the cumulative emissions reductions in the pathway to net zero by 2050 are linked to consumer choices, such as purchasing an electric vehicle, retrofitting a house with energy-efficient technologies, or installing a heat pump.[5] With 28% (23.1 million) of homes in the US owned and occupied by people of color,[67] and approximately 31% (140 gigawatts [GW]) of rooftop solar potential on residential rooftops owned and occupied by people who earn very low to moderate income,[68] discussion of the

potential role and impact of these groups in technology adoption and the broader energy transition have risen to the forefront.

Often, skepticism about integrating equity considerations into the clean-energy transition focuses on the deployment stage with concerns about whether procedural justice—ensuring that impacted communities play a meaningful role in the decision-making process—will slow the process of deployment. Newell et al. discuss barriers and tensions that arise between rapid, large-scale decarbonization and pursuing procedural justice in the energy transition given existing power and resource structures.[26] First, they highlight a need for greater clarity around "which issues and for whom enhanced citizen engagement works well," given uneven opportunities for citizen engagement and a tendency for privileged, wealthy, and more educated groups to dominate in participatory processes.[26] A lack of meaningful commitments to communities and insincere motives for pursuing citizen consultation also delays progress. Second, Newell et al.[26] discuss how incumbent firms, such as large utilities, banks, construction companies, car manufacturers, and so on, have technical, financial, and organizational resources to deploy technologies more quickly and at larger scales than grassroots innovators. Yet, incumbent firms have historically prioritized wealthier consumers and short-term investments, neglecting opportunities available through pursuing energy justice.

The historic buildout of much of the US current infrastructure, which was funded by significant public investment, occurred with little consideration to community impacts, equity, or justice, leading to continuing systemic disparities that limit the future transition. For instance, Brockway et al. reveal that grid infrastructure limits—resulting from prior grid maintenance and upgrade decisions—exacerbate inequalities in current adoption rates further reducing future access to new solar PV capacity for Black-identifying and disadvantaged census blocks.[69] These infrastructure limits not only cause disparities in access for certain demographic groups, but also hinder the state of California's ability to achieve its electric vehicle adoption and residential load electrification goals necessary for a rapid clean-energy transition.

In addition to the toxic waste landfills mentioned previously,[30,31] many types of noxious power plants and other energy infrastructures were disproportionately sited in communities of color throughout the nation.[70] In many cities, highway construction destroyed communities of color, and in the 1950s and 1960s, thousands of homes disproportionately occupied by Black and Latino families were torn down in the name of "urban renewal" without due process or procedural justice.[71] Such rapid yet unjust deployment processes of the past are not possible under the National Environmental Policy Act (NEPA) and many similar state and local laws[72] that are critical to due process in our democratic society.

Given that local, state, and federal laws require the participation and consideration of potentially impacted environmental justice communities, better incorporation of equity considerations in deployment processes can result in more successful technology implementation. Case studies and analyses of deployment activity outcomes show both aligning with community values—such as trust, justice, equity, and fairness—and addressing community concerns bolster successful implementation.[73–76] For example, meaningfully embedding aspects of procedural justice through community-based consultation and decision-making and enabling opportunities for communities to financially participate in wind turbine deployment has been associated with successful outcomes.[77,78]

On the other hand, mobilizations against clean-energy projects when community concerns are not considered from the outset can hinder transition efforts by delaying deployment, slowing the phase-out of carbon-intensive energy systems, eliciting costly settlements and protests, and causing changes to design and policy at the time of deployment.[79] Boudet reviewed public reactions to new energy technologies, noting the need to understand interconnected roles of technology, people, place, and process.[74] Given increasing likelihood of people and place-based factors playing an outsized role in shaping public perceptions of energy technologies, Boudet highlights that "understanding and adapting technologies and decision-making processes to a particular place and people will become increasingly important for the successful deployment of new energy technologies."[74]

Decisions made upstream of deployment, such as a project's size and visual impact, have also been shown as factors influencing the energy justice outcomes and community opposition to renewable energy technology deployment across the literature.[73,75,80,81] In addition to a technology's form and function, taking dimensions of equity, justice, and fairness that enable successful deployment into account as early as possible in energy technology research, development, demonstration, and design activities provides an opportunity to better consider how to enhance symbiosis between human needs and technology.[82] Enhancing and streamlining compatibility in this manner has the propensity to minimize opposition and the need for late, less impactful, and costly changes[83] in response to said opposition.

DEVELOPMENT AND DEMONSTRATION

The development and demonstration stages of the R&D[5] continuum provide unique opportunities to ground technology design and evaluation in justice considerations and the full diversity of end-user preferences to facilitate successful deployment.[82,84] Here, development encompasses technology design from conceptualization to realization, whereas demonstration is considered design validation in relevant environments to prepare for deployment. Decisions made when designing technologies are immensely important to the outcomes of the technologies. Design decisions at the earliest stages not only determine the ultimate form and function of energy technologies, but they also solidify costs—with an estimated 80% of manufacturing costs determined at the design stage.[85,86] Further, these technical design decisions also establish the values, winners, and losers associated with those technologies.

Given development and demonstration activities solidify the form and function of technologies, it is at these design-intensive stages that the incorporation of values and assumptions in the technology itself is most salient.[87,88] At these stages, the values that drive deployment success, such as equity, fairness, and community altruism, can be considered to allow for more

Box 2.

NSF Broader Impacts are defined as "the potential to benefit society and contribute to the achievement of specific, desired societal outcomes." (https://www.nsf.gov/pubs/policydocs/pappg18_1/pappg_3.jsp#IIIA2b).

streamlined technology implementation. Elucidating values and assumptions that drive design decisions also provides clarity regarding which members of the population are considered in technology development and demonstration.

Understanding these values and assumptions is important to avoid making brittle decisions during development and demonstration that will propagate through subsequent stages of R&D[5]. "Brittle decisions" are defined as those that are "optimal for a particular set of assumptions but that perform poorly, or even disastrously, under other assumptions."[89] An example of brittle decision-making is the forced replacement of traditional Alaska Native homes with poorly insulated, fossil-fuel-dependent Euro-American wood-frame houses, which has created continued energy and food security issues and high energy burdens for Alaska Natives.[90] Methods such as user-centered design, participatory design, and universal design provide ways to avoid making brittle decisions.

User-centered design is an overarching term used to describe design processes in which end-users guide or influence the ultimate product outcomes.[91] Across the literature, user-centered design processes have been used to avoid brittle decision-making that does not consider the diverse array of end-users or their settings. Adequate technology development and design requires accurate understandings, rather than assumptions, of the context in which the technology will be used. For example, user-centered techniques have been used to address failures associated with technological approaches to "improved cookstoves" for developing countries. Prior research focused on technically improving cookstove combustion and fuel efficiency under the assumption that improved efficiency would have both economic and ecological benefits for households, and dissemination of these improved cookstoves was alone sufficient to achieve adoption and sustained use.[92] However, these improved cookstoves repeatedly failed to gain widespread adoption because they did not meet the needs of the primary users who found the cookstoves difficult to install, more time-intensive and cumbersome, and incompatible with locally available cookware.[92,93]

To ensure adoption and sustained use, researchers and engineers have increasingly focused on strategies for clean cookstoves development and dissemination that are tailored to the needs and preferences of end-users. Beyond increased adoption, user-centered techniques have been associated with improved ecological outcomes for clean cookstoves. Gill-Wiehl and Kammen demonstrate that a cookstove strategy that prioritizes the health of end-users (even one that results in the increased use of liquefied petroleum gas [LPG]—a fossil fuel) leads to net reductions in GHG emissions.[94]

Participatory design describes design processes that involve the users as co-designers during technology development.[91] Based on commitments to democracy, empowerment, mutual learning, and skillfulness, participatory design not only affects technological outcomes but may also engender organizational change, new practices, and insights.[95] Participatory methods have been used in energy system modeling and planning to better understand community perspectives, build trust, and ensure more robust research results.[96] These methods have also been used to co-design culturally compatible and sustainable housing with Indigenous communities.[97]

Whereas participatory design methods focus on localized, context-based innovation, universal design creates systems, products, and environments made to be used by all people without a need for customization or specialization.[98] Oftentimes, universal design is employed when making devices more accessible, but it can also be applied to infrastructure as we strive to create disability-inclusive climate resilience strategies.[99] Upstream of early-stage development and design, community-based participatory research has also been associated with enhanced intervention quality and increased community capacity.[100,101] Ultimately, development and demonstration activities are informed by the research that precedes these stages, making the findings, decisions, and recommendations of researchers particularly important for ensuring equitable technology design, manufacturing, and implementation.

