Opening the wormhole: Linkages between justice in energy transitions and energy systems modelling literature – implications for policy development

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Abstract

Sometimes academics from different disciplines feel like they are working on different planets that orbit stars lightyears apart. Justice in energy transitions (JET) and the energy modelling literatures are no exception. While both fields are working towards a common sustainable and equitable future, rarely do equity and justice considerations enter modelling studies, and vice versa, rarely do JET papers consider modelling and engineering analysis. This paper documents collaborative research conducted by JET and energy modelling researchers at Simon Fraser University in British Columbia, Canada. Through literature reviews and dialogue, we identified overlaps between JET and energy modelling and set an initial research agenda. By opening the wormhole connecting our fields, we hope to inspire more transdisciplinary research and inform future justice-oriented energy policy. We call on fellow JET and energy modelling researchers to join us in learning from one another and working towards a more sustainable and just future. We also call on policymakers to utilize transdisciplinary research to inform just energy futures.

Keywords

Justice in Energy Transitions, Energy Modelling, Energy Transition, Community Engagement, Equity, Justice.

Introduction

Sometimes academics from different disciplines feel like they are working on different planets that orbit stars lightyears apart. The case of the justice in energy transitions and the energy modelling literatures are an excellent example. In many ways both fields are working towards a common sustainable and equitable future. However, rarely do equity and justice considerations enter modelling studies, and vice versa, rarely do justice in energy transitions papers go beyond argument-based analysis to consider technical challenges using modelling and engineering analysis. In this paper, we attempt to open the wormhole between these disciplines and examine the potential benefits of these two fields working together. This will hopefully serve as an example for other justice in energy transitions and energy modelling academics to join us in crossing the wormhole as well as illustrate some of the challenges and opportunities we discovered connecting our disparate disciplines.

From an energy systems modeller/engineering perspective, we are working to find feasible pathways to sustainable energy systems. We do this using energy systems models that allow us to examine the technical and physical constraints on the energy system and how policy options interact with these constraints. In recent years there has been a move to expanding energy systems models to include climate, land, energy and water systems nexus (CLEWs) considerations [1]. A logical extension of this work is to expand the model space even further, to consider equity and justice considerations such as energy access and energy poverty to address additional aspects of the UN Sustainable Development Goals [2]. This interest led us to connect to justice in energy transitions researchers to see how this might be feasible.

From a justice in energy transitions (JET) researcher perspective, we focus on people, practices, and policies within socio-technical systems to study or facilitate change. Change is understood to be co-evolutionary, and involves a broad range of actors, sectors, and systems [3]. JET draws from the field of sustainability transitions, which focuses on the trajectory of change towards sustainability and seeks to uncover the origins, patterns, and mechanisms that drive transitions. However, we are particularly interested in the role of power, ethics, and justice in energy transitions. This has emerged from the need to ensure that transitions are not only sustainable, but just [4]. In our work, we aim to explore and uncover the transitions dynamics that create, embed, exacerbate, or reduce issues with ethics implications like poverty, inequality, and access [5].

From what was originally an exploratory discussion emerged a rich exploration of the perspectives of the different disciplines. We discovered that the wormhole had many opportunities but also some pitfalls. Energy modellers trying to influence policy need to incorporate justice considerations into their work, and justice in energy transitions researchers need to incorporate numerical and modelling analysis into their work. Working together will strengthen policy making for a more sustainable future.

This paper outlines our approach to crossing the wormhole, how we investigated and shared perspectives from each discipline to develop a common understanding of language and processes, and where we see opportunities for further collaboration going forward. We welcome and encourage other justice in energy transitions and energy modelling researchers to join us for the ride through the wormhole.

Approach

Collaborative inquiry guided the approach of this interdisciplinary investigation. The approach was emergent, stemming from a single question: *How can the concepts of equity and justice influence the field of energy modelling and how can energy modelling help ground scholarship in justice in energy transitions?* The principal investigator and co-investigator also identified the importance of community and stakeholder engagement in co-creating scholarship that bridges the academic divide. Through a grant from the Community-Engaged Research Initiative (CERi) at Simon Fraser University (SFU), the principal investigator, in consultation with the co-investigator, funded two students to support this initial research study - one sustainable energy engineering PhD student and one resource and environmental management master's student – to represent each respective field's literature.