RESEARCH

Whether basic or applied, research, which can be considered systematic investigation and early-stage technology conceptualization, provides direction for every other stage of R&D[5]. We cannot assume that today's energy research will inevitably benefit society as a whole many years down the road—especially without better understanding the social, political, economic, and cultural contexts in which research is undertaken and technology is developed.[102,103] The need for equitable energy technology research is beginning to gain traction with discussions of equitable funding opportunities and more inclusive practices and engagement in technology development rising to the forefront.[104] Funders are increasingly recognizing the importance of integrating social science in energy research to understand opportunities and barriers to equitable adoption of clean-energy technologies.[102,104] Funders also play a major role in reconciling the inequitable distribution of benefits in research funding. For example, Woodson et al. analyzed National Science Foundation (NSF) sponsored nanotechnology grants from 2013 to 2017 to identify how the benefits of these projects were distributed. They found that work tended to directly benefit "advantaged" groups.[105] Even when researchers analyzed a larger set of NSF Broader Impacts (Box 2) statements across various research areas, Broader Impacts statements seeking to benefit advantaged groups were more frequently identified than those seeking to benefit marginalized groups.[106]

Moreover, when researchers discuss equity, it is important to consider who is included and excluded from defining what is, indeed, considered "equitable."[107] Values that drive technology development—be they values of those funding the research, those doing the research, or the institutions for which they work—in the energy transition are not inherently neutral.[88,108]

When considering values imbued in clean-energy technology, research informs all other stages of the R&D[5] continuum. From the earliest stages, researchers and funding agencies determine technological possibilities and concepts worth exploring. These values may emerge in overt ways, such as an institution, research group, or engineering team explicitly communicating and incorporating values into the technology they are developing,[109,110] or values could emerge in more covert ways as biases in systems, processes, and technologies.[111]

Friedman and Nissembaum characterized bias in computer systems that can extend to other systems—for our purposes, the energy system.[111] They define biased systems as those "that systematically and unfairly discriminate against certain individuals or groups of individuals in favor of others. A system discriminates unfairly if it denies an opportunity or a good or if it assigns an undesirable outcome to an individual or group of individuals on grounds that are unreasonable or inappropriate."[111] They introduce three types of biases for researchers, engineers, and designers to consider as they are developing technologies: preexisting bias, technical bias, and emergent bias.

Preexisting bias has its roots in social institutions, practices, and attitudes. It exists in the context of the wider society and likely influences the technology designer. The historical exclusion, devaluation, and resulting underrepresentation of minoritized groups and women in the research enterprise despite well-documented benefits of diversification[112,113] can be considered an example of preexisting bias. Technical bias arises from technical constraints or considerations; this bias is inherent to the design of the technology itself. The economic, social, and ecological issues surrounding cobalt in lithium-ion batteries demonstrate impacts of technical bias in research due to early-stage material selection.[114–116] Critical materials needed for batteries (cobalt, lithium, nickel, graphite, and manganese) are finite and mined in only a few regions of the world, which are often in countries with less-stringent environmental and human health regulations[45]—further demonstrating the health consequences of domestic energy decisions on vulnerable communities across the globe. Finally, emergent bias, such as the disproportionate impacts of climate change on low-income populations and communities of color,[117–119] arises in the context of the technology's use.

To manage biases in energy research, and subsequent R&D[5] stages, it is important to acknowledge the existence of these biases and seek to address these technological shortcomings because such actions are fortified when there is support from the larger professional community.[111] Traditional approaches to make research more equitable include attempts to diversify research teams, engage a broader range of stakeholders, promote inclusive policies and practices, and disseminate research findings more widely. Now, there exist more tools and resources to better incorporate ethical concerns, concerns of equity, and concerns of justice into energy research. Options range from pursuing interdisciplinary research from the earliest stages[102] to engaging and co-creating with communities and better orienting equity throughout all stages of energy research and design.[120]

Tools that can facilitate consideration of potential inequities early in the process include: the Justice Underpinning Science and Technology Research (JUST-R) metrics framework,[121,122] green chemistry,[123] and agent-based modeling,[124,125] among others.[126–128] Additionally, more dynamic and inclusive modeling, which may include a range of models, such as climate models, behavioral models, cost projections, along with demographic data,[129] can inform the design of more holistic and robust research and development activities that subsequently affect later stages of R&D[5]. As researchers, scientists, and engineers, taking action to minimize biases and avoid making "brittle decisions" in research design, technology development, and subsequent deployment can enable us to do more equitable and far-reaching work.

GAPS AND FUTURE DIRECTIONS

From this literature review, we recognize that incorporating equity and justice considerations into technological pursuits can have substantial implications on the course of the energy transition that we are just beginning to understand. Here, we see that at earlier stages of the R&D[5] continuum, there were fewer studies on justice considerations in technical work in the energy field, specifically. Although there is increasing focus on energy justice considerations in technical energy research, as exhibited in the article by Ratcliff et al. on soft materials for photoelectrochemical fuel production,[130] an opportunity exists for deeper consideration of justice at these early stages of R&D[5]. Additionally, more research is needed to understand the impacts of equity on both energy technology design and its outcomes, especially at the earlier stages of research, development, and design. In this area, we see several existing knowledge gaps worthy of exploration. The literature can benefit from longitudinal studies on the impacts of equity-informed technology development, providing greater understanding of how equity considerations traverse and influence each stage of R&D[5]. Further, it will be important to evaluate proposed frameworks and practices for integrating energy justice across technology R&D[5] in different geographical, social, and political contexts.

Decision science studies can provide much needed insight into how we view, assess, prioritize, and address risks to frontline communities in transition and mitigation efforts—drawing from both contemporary and historical perspectives. For example, integrating traditional ecological knowledge held in native communities could reframe and reform our approaches to sustainable development, relationships with our environment, and the development of our energy systems.[131,132] Furthermore, greater understanding of how clean-energy innovation can grapple with restorative justice, which aims to repair harm done to individuals, communities, society, and ecosystems,[133] appears to be a major gap in the literature that warrants further study. Energy inequities look different in different parts of the world, resulting from different histories of development, and therefore restorative justice approaches may vary across intra- and international boundaries. Furthermore, as we pursue energy justice in the US, we should be careful not to unintentionally create energy injustices elsewhere. Grappling with the multi-scale, systems-level dimensions of energy justice, especially in the hopes of full domestic decarbonization, remains a challenge worthy of further exploration.

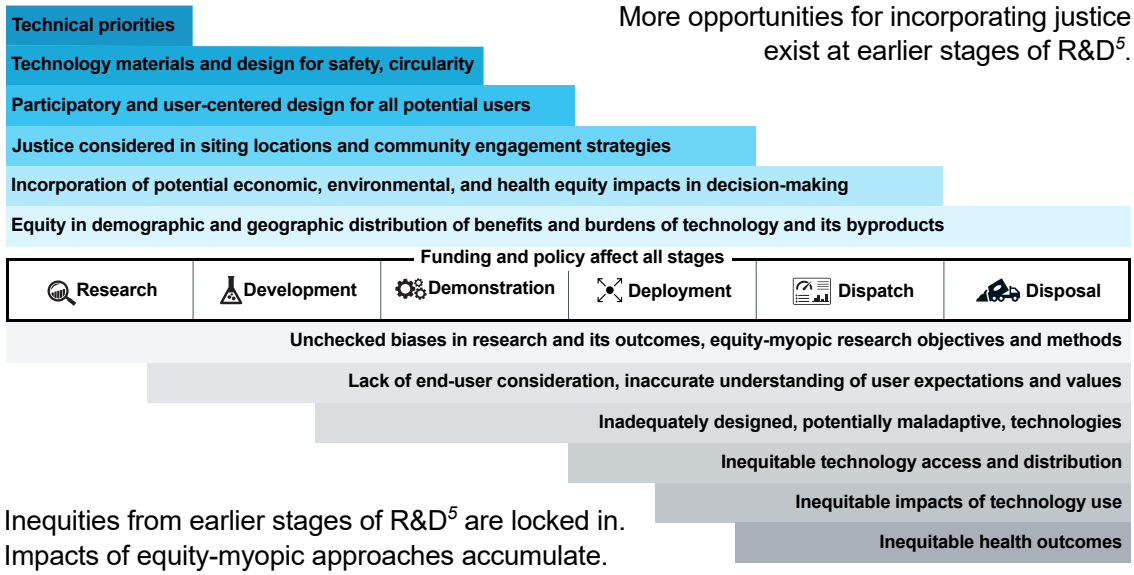

Figure 1. Opportunities to incorporate justice and compounding inequities across R&D[5]

Opportunities (top) available for incorporating energy justice throughout clean-energy R&D[5], which are most numerous at earlier stages, and outcomes (bottom) of equity-myopic approaches that accumulate throughout the R&D[5] continuum. More equitable policymaking and funding opportunities incentivize and shape more equitable technology creation and implementation; therefore, these elements are shown to affect all stages of R&D[5]. Figure informed by literature found in Tables SA.1–SE.2.

CONCLUSIONS

A complete and sustainable clean-energy transition will likely depend not only on equitable energy policymaking but also on the incorporation of energy justice throughout all stages of R&D[5] by the researchers, engineers, and the clean-energy workforce who create, build, use, and maintain energy technologies. Given that energy justice and equity allows us to effectively streamline context-specific,[103] user-centered technology development and deployment, we recognize early and intentional incorporation of equity and justice principles in clean-energy R&D[5] can both engender more just outcomes and push the clean-energy transition forward overall. Particularly in the context of a democratic society, minimizing barriers to both technology acceptance and diffusion by mitigating bias and harms to vulnerable communities propels the clean-energy transition and better ensures we are not prioritizing maladaptive, short-term solutions in our urgent creation of a long-term energy system.[134]

Siloed approaches to adaptation and mitigation strategies are often found to be ineffective, especially if these strategies do not address underlying drivers of vulnerability.[16] As we navigate the tensions and trade-offs inherent to pursuing a broad and deep energy transition,[25] a wider systems-level perspective of equity throughout all stages of R&D[5] can act as a means to relieve anticipated tensions related to the substantial technological, ecological, economic, and social changes expected due to the energy transition. Equity-centric techniques can enable more context-specific technological development and provide a broader view of the potential impacts of our technical decisions. For example, climate resilience development pathways integrate adaptation and mitigation measures to advance sustainable development for all.[16,135] Along with ecological, energy, and societal considerations, a key aspect of climate resilient development is equity. Climate resilient development processes link several sources of knowledge, such as scientific, Indigenous, and local knowledge, to create more locally appropriate, relevant, and sustainable outcomes, which further accelerates and deepens system transitions by overcoming jurisdictional and organizational barriers.[16]

A lack of equity and justice incorporation throughout R&D[5] not only exposes us to the risk of delaying a successful energy transition, but also to the compounding effects of inequity lock-in, which can result in the development and deployment of maladaptive technologies. Beyond their moral and ethical shortcomings, maladaptive clean-energy technologies are inherently less effective as sustainable solutions because they further entrench inequities in the energy system, leading to issues that will eventually require subsequent action in the form of less impactful, more costly late-stage solutions.[16,79,83,134] From this synthesis of inter-related literatures, we see that inequitable outcomes are not necessarily inevitable, and the pursuit of a just energy transition requires deliberate efforts from the earliest stages of technology development. At the earliest stages of the R&D[5] continuum, opportunities to incorporate justice in clean-energy R&D[5] are most plentiful because early-stage outcomes influence subsequent stages (see Figure 1). Yet, at these early stages there is likely more uncertainty about future outcomes,[122] leading to the need for more robust research into the long-term effects of embedding equity at these early stages of energy technology creation.

As large, complex infrastructures that are planned, built, and used over long time frames, many clean-energy systems are

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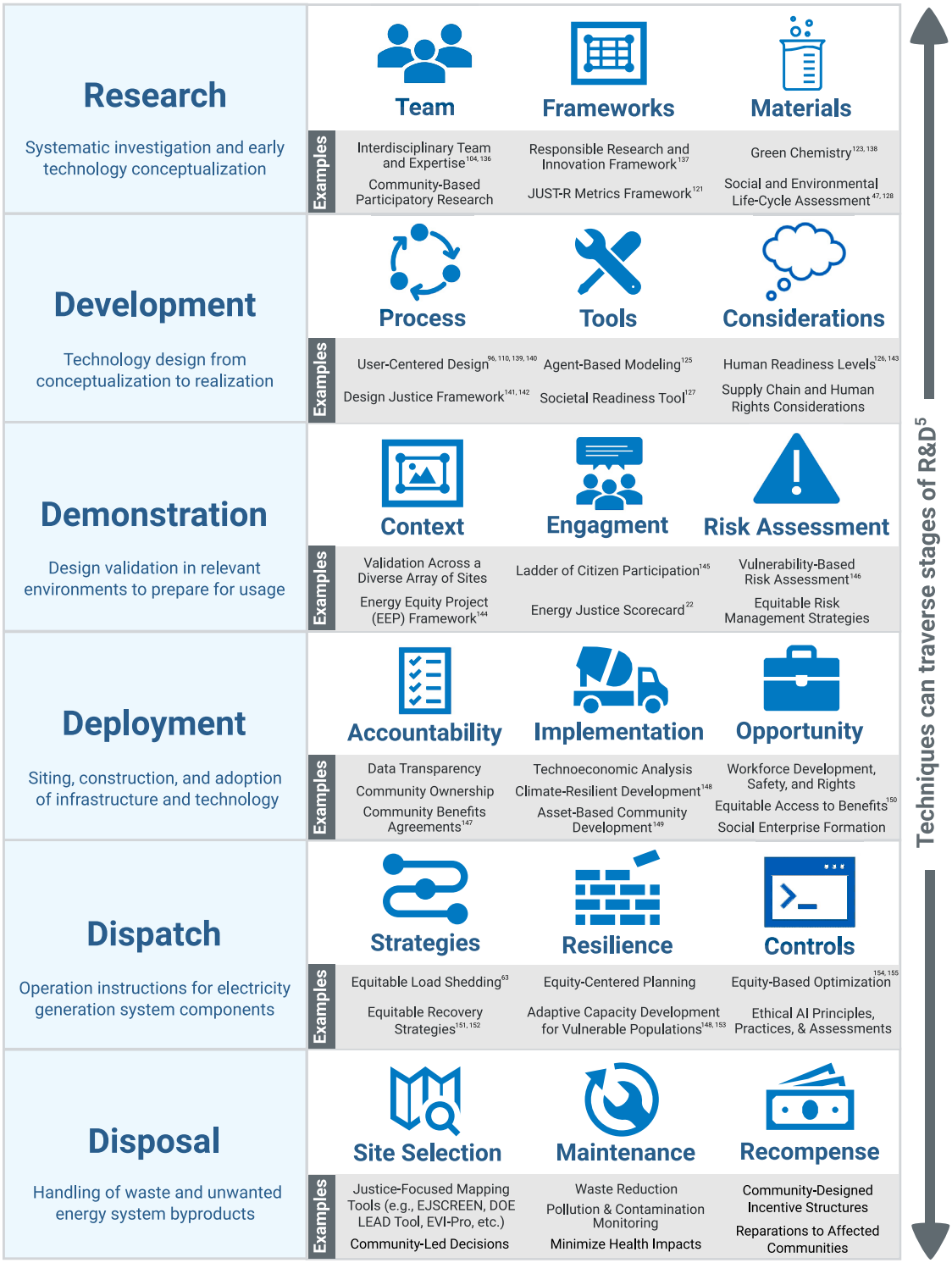