The initial research study centered collaboration through sustained dialogue between team members and literature review. The two students met weekly across the initial study period and the entire team met monthly to provide project updates, discuss literature, identify research gaps between fields, and develop a series of questions for further collaborative research. As a starting point, the students developed a series of literature reviews from their respective fields, including environmental justice, climate justice, and energy justice to support understandings of the justice in energy transitions scholarship and energy modelling and energy systems to support understandings of the energy modelling scholarship. Through this collaborative process, the team benefited from cross-disciplinary dialogue and sharing key evolutions and concepts of significance. From this coordinated literature review, the students identified a list of questions for further research to contribute to this emerging field of research.

During the initial research study, the team identified key differences in how each field conducts research and analyzes data. Justice in energy transitions scholarship focuses on qualitative approaches. Research methodologies typically include coded literature analysis, interviews, focus groups, and framework development and application. Data collection methodologies center equity and justice and attempt to minimize extraction from/harm to research participants. Resulting qualitative insights are often difficult to translate into quantitative data. Conversely, the energy engineering and modelling field conducts research by inputting numerical data on energy supply and demand into systems models to obtain numerical results. Methodologies are generally focused on quantitative analysis of the technical aspects of the energy transition. The differences in each respective field were seen as strengths to bring into a transdisciplinary research process. Transdisciplinary research is often characterized by collaboration and shared knowledge that leads to transformation in society [6]. Science and society are connected in transdisciplinary research and knowledge co-development between academics and non-academic participants is critical to reaching a sense of integration, purpose, and transformation [7]. This research meets a current scholarly call to action to include more dialogue and engagement between energy transitions and energy justice research [8], [9].

Using a transdisciplinary research lens, the importance of defining key terminology within our respective fields became clearer. During the initial research, the team developed shared definitions of key terms and concepts in each field as shown in Table 1. The subsequent literature reviews as described in the following section expand upon these key terms and highlight key evolutions and scholarly contributions significant in each field.

Table 1: Key Terms and Concepts

Justice in energy transitions scholarship	*Energy modelling*
Equity - fair access to equal opportunities and resources. *Justice* - transformative change to repair inequities. Connections between the following subfields:	*Modelling* - simplified representations of real-life systems that help us understand the function of those systems and the potential consequences of changes or future events. *Energy systems modelling* - the function of existing or future energy systems that help us

• *Environmental justice* – mending past and present environmental racism and inequities. • *Climate justice* - mitigating unequal burden to adapt to climate change. • *Energy justice* - ensuring equitable energy access while reducing burden and impacts on frontline communities. • *Just transition* - centering justice and equity while transitioning to a clean energy future.	understand the trends and run experiments to study the probable results, before making decisions and implementing policies. *Indicators* – the metrics to measure, compare and improve the system.

Literature Reviewed

The literature reviewed reflects relevant concepts from both the justice in energy transitions scholarship and the energy modelling field. The first section discusses key concepts, terms, and scholarly evolutions from environmental justice, climate justice, and energy justice. The second section turns to energy modelling and applies an equity and justice lens within energy modelling. Together, these literature reviews support an interdisciplinary investigation into equity and justice in energy modelling and inform the relevant overlaps discussed later in this paper.

From Environmental Justice to Climate Justice and Energy Justice

The field of energy transitions scholarship is grounded in understanding equity and justice within the process of transitioning from fossil fuel use to clean energy sources and a low carbon future. Applying the definitions above, equity and justice must be considered to ensure that the transition to cleaner energy extraction, production, transmission, and consumption is fair, and does not exacerbate existing social, economic, and environmental inequities. Three intersecting bodies of literature – environmental justice, climate justice, and energy justice – were reviewed to better understand the dynamics connecting equity, justice, and energy. For each body of literature, this review defines the concept, identifies related terms, examines key evolutions, and draws connections to energy modelling.

Environmental justice

With origins in the civil rights and labour movements in the United States in the 1980s, the term environmental justice (EJ) is commonly defined as "the fair treatment and meaningful involvement of all people regardless of race, color, culture, national origin, income, and educational levels with respect to the development, implementation, and enforcement of protective environmental laws, regulations, and policies" [10]. Environmental justice activism began as low-income communities of color organized to fight back against environmental racism, or racialized discrimination in environmental policymaking, regulations, and decision-making [11]. These communities recognized the disproportionate impacts on their health, wellbeing, and environmental circumstances, inspiring community organizing to both document these cumulative impacts and push for stronger regulations and justice [12].