Figure 2. Techniques, tools, and frameworks for incorporating justice in each stage of R&D[5]

Techniques, frameworks, methodologies, and tools that can be applied to incorporate energy justice considerations throughout the R&D[5] continuum. Note these frameworks, techniques, and tools can traverse, and are likely applicable to, many stages of R&D[5]. Community engagement and the centering of frontline communities are particularly important, especially for ensuring a more accurate understanding of the situations these communities face and avoiding brittle decision-making. These elements are either embedded in the techniques displayed here or can be pursued in tandem with them. Example references: Ravikumar

(legend continued on next page)

susceptible to the same failure modes that have led other energy technologies to fall short of their original objectives, take longer than expected, cost more, and cause detrimental harm to the communities they were meant to serve. These failure modalities may be driven by data gaps, community push-back, technology lock-in through path dependencies,[17] brittle decision-making, maladaptation, or poor decision-making under uncertainty. Embedding thoughtful and purposeful consideration of all communities—especially historically vulnerable and marginalized groups and frontline communities—throughout all stages of R&D[5] can aid in mitigating these failure modalities. There is no one framework or method that can be employed to address these failure modalities or to incorporate equity throughout the R&D[5] continuum. Social, economic, technological, and cultural contexts demand a diverse array of tools and perspectives to pursue equitable outcomes. Here, we draw on a number of frameworks and approaches across the literature that can be immediately implemented to integrate equity at various stages of R&D[5], which are summarized in Figure 2 and expounded upon in this paper's supplemental information.

Although the energy transition will be dynamic with myriad unpredictable consequences, if equity and justice remain as important in the future energy system as they have been in the past, we will be well served by more robustly embedding these considerations now before further inequity lock-in. Without incorporating equity, the clean-energy transition is limited. It will be difficult, if not improbable, to achieve a just and sustainable energy transition without a comprehensive embedding of equity principles across all stages of R&D[5]. Researching, designing, developing, and deploying clean-energy technologies with an eye toward justice is a profound reframing of these activities, but such a change in viewpoint better ensures a focus on the transition's ultimate goals from the beginning—a fast, sustainable, and equitable transition to a clean-energy economy for all.

SUPPLEMENTAL INFORMATION

Supplemental information can be found online at https://doi.org/10.1016/j.crsus.2024.100018.

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AUTHOR CONTRIBUTIONS

Conceptualization, B.K.A., W.H., I.F., and K.A.; investigation, B.K.A., W.H., and I.F.; writing – original draft, B.K.A., W.H., and I.F.; writing – review & editing, B.K.A., W.H., I.F., K.F., and K.A.; visualization, B.K.A., W.H., and I.F.; supervision, K.F. and K.A.; project administration, K.A.; funding acquisition, K.A.

DECLARATION OF INTERESTS

The authors declare no competing interests.

REFERENCES

1. Intergovernmental Panel on Climate Change (IPCC) (2022). Summary for Policymakers. In Global Warming of 1.5°C: IPCC Special Report on Impacts of Global Warming of 1.5°C above Pre-industrial Levels in Context of Strengthening Response to Climate Change, Sustainable Development, and Efforts to Eradicate Poverty (Cambridge University Press), pp. 1–24.
2. The White House (2021). FACT SHEET: President Biden Sets 2030 Greenhouse Gas Pollution Reduction Target Aimed at Creating Good-Paying Union Jobs and Securing U.S. Leadership on Clean Energy Technologies (White House). https://www.whitehouse.gov/briefing-room/statements-releases/2021/04/22/fact-sheet-president-biden-sets-2030-greenhouse-gas-pollution-reduction-target-aimed-at-creating-good-paying-union-jobs-and-securing-u-s-leadership-on-clean-energy-technologies/.
3. Guterres, A. (2020). Carbon neutrality by 2050: the world's most urgent mission. United Nations Secretary-General. https://www.un.org/sg/en/content/sg/articles/2020-12-11/carbon-neutrality-2050-the-world%E2%80%99s-most-urgent-mission.
4. Denholm, P., Brown, P., Cole, W., Mai, T., Sergi, B., Brown, M., Jadun, P., Ho, J., Mayernik, J., McMillan, C., et al. (2022). Examining Supply-Side Options to Achieve 100% Clean Electricity by 2035 (National Renewable Energy Lab (NREL)).
5. International Energy Agency (2021). Net Zero by 2050 A Roadmap for the Global Energy Sector (International Energy Agency).
6. Carley, S., and Konisky, D.M. (2020). The justice and equity implications of the clean energy transition. Nat. Energy *5*, 569–577.
7. Banerjee, A., Prehoda, E., Sidortsov, R., and Schelly, C. (2017). Renewable, ethical? Assessing the energy justice potential of renewable electricity. AIMS Energy *5*, 768–797.
8. Sovacool, B.K., Newell, P., Carley, S., and Fanzo, J. (2022). Equity, technological innovation and sustainable behaviour in a low-carbon future. Nat. Hum. Behav. *6*, 326–337.
9. Levenda, A.M., Behrsin, I., and Disano, F. (2021). Renewable energy for whom? A global systematic review of the environmental justice implications of renewable energy technologies. Energy Res. Soc. Sci. *71*, 101837.
10. Baker, S.H. (2018). Emerging Challenges in the Global Energy Transition: A View from the Frontlines. Energy Justice: US and International Perspectives (Raya Salter, Carmen G. Gonzalez, and Elizabeth Ann Kronk Warner eds.), Northeastern University School of Law Research Paper No. 347-2019. https://ssrn.com/abstract=3362473.
11. Sunter, D.A., Castellanos, S., and Kammen, D.M. (2019). Disparities in rooftop photovoltaics deployment in the United States by race and ethnicity. Nat. Sustain. *2*, 71–76.

et al.[104] and Cronin et al.[136]; Stilgoe et al.[137]; Dutta et al.[121]; Lane et al.[123] and Anastas and Eghbali[138]; Norgren et al.[47] and Bozeman et al.[128]; McGookin et al.,[96] Jenkins et al.,[110] Aziz et al.,[139] and van de Poel[140]; Costanza-Chock et al.[141] and Das et al.[142]; Mabey et al.[125]; Bernstein et al.[127]; Salazar et al.[126] and Phillips[143]; Energy Equity Project[144]; Arnstein[145]; Baker et al.[22]; Esmalian et al.[146]; Energy.gov.[147]; Schipper et al.[148]; Mathie and Cunningham[149]; Farley et al.[150]; Kody et al.[63]; Lee et al.[151] and Lin et al.[152]; Schipper et al.[148] and Kim et al.[153]; and Heleno et al.[154] and Syal.[155]

12. Hernández, D. (2015). Sacrifice Along the Energy Continuum: A Call for Energy Justice. Environ. Justice *8*, 151–156.
13. Heffron, R.J., and McCauley, D. (2022). The 'just transition' threat to our Energy and Climate 2030 targets. Energy Policy *165*, 112949.
14. Baker, S.H. (2019). Anti-resilience: a roadmap for transformational justice within the energy system. Harv. C.R.-CLL Rev *54*, 1.
15. Baker, E.D. (2022). A just energy transition requires research at the intersection of policy and technology. PLoS Clim. *1*, e0000084.
16. Pörtner, H.-O., Roberts, D.C., Tignor, M., Poloczanska, E.S., Mintenbeck, K., Alegría, A., Craig, M., Langsdorf, S., Löschke, S., Möller, V., et al. (2022). 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (Cambridge University Press).
17. Unruh, G.C. (2000). Understanding carbon lock-in. Energy Policy *28*, 817–830.
18. Yarmuth, J.A. (2022), H.R.5376 - 117th Congress (2021-2022): Inflation Reduction Act of 2022. https://www.congress.gov/bill/117th-congress/house-bill/5376.
19. de Wildt, T.E., Chappin, E.J.L., van de Kaa, G., and Herder, P.M. (2018). A comprehensive approach to reviewing latent topics addressed by literature across multiple disciplines. Appl. Energy *228*, 2111–2128.
20. Barlow, J., Tapio, R., and Tarekegne, B. (2022). Advancing the state of energy equity metrics. Electr. J. *35*, 107208.
21. Ikeme, J. (2003). Equity, environmental justice and sustainability: incomplete approaches in climate change politics. Glob. Environ. Change *13*, 195–206.
22. Baker, S., DeVar, S., and Parkash, S. (2019). The Energy Justice Workbook (Initiative for Energy Justice).
23. Jenkins, K., McCauley, D., Heffron, R., Stephan, H., and Rehner, R. (2016). Energy justice: A conceptual review. Energy Res. Soc. Sci. *11*, 174–182.
24. Sovacool, B.K., Heffron, R.J., McCauley, D., and Goldthau, A. (2016). Energy decisions reframed as justice and ethical concerns. Nat. Energy *1*, 1–6.
25. Andersen, A.D., Geels, F.W., Coenen, L., Hanson, J., Korsnes, M., Linnerud, K., Makitie, T., Nordholm, A., Ryghaug, M., and Skjolsvold, T. (2023). Faster, broader, and deeper! Suggested directions for research on net-zero transitions. Oxf. Open Energy *2*, oiad007.
26. Newell, P.J., Geels, F.W., and Sovacool, B.K. (2022). Navigating tensions between rapid and just low-carbon transitions. Environ. Res. Lett. *17*, 041006.
27. Jenkins, K.E.H., Sovacool, B.K., Mouter, N., Hacking, N., Burns, M.-K., and McCauley, D. (2021). The methodologies, geographies, and technologies of energy justice: a systematic and comprehensive review. Environ. Res. Lett. *16*, 043009.
28. Ghazavi, V. (2018). Systems Justice. J. Des. Sci. https://doi.org/10.21428/108cfcb9.
29. Spina, F. (2015). Environmental Justice and Patterns of State Inspections. Soc. Sci. Q. *96*, 417–429.
30. Commission for Racial Justice, United Church of Christ (1987). Toxic Wastes and Race in the United States: A National Report on the Racial and Socio-economic Characteristics of Communities with Hazardous Waste Sites. https://www.nrc.gov/docs/ML1310/ML13109A339.pdf.
31. Bullard, R.D., Mohai, P., Saha, R., and Wright, B. (2007). Toxic Wastes and Race at Twenty: 1987–2007 (United Church of Christ).
32. EPA (2020). Population surrounding 1,857 Superfund remedial sites. (EPA Office of Communications, Partnerships, and Analysis). https://outlook.office.com/mail/inbox/id/AAQkADAyNWViYjc3LTI3OGQtNDRjOC04OWU3LTExMjU2Zjg3NzBlZgAQAErw9YWvUtBNqV%2F%2FtjXe5gY%3D?realm=mcgill.ca&path=/mail/search.
33. Luther, L.G. (2011). The National Environmental Policy Act: Background and Implementation (Congressional Research Service).
34. McSlarrow, K.E. (1991). Review of National Oil and Hazardous Substances Pollution Contingency Plan. J. Environ. Law *3*, 172–177.
35. US EPA Office of Land and Emergency Management (2016). Resource Conservation and Recovery Act Timeline. https://www.epa.gov/rcra/resource-conservation-and-recovery-act-timeline.
36. Clinton, W.J. (1994). Summary of Executive Order 12898 - Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations. https://www.epa.gov/laws-regulations/summary-executive-order-12898-federal-actions-address-environmental-justice.
37. Amin, R., Nelson, A., and McDougall, S. (2018). A Spatial Study of the Location of Superfund Sites and Associated Cancer Risk. Stat. Public Policy *5*, 1–9.
38. Kiaghadi, A., Rifai, H.S., and Dawson, C.N. (2021). The presence of Superfund sites as a determinant of life expectancy in the United States. Nat. Commun. *12*, 1947.
39. Currie, J., Greenstone, M., and Moretti, E. (2011). Superfund Cleanups and Infant Health. Am. Econ. Rev. *101*, 435–441.
40. Gómez, J.A. (2021). Superfund EPA: should take additional actions to manage risks from climate change effects, statement of J. Alfredo Gómez, Director, Natural Resources and Environment, Testimony Before the Subcommittee on Environment and Climate Change, Committee on Energy and Commerce, House of Representatives. United States. Government Accountability Office (United States Government Accountability Office).
41. U.S. EPA Office of Land and Emergency Management (2021). End-of-Life Solar Panels: Regulations and Management. https://www.epa.gov/hw/end-life-solar-panels-regulations-and-management.
42. Mirletz, H., Hieslmair, H., Ovaitt, S., Curtis, T.L., and Barnes, T.M. (2023). Unfounded concerns about photovoltaic module toxicity and waste are slowing decarbonization. Nat. Phys. *19*, 1376–1378.
43. Weckend, S., Wade, A., and Heath, G. (2016). End of Life Management: Solar Photovoltaic Panels (International Energy Agency and International Renewable Energy Agency).
44. Heath, G.A., Silverman, T.J., Kempe, M., Deceglie, M., Ravikumar, D., Remo, T., Cui, H., Sinha, P., Libby, C., Shaw, S., et al. (2020). Research and development priorities for silicon photovoltaic module recycling to support a circular economy. Nat. Energy *5*, 502–510.
45. Curtis, T., Smith, L., Buchanan, H., and Heath, G. (2021). A circular economy for lithium-ion batteries used in mobile and stationary energy storage: drivers, barriers, enablers, and U.S. policy considerations. https://doi.org/10.2172/1768315.
46. Ahrens, A., Bonde, A., Sun, H., Wittig, N.K., Hammershøj, H.C.D., Batista, G.M.F., Sommerfeldt, A., Frølich, S., Birkedal, H., and Skrydstrup, T. (2023). Catalytic disconnection of C–O bonds in epoxy resins and composites. Nature *617*, 730–737.
47. Norgren, A., Carpenter, A., and Heath, G. (2020). Design for Recycling Principles Applicable to Selected Clean Energy Technologies: Crystalline-Silicon Photovoltaic Modules, Electric Vehicle Batteries, and Wind Turbine Blades. J. Sustain. Metall. *6*, 761–774.
48. Mirletz, H., Ovaitt, S., Sridhar, S., and Barnes, T.M. (2022). Circular economy priorities for photovoltaics in the energy transition. PLoS One *17*, e0274351.
49. NREL (National Renewable Energy Laboratory) (2022). Annual Technology Baseline. https://atb.nrel.gov/electricity/2022/definitions#technologydetail.
50. Ahmed, I., Rehan, M., Basit, A., and Hong, K.-S. (2022). Greenhouse gases emission reduction for electric power generation sector by efficient dispatching of thermal plants integrated with renewable systems. Sci. Rep. *12*, 12380.
51. Declet-Barreto, J., and Rosenberg, A.A. (2022). Environmental justice and power plant emissions in the Regional Greenhouse Gas Initiative states. PLoS One *17*, e0271026.

52. Nelson, J., Johnston, J., Mileva, A., Fripp, M., Hoffman, I., Petros-Good, A., Blanco, C., and Kammen, D.M. (2012). High-resolution modeling of the western North American power system demonstrates low-cost and low-carbon futures. Energy Policy *43*, 436–447.