Within academia, environmental justice scholarship has several significant evolutions, including (a) the prioritization of intersectionality in discussing environmental injustice drivers and impacts [13], (b) the application of environmental justice outside of its American origins with linkages to related movements [14], [15], and (c) greater specificity of the vertical and horizontal scales with which environmental justice operates spatially and temporally [15]. In thinking about connections to energy modelling, environmental justice literature identifies relationships between environmental racism and the siting of fossil fuel infrastructure and energy transmission pathways. The distance to these locations from equity-denied populations could be assessed within a modelling scenario.

Climate justice

Adjacent to environmental justice, climate justice grew as both a social justice movement and academic field starting in the early 2000s. The term climate justice highlights "a reshaping of climate action from a technical effort to cut emissions into an approach that also addresses human rights and social inequality" [16]. Climate injustice, or the climate gap, refers to the imbalance of who is impacted by climate change, the frequency and intensity of those impacts, and the ability to adapt to these changes [17]. Conversely, climate justice describes transforming those imbalanced systems to the benefit of those who have contributed the least to climate change yet are most at risk of harmful climate impacts [15]. Climate equity, a frequently used related term, describes finding balance between those who have access to resources for adaptation and those who have been systemically denied these resources[18]. Impacted communities are often described by their vulnerability to climate change or their adaptive capacity to sustain community resilience [19]–[21]. Scholars also examine different dimensions of equity and justice (i.e., procedural, distributive, recognitional) to understand how climate equity and justice are being enacted [22]. Finally, climate justice is reliant on just transition, or the notion that the transition away from fossil fuels and extractive economies centers care and justice, to not exacerbate existing inequities [23].

Within academia, evolutions in climate justice scholarship include: (a) deeper inquiries into inclusivity, equity, and accountability related to systemic racism [24]; (b) understandings of just urban climate adaptation in both physical form and planning processes [22]; and (c) bridging scholarship siloes, such as NEXUS food-water-energy-climate modelling, to evaluate vulnerability and readiness to adaptation [25]. In examining overlaps between climate justice and energy modelling, clear connections between climate justice and fossil fuel extraction and consumption emerge. Energy production, use, and decision-making exacerbate climate justice concerns. Energy modelling could include climate impacts scenario-planning to anticipate unintended climate justice consequences.

Energy justice

With academic origins in the United Kingdom and Northern Europe, energy justice is defined as the application of "justice principles to energy policy, energy production and systems, energy consumption, energy activism, energy security, the energy trilemma, political economy of energy, and climate change" [26]. Fuel poverty, occurring when households spend more than 10 or 15 percent of their monthly income on energy services at the expense of purchasing food [27], is a foundational concept within this body of literature. However, recent scholarship uses energy burden to take a more intersectional view of income

level, energy costs, and systemic racism [28]. Scholars also reference energy democracy as a form of applying energy justice in practice [29].

Key evolutions in energy justice scholarship include (a) the application of restorative justice to energy justice [30]; (b) the lack of activist origins guiding scholarship [31], [32]; (c) the role of colonialism and capitalism in perpetuating current energy systems [33], [34]; (d) how race and gender could be centered within the field [24], [35], [36]; and (e) the role of energy justice in ensuring a right to energy, in particular cooling during extreme heat [37], [38]. In connecting energy justice scholarship to energy modelling, energy justice focuses mainly on classism and accessibility. Energy modelling could consider energy affordability and related social trade-offs of not having energy access in its scenario planning.

Together, these three bodies of literature ground justice in energy transitions scholarship and inform ways that energy modelling might incorporate equity and justice principles. Environmental justice calls attention to justice for human and more-than-human beings in relation to the environment. Climate justice brings in systems thinking to connect justice concerns, carbon emissions, and resulting climate change, and energy justice offers a specific sectorial view of justice within the energy sector. Justice in energy transitions builds upon these differing lines of inquiry across geographic and temporal scales – asking what is justice and for whom?

Justice in Energy Transitions

Separate from yet related to just transition activism and scholarship, the justice in energy transitions (JET) field utilizes the dimensions of justice (i.e., procedural, distributive, recognition) to better understand how and for whom justice is being enacted within the process of an energy transition [4]. For their framework, Williams and Doyon draw upon the work of several scholars [39], [40] to identify specific questions pertaining to each dimension of justice and JET. Distributive justice & JET focuses on "equitable distribution of economic benefits" [39] whereas procedural justice & JET centers "equal participation in decision procedures, equal capabilities to participate," [39] asking "who defines what is just, and for whom" [40]. Recognition justice views JET from a different angle, focusing on "recognition of variety of needs and cultures" [39]. Together, these dimensions of justice propose different avenues for JET researchers to examine how equity and justice operate within energy transitions.