53. Rennert, K., Errickson, F., Prest, B.C., Rennels, L., Newell, R.G., Pizer, W., Kingdon, C., Wingenroth, J., Cooke, R., Parthum, B., et al. (2022). Comprehensive evidence implies a higher social cost of CO2. Nature *610*, 687–692.

54. Environmental Protection Agency (2022). Report on the Social Cost of Greenhouse Gases: Estimates Incorporating Recent Scientific Advances (United States Environmental Protection Agency).

55. Tessum, C.W., Paolella, D.A., Chambliss, S.E., Apte, J.S., Hill, J.D., and Marshall, J.D. (2021). PM2. 5 polluters disproportionately and systemically affect people of color in the United States. Sci. Adv. *7*, eabf4491.

56. Hajat, A., Hsia, C., and O'Neill, M.S. (2015). Socioeconomic Disparities and Air Pollution Exposure: a Global Review. Curr. Environ. Health Rep. *2*, 440–450.

57. Ravi, V., Li, Y., Heath, G., Marroquin, I., Day, M., and Walzberg, J. (2023). Chapter 11. Truck Electrification for Improved Air Quality and HealthFINAL REPORT: LA100 Equity Strategies. https://doi.org/10.2172/2221835. https://www.nrel.gov/docs/fy24osti/85958.pdf.

58. Kerl, P.Y., Zhang, W., Moreno-Cruz, J.B., Nenes, A., Realff, M.J., Russell, A.G., Sokol, J., and Thomas, V.M. (2015). New approach for optimal electricity planning and dispatching with hourly time-scale air quality and health considerations. Proc. Natl. Acad. Sci. USA *112*, 10884–10889.

59. Buonocore, J.J., Salimifard, P., Michanowicz, D.R., and Allen, J.G. (2021). A decade of the U.S. energy mix transitioning away from coal: historical reconstruction of the reductions in the public health burden of energy. Environ. Res. Lett. *16*, 054030.

60. Tormos-Aponte, F., García-López, G., and Painter, M.A. (2021). Energy inequality and clientelism in the wake of disasters: From colorblind to affirmative power restoration. Energy Policy *158*, 112550.

61. Ferrall, I. (2022). Quantitative approaches to energy justice: the theory and praxis of examining fair access to reliable electricity Chapter 6 Leaving communities of color in the dark: Rotating outages in California create energy and social injustices (UC Berkeley).

62. Carvallo, J., Hsu, F.C., Shah, Z., and Taneja, J. (2021). Frozen Out in Texas: Blackouts and Inequity. Rockefeller Found. https://www.rockefellerfoundation.org/case-study/frozen-out-in-texas-blackouts-and-inequity/.

63. Kody, A., West, A., and Molzahn, D.K. (2022). Sharing the load: Considering fairness in de-energization scheduling to mitigate wildfire ignition risk using rolling optimization. In 61st Conference on Decision and Control. (CDC) (IEEE Publications), pp. 5705–5712.

64. Clark, S.S., Peterson, S.K.E., Shelly, M.A., and Jeffers, R.F. (2023). Developing an equity-focused metric for quantifying the social burden of infrastructure disruptions. Sustain. Resil. Infrastruct. *8*, 356–369.

65. Cong, S., Nock, D., Qiu, Y.L., and Xing, B. (2022). Unveiling hidden energy poverty using the energy equity gap. Nat. Commun. *13*, 2456.

66. Dargin, J.S., and Mostafavi, A. (2020). Human-centric infrastructure resilience: Uncovering well-being risk disparity due to infrastructure disruptions in disasters. PLoS One *15*, e0234381.

67. U.S. Census Bureau (2021). 2017–2021 American Community Survey 5-Year Subject Tables S2503 and S2502. https://www.census.gov/acs/www/data/data-tables-and-tools/subject-tables/.

68. Sigrin, B.O., and Mooney, M.E. (2018). Rooftop Solar Technical Potential for Low-to-Moderate Income Households in the United States. https://www.nrel.gov/solar/market-research-analysis/assets/pdfs/lmi-potential-webinar-transcript.pdf.

69. Brockway, A.M., Conde, J., and Callaway, D. (2021). Inequitable access to distributed energy resources due to grid infrastructure limits in California. Nat. Energy *6*, 892–903.

70. Cushing, L.J., Li, S., Steiger, B.B., and Casey, J.A. (2023). Historical redlining is associated with fossil fuel power plant siting and present-day inequalities in air pollutant emissions. Nat. Energy *8*, 52–61.

71. Nelson, R.K. and Ayers, E.L. Digital Scholarship Lab Renewing Inequality. https://dsl.richmond.edu/panorama/renewal/#view=0/0/1&viz=cartogram.

72. NEPA. National Environmental Policy Act – States and Local Jurisdictions with NEPA-like Environmental Planning Requirements. https://ceq.doe.gov/laws-regulations/states.html.

73. Roddis, P., Carver, S., Dallimer, M., Norman, P., and Ziv, G. (2018). The role of community acceptance in planning outcomes for onshore wind and solar farms: An energy justice analysis. Appl. Energy *226*, 353–364.

74. Boudet, H.S. (2019). Public perceptions of and responses to new energy technologies. Nat. Energy *4*, 446–455.

75. Sareen, S., and Haarstad, H. (2018). Bridging socio-technical and justice aspects of sustainable energy transitions. Appl. Energy *228*, 624–632.

76. Bidwell, D. (2013). The role of values in public beliefs and attitudes towards commercial wind energy. Energy Policy *58*, 189–199.

77. Mundaca, L., Busch, H., and Schwer, S. (2018). 'Successful' low-carbon energy transitions at the community level? An energy justice perspective. Appl. Energy *218*, 292–303.

78. Ottinger, G., Hargrave, T.J., and Hopson, E. (2014). Procedural justice in wind facility siting: Recommendations for state-led siting processes. Energy Policy *65*, 662–669.

79. Sovacool, B.K., Hess, D.J., Cantoni, R., Lee, D., Claire Brisbois, M., Jakob Walnum, H., Freng Dale, R., Johnsen Rygg, B., Korsnes, M., Goswami, A., et al. (2022). Conflicted transitions: exploring the actors, tactics, and outcomes of social opposition against energy infrastructure. Glob. Environ. Change *73*, 102473.

80. Nordholm, A., and Sareen, S. (2021). Scalar Containment of Energy Justice and Its Democratic Discontents: Solar Power and Energy Poverty Alleviation. Front. Sustain. Cities *3*, 626683.

81. Enserink, M., Van Etteger, R., Van den Brink, A., and Stremke, S. (2022). To support or oppose renewable energy projects? A systematic literature review on the factors influencing landscape design and social acceptance. Energy Res. Soc. Sci. *91*, 102740.

82. Martin, A., Agnoletti, M.-F., and Brangier, E. (2020). Users in the design of Hydrogen Energy Systems: A systematic review. Int. J. Hydrog. Energy *45*, 11889–11900.

83. Paulson, B.C. (1976). Designing to Reduce Construction Costs. J. Constr. Div. *102*, 587–592.

84. Bao, Q., Sinitskaya, E., Gomez, K.J., MacDonald, E.F., and Yang, M.C. (2020). A human-centered design approach to evaluating factors in residential solar PV adoption: A survey of homeowners in California and Massachusetts. Renew. Energy *151*, 503–513.

85. Tan, J.J.Y., Otto, K.N., and Wood, K.L. (2017). Relative impact of early versus late design decisions in systems development. Des. Sci. *3*, e12.

86. Ashuri, T., Zaaijer, M.B., Martins, J.R.R.A., van Bussel, G.J.W., and van Kuik, G.A.M. (2014). Multidisciplinary design optimization of offshore wind turbines for minimum levelized cost of energy. Renew. Energy *68*, 893–905.

87. Manders-Huits, N. (2011). What Values in Design? The Challenge of Incorporating Moral Values into Design. Sci. Eng. Ethics *17*, 271–287.