This emerging field draws upon key learnings from both transitions and energy justice scholarship and its methodologies include literature review, framework development, and case study application. As this field evolves, there have been calls to engage in more collaborative and interdisciplinary work [41], [42] as well as engage more with non-Western theorists, post-colonial thought, and non-human impact [43], [44]. For the time being, justice in energy transitions remains largely conceptual and could benefit from more applied research methodologies. Energy modelling could also benefit from applying justice in energy transitions frameworks, contributing to case studies informed by interdisciplinary approaches. To better understand the potential overlaps between the two fields, energy modelling scholarship will be reviewed in the following section.

Equity and Justice in Energy Modelling

The JET literature reviewed above discusses mainly qualitative solutions to the challenge of a just energy system transition. Unfortunately, qualitative solutions often overlook non-obvious technical challenges that can be elucidated by quantitative techniques, such as energy modelling. This section provides an overview of energy systems modelling, discusses how modelling tools have expanded beyond the energy system and then discusses how equity might be incorporated into energy systems models.

Energy systems modelling to Nexus modelling

Energy systems models represent the interconnections of energy resources with energy demands to help engineers and policy-makers understand trends, challenges and opportunities. Broadly, and admittedly glossing over significant areas of the field, energy systems models can be classified into (1) energy-economy models that consider the economic aspects of the energy transition but often lack technical detail; (2) capacity expansion models that allow the modeller to determine optimal pathways for energy system build-out but do not allow for economic feedbacks or operational details to be included; and (3) operational models that include consideration of short time frame operational challenges but cannot consider the costs of system expansion [45]. Though our approach in this paper is applicable to all three model types, we focus mainly on the capacity expansion modelling category, as it has the most overlap with the JET energy transitions objectives of planning for a transition to a more just energy system.

Capacity expansion models are generally implemented as either linear programming models, where non-linearities, such as start-up time and minimum operation constraints, are ignored for computational simplicity or as mixed integer linear programs (MILPs) where these complexities are considered but long-term details are removed to ensure tractability. In either case, the objective is to identify a suitable long-term strategy that is technically feasible and incorporates identified policy objectives, such as carbon emissions reductions or renewable energy generation targets. Alternately, policies, such as carbon pricing or coal shutdowns, can be implemented and the climate and energy system impacts determined to see how effective such policies are with respect to their stated intent.

Energy systems modelling has, in recent years, been expanding to include additional criteria in the decision-making algorithms. For example, Vinca et al. combine the capacity expansion model MESSGEix with the CWatM water management tool to evaluate how water and energy interactions impact the most feasible paths for decarbonization [46]. The Climate, Land, Energy and Water systems (CLEWs) modelling framework is another example of the expansion of capacity expansion modelling to incorporate different sectors in their analysis [1]. The CLEWs framework has been applied in a variety of countries from Vietnam to Canada and beyond [47] [48].

Incorporating Equity and the SDGs

With the adoption of the United Nations Sustainable Development Goals (SDGs) in 2015, researchers started to consider how existing models can address the SDG challenges. For example, Niet et al. call for models to be expanded to incorporate more of the SDGs to ensure that trade-offs are identified and co-benefits are quantified to enhance policy insights [2]. The 17 SDGs focus on environmental, economic, and social concerns and each includes a number of indicators with the goal of significant progress on each indicator by 2030 towards a more sustainable world. Researchers promptly identified that these goals have significant interactions and overlaps and that addressing any one goal requires consideration of many (if not all) of the other goals [49]. Policymakers, and therefore their advisors, need to consider the interconnections between different sectors so the co-benefits, as well as trade-offs, with numerous

other goals, are effectively considered. Expanding models to address these interconnections across the SDGs will help with coherent and effective policy.

In addition to the research on SDGs, some recent works have attempted to incorporate equity into energy optimization frameworks. Papers that discuss both equity and modelling are rare with just a few recent papers explicitly discussing the topic. Even when claiming incorporating modelling and equity, in many cases, the models do not directly consider equity, but are informed by community engagement and/or social science researcher involvement. For example, Rubiano et al. discuss how the techno-optimal solutions from many energy systems models often leave out justice considerations and that, therefore, often injustices result from policies implemented from modelling [50]. Belaïd review the implications of badly designed climate policies on energy poverty from a global perspective. They highlight the challenges of decarbonization and how addressing the SDGs holistically is critical for energy justice [51]. McGookin et al. discuss how to incorporate participatory methods, such as community engagement in energy modelling and how that can address some of these challenges [52]. Heleno et al. combine sociodemographic and techno-economic models and optimize the portfolio of technologies while attempting to reduce the energy burdens on vulnerable populations [53]. They apply their case study to Detroit and find that including these considerations in the modelling change the outputs and reduce energy justice implications.