88. van de Poel, I. (2009). Values in Engineering Design. In Philosophy of Technology and Engineering Sciences Handbook of the Philosophy of Science, A. Meijers, ed. (North-Holland), pp. 973–1006.

89. Hallegatte, S., Rentschler, J., and Rozenberg, J. (2019). Lifelines: the Resilient Infrastructure Opportunity (World Bank Publications).

90. Hossain, Y., Loring, P.A., and Marsik, T. (2016). Defining energy security in the rural North—Historical and contemporary perspectives from Alaska. Energy Res. Soc. Sci. *16*, 89–97.

91. Abras, C., Maloney-Krichmar, D., and Preece, J. (2004). User-centered design. In Encyclopedia of Human-Computer Interaction, W. Bainbridge, ed. (Sage Publications), pp. 445–456.

92. Barnes, D.F., Openshaw, K., Smith, K.R., and van der Plas, R. (1994). What Makes People Cook with Improved Biomass Stoves? A Comparative International Review of Stove Programs (The World Bank).

93. Ruiz-Mercado, I., Masera, O., Zamora, H., and Smith, K.R. (2011). Adoption and sustained use of improved cookstoves. Energy Policy *39*, 7557–7566.

94. Gill-Wiehl, A., and Kammen, D.M. (2022). A pro-health cookstove strategy to advance energy, social and ecological justice. Nat. Energy *7*, 999–1002.

95. Bødker, S., Dindler, C., Iversen, O.S., and Smith, R.C. (2022). What Are the Results of Participatory Design? In Participatory Design Synthesis Lectures on Human-Centered Informatics, S. Bødker, C. Dindler, O.S. Iversen, and R.C. Smith, eds. (Springer International Publishing), pp. 95–102.

96. McGookin, C., Ó Gallachóir, B., and Byrne, E. (2021). Participatory methods in energy system modelling and planning – A review. Renew. Sustain. Energy Rev. *151*, 111504.

97. Edmunds, D.S., Shelby, R., James, A., Steele, L., Baker, M., Perez, Y.V., and TallBear, K. (2013). Tribal Housing, Codesign, and Cultural Sovereignty. Sci. Technol. Hum. Values *38*, 801–828.

98. Steinfeld, E., and Maisel, J. (2012). Universal Design: Creating Inclusive Environments (John Wiley & Sons).

99. Stein, P.J.S., Stein, M.A., Groce, N., and Kett, M. (2023). The role of the scientific community in strengthening disability-inclusive climate resilience. Nat. Clim. Change *13*, 108–109.

100. Viswanathan, M., Ammerman, A., Eng, E., Garlehner, G., Lohr, K.N., Griffith, D., Rhodes, S., Samuel-Hodge, C., Maty, S., and Lux, L. (2004). Community-based participatory research: Assessing the evidence: Summary. Evid. Rep. Technol. Assess., 1–8.

101. Wallerstein, N., Oetzel, J.G., Sanchez-Youngman, S., Boursaw, B., Dickson, E., Kastelic, S., Koegel, P., Lucero, J.E., Magarati, M., Ortiz, K., et al. (2020). Engage for Equity: A Long-Term Study of Community-Based Participatory Research and Community-Engaged Research Practices and Outcomes. Health Educ. Behav. *47*, 380–390.

102. Sovacool, B.K., Ryan, S.E., Stern, P.C., Janda, K., Rochlin, G., Spreng, D., Pasqualetti, M.J., Wilhite, H., and Lutzenhiser, L. (2015). Integrating social science in energy research. Energy Res. Soc. Sci. *6*, 95–99.

103. Fell, M.J., Roelich, K., and Middlemiss, L. (2022). Realist approaches in energy research to support faster and fairer climate action. Nat. Energy *7*, 916–922.

104. Ravikumar, A.P., Baker, E., Bates, A., Nock, D., Venkataraman, D., Johnson, T., Ash, M., Attari, S.Z., Bowie, K., Carley, S., et al. (2023). Enabling an equitable energy transition through inclusive research. Nat. Energy *8*, 1–4.

105. Woodson, T.S., Hoffmann, E., and Boutilier, S. (2021). Evaluating the NSF broader impacts with the Inclusion-Immediacy Criterion: A retrospective analysis of nanotechnology grants. Technovation *101*, 102210.

106. Woodson, T., and Boutilier, S. (2022). Impacts for whom? Assessing inequalities in NSF-funded broader impacts using the Inclusion-Immediacy Criterion. Science and Public Policy *49*, 168–178.

107. Flegal, J.A., and Gupta, A. (2018). Evoking Equity as a Rationale for Solar Geoengineering Research? Scrutinizing emerging expert visions of equity. Int. Environ. Agreem. Polit. J. Law Econ. *18*, 45–61.

108. van de Poel, I., and Taebi, B. (2022). Value Change in Energy Systems. Sci. Technol. Hum. Values *47*, 371–379.

109. Friedman, B., Kahn, P.H., Borning, A., and Huldtgren, A. (2013). Value sensitive design and information systems. In Early Engagement and New Technologies: Opening up the Laboratory (Springer), pp. 55–95.

110. Jenkins, K.E.H., Spruit, S., Milchram, C., Höffken, J., and Taebi, B. (2020). Synthesizing value sensitive design, responsible research and innovation, and energy justice: A conceptual review. Energy Res. Soc. Sci. *69*, 101727.

111. Friedman, B., and Nissenbaum, H. (1996). Bias in Computer Systems. ACM Trans. Inf. Syst. *14*, 330–347.

112. Hofstra, B., Kulkarni, V.V., Munoz-Najar Galvez, S.M.-N., He, B., Jurafsky, D., and McFarland, D.A. (2020). The Diversity–Innovation Paradox in Science. Proc. Natl. Acad. Sci. USA *117*, 9284–9291.

113. Kozlowski, D., Larivière, V., Sugimoto, C.R., and Monroe-White, T. (2022). Intersectional inequalities in science. Proc. Natl. Acad. Sci. USA *119*, e2113067119.

114. Muralidharan, N., Self, E.C., Nanda, J., and Belharouak, I. (2022). Next-Generation Cobalt-Free Cathodes–A Prospective Solution to the Battery Industry's Cobalt Problem. Advan. Energy Mater. *12*, 2103050.

115. Banza Lubaba Nkulu, C., Casas, L., Haufroid, V., De Putter, T., Saenen, N.D., Kayembe-Kitenge, T., Musa Obadia, P., Kyanika Wa Mukoma, D., Lunda Ilunga, J.M., Nawrot, T.S., et al. (2018). Sustainability of artisanal mining of cobalt in DR Congo. Nat. Sustain. *1*, 495–504.

116. Zeng, A., Chen, W., Rasmussen, K.D., Zhu, X., Lundhaug, M., Müller, D.B., Tan, J., Keiding, J.K., Liu, L., Dai, T., et al. (2022). Battery technology and recycling alone will not save the electric mobility transition from future cobalt shortages. Nat. Commun. *13*, 1341.

117. Hsiang, S., Kopp, R., Jina, A., Rising, J., Delgado, M., Mohan, S., Rasmussen, D.J., Muir-Wood, R., Wilson, P., Oppenheimer, M., et al. (2017). Estimating economic damage from climate change in the United States. Science *356*, 1362–1369.

118. Diffenbaugh, N.S., and Burke, M. (2019). Global warming has increased global economic inequality. Proc. Natl. Acad. Sci. USA *116*, 9808–9813.

119. US EPA (2021). Climate Change and Social Vulnerability in the United States: A Focus on Six Impacts (United States Environmental Protection Agency).

120. Dombrowski, L., Harmon, E., and Fox, S. (2016). Social justice-oriented interaction design: Outlining key design strategies and commitments (Proceedings of the 2016 ACM Conference on Designing Interactive Systems), pp. 656–671.

121. Dutta, N.S., Gill, E., Arkhurst, B.K., Hallisey, M., Fu, K., and Anderson, K. (2023). JUST-R metrics for considering energy justice in early-stage energy research. Joule *7*, 431–437.

122. Arkhurst, B.K., Houghteling, C.R., Dutta, N.S., Clarke, A., Fu, K., Anderson, K., and Gill, E. (2023). Evaluating energy justice metrics in early-stage science and technology research using the JUST-R metrics framework. Front. Environ. Sci. *11*.

123. Lane, M.K.M., Rudel, H.E., Wilson, J.A., Erythropel, H.C., Backhaus, A., Gilcher, E.B., Ishii, M., Jean, C.F., Lin, F., Muellers, T.D., et al. (2023). Green chemistry as just chemistry. Nat. Sustain. *6*, 502–512.

124. Syal, S.M., Ding, Y., and MacDonald, E.F. (2020). Agent-Based Modeling of Decisions and Developer Actions in Wind Farm Landowner Contract Acceptance. J. Mech. Des. *142*, 091403.

125. Mabey, C.S., Armstrong, A.G., Mattson, C.A., Salmon, J.L., Hatch, N.W., and Dahlin, E.C. (2021). A computational simulation-based framework for estimating potential product impact during product design. Des. Sci. *7*, e15.

126. Salazar, G., See, J.E., Handley, H.A.H., and Craft, R. (2020). Understanding Human Readiness Levels. Proc. Hum. Factors Ergon. Soc. Annu. Meet. *64*, 1765–1769.

127. Bernstein, M.J., Nielsen, M.W., Alnor, E., Brasil, A., Birkving, A.L., Chan, T.T., Griessler, E., de Jong, S., van de Klippe, W., Meijer, I., et al. (2022). The Societal Readiness Thinking Tool: A Practical Resource for Maturing the Societal Readiness of Research Projects. Sci. Eng. Ethics *28*, 6.

128. Bozeman, J.F., III, Nobler, E., and Nock, D. (2022). A Path Toward Systemic Equity in Life Cycle Assessment and Decision-Making: Standardizing Sociodemographic Data Practices. Environ. Eng. Sci. *39*, 759–769.

129. Jones, A., Nock, D., Samaras, C., Qiu, Y., and Xing, B. (2023). Climate change impacts on future residential electricity consumption and energy burden: A case study in Phoenix, Arizona. Energy Policy *183*, 113811.

130. Ratcliff, E.L., Chen, Z., Davis, C.M., Suh, E.H., Toney, M.F., Armstrong, N.R., Reid, O.G., and Greenaway, A.L. (2023). Soft Materials for Photoelectrochemical Fuel Production. ACS Energy Lett. *8*, 5116–5127.

131. Whyte, K. (2018). Settler Colonialism, Ecology, and Environmental Injustice. Environ. Soc. *9*, 125–144.

132. Mazzone, A., Fulkaxò Cruz, D.K., Tumwebaze, S., Ushigua, M., Trotter, P.A., Carvajal, A.E., Schaeffer, R., and Khosla, R. (2023). Indigenous cosmologies of energy for a sustainable energy future. Nat. Energy *8*, 19–29.

133. McCauley, D., and Heffron, R. (2018). Just transition: Integrating climate, energy and environmental justice. Energy Policy *119*, 1–7.

134. Partridge, T., Thomas, M., Pidgeon, N., and Harthorn, B.H. (2018). Urgency in energy justice: Contestation and time in prospective shale extraction in the United States and United Kingdom. Energy Res. Soc. Sci. *42*, 138–146.

135. Werners, S.E., Sparkes, E., Totin, E., Abel, N., Bhadwal, S., Butler, J.R.A., Douxchamps, S., James, H., Methner, N., Siebeneck, J., et al. (2021). Advancing climate resilient development pathways since the IPCC's fifth assessment report. Environ. Sci. Policy *126*, 168–176.

136. Cronin, J., Hughes, N., Tomei, J., Caiado Couto, L., Ali, M., Kizilcec, V., Adewole, A., Bisaga, I., Broad, O., Parikh, P., et al. (2021). Embedding justice in the 1.5°C transition: A transdisciplinary research agenda. Energy Transit. *1*, 100001.

137. Stilgoe, J., Owen, R., and Macnaghten, P. (2013). Developing a framework for responsible innovation. Resour. Policy *42*, 1568–1580.

138. Anastas, P., and Eghbali, N. (2010). Green chemistry: principles and practice. Chem. Soc. Rev. *39*, 301–312.

139. Aziz, M.J., Gayme, D.F., Johnson, K., Knox-Hayes, J., Li, P., Loth, E., Pao, L.Y., Sadoway, D.R., Smith, J., and Smith, S. (2022). A co-design framework for wind energy integrated with storage. Joule *6*, 1995–2015.

140. van de Poel, I. (2013). Translating Values into Design Requirements. In Philosophy and Engineering: Reflections on Practice, Principles and Process, D.P. Michelfelder, N. McCarthy, and D.E. Goldberg, eds. (Springer Netherlands), pp. 253–266.

141. Costanza-Chock, S. (2020). Design Justice: Community-Led Practices to Build the Worlds We Need (The MIT Press).

142. Das, M., Roeder, G., Ostrowski, A.K., Yang, M.C., and Verma, A. (2023). What Do We Mean When We Write About Ethics, Equity, and Justice in Engineering Design? J. Mech. Des. *145*, 061402.

143. Phillips, E.L. (2010). The Development and Initial Evaluation of the Human Readiness Level Framework. Master's thesis.

144. Energy Equity Project (2022). Energy Equity Framework: Combining Data and Qualitative Approaches to Ensure Equity in the Energy Transition (University of Michigan – School for Environment and Sustainability (SEAS)).

145. Arnstein, S.R. (1969). A ladder of citizen participation. J. Am. Inst. Plann. *35*, 216–224.

146. Esmalian, A., Wang, W., and Mostafavi, A. (2022). Multi-agent modeling of hazard–household–infrastructure nexus for equitable resilience assessment. Computer. aided. Civil Eng. *37*, 1491–1520.

147. Energy.gov.. DOE Office of Economic Impact and Diversity Community Benefit Agreement (CBA) Toolkit. https://www.energy.gov/diversity/community-benefit-agreement-cba-toolkit.

148. Schipper, E.L.F., Revi, A., Preston, B.L., Carr, E.R., Eriksen, S.H., Fernandez-Carril, L.R., Glavovic, B.C., Hilmi, N.J.M., Ley, D., and Mukerji, R. (2022). Climate resilient development pathways climate change 2022: impacts, adaptation and vulnerability. IPCC Sixth Assessment Report.

149. Mathie, A., and Cunningham, G. (2003). From clients to citizens: Asset-based community development as a strategy for community-driven development. Dev. Pract. *13*, 474–486.

150. Farley, C., Howat, J., Bosco, J., Thakar, N., Wise, J., and Su, J. (2021). Advancing equity in utility regulation (Lawrence Berkeley National Lab.(LBNL)).

151. Lee, C.-C., Maron, M., and Mostafavi, A. (2022). Community-scale big data reveals disparate impacts of the Texas winter storm of 2021 and its managed power outage. Humanit. Soc. Sci. Commun. *9*, 335.

152. Lin, Y., Wang, J., and Yue, M. (2022). Equity-based grid resilience: How do we get there? Electr. J. *35*, 107135.

153. Kim, Y., Smith, J.B., Mack, C., Cook, J., Furlow, J., Njinga, J.-L., and Cote, M. (2017). A perspective on climate-resilient development and national adaptation planning based on USAID's experience. Clim. Dev. *9*, 141–151.

154. Heleno, M., Sigrin, B., Popovich, N., Heeter, J., Jain Figueroa, A., Reiner, M., and Reames, T. (2022). Optimizing equity in energy policy interventions: A quantitative decision-support framework for energy justice. Appl. Energy *325*, 119771.

155. Syal, S.M. (2022). Embedding Human Perspective and Equity in the Design of Sustainable Energy and Transportation Systems. ProQuest Diss. Theses.