Given the lack of modelling papers that directly address equity considerations, and the lack of numeracy and modelling in the JET literature, there is significant scope for research to build bridges between these two disparate fields.

Findings - Identifying Shared Language and Processes

The following section considers themes and high-level learnings from the literature reviews presented above. During the initial research study, each team member reviewed and gave feedback on each literature review, asking questions to both improve clarity of the review and to identify where there were differences between the two fields (i.e., differences in definitions and indicator use). This ongoing dialogue allowed us to find similarities within our field and understand where the two fields intersect. From these discussions, the following four overall themes of commonality between our fields emerged: focus on systems thinking, applied disciplines, commitment to sustainability, and interdisciplinary. Each section below expands on these themes.

Focus on Systems Thinking

Both fields share a focus on systems thinking as a core element of their approach to their work. Literature that informs JET scholarship identifies a clear theme around systems thinking. From the energy justice literature, Heffron and McCauley provide different frameworks with which to apply energy justice over time, including examining different dimensions of justice, the energy life cycle, and principles to practice energy justice (i.e., availability, affordability, due process, transparency) [54]. Together, these framework elements demonstrate guidance for applying energy justice in case studies and could be applied in energy modelling. Recent literature has also called for JET scholarship and other related fields to work collaboratively and reflexively [9] and acknowledge the dynamics and influence of systemic racism and colonialism within place [24], moving the field from theory to practice. Energy modelling also has evolved to center cross-sector systems thinking [55]. In the past, energy models were mostly focused on technical aspects and meeting a given energy demand in the most cost-effective

manner. More recently, modellers started incorporating other concepts and models now commonly include cross-sectoral connections. Many models now address not just electricity systems, but also include energy used in transport, home heating, industry, etc. As noted above, this has expanded to include land and water systems in the CLEWs framework [1] and consideration of how to address the SDGs [2]. As these cross-sectoral modelling challenges have emerged, modellers have adopted a systems approach to ensure that important connections are considered in model inputs and outputs. Figure 1 illustrates some of the cross-sectoral interactions that are now being considered in energy systems models. This focus on systems thinking formed a common foundation as we explored the intersections between JET and energy systems modelling.

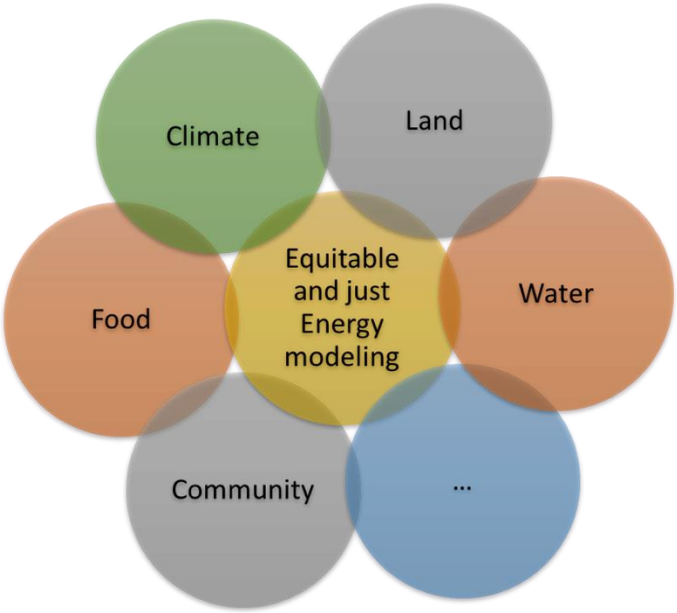

Figure 1: Nexus interactions and systems thinking

Applied Disciplines

Both JET and Energy Modelling are focussed on making change in the world as applied disciplines. Energy modelling has the goal of providing effective and adoptable long-term energy plans for countries and regions and enabling stakeholders in these places to make better policy decisions. Recent papers have called for open and reproducible workflows to support this applied approach [56], [57]. Similarly, JET is focussed on enabling good policy decision making by working with and for stakeholders and policymakers [58]. Lacey-Barnacle et al. discuss how the JET focus on applied activities shapes the field and its approach [59]. Similarly, Pfenninger et al. note that energy modelling needs to be open and accessible for stakeholders and van Bruggen et al. discuss the importance of having stakeholders involved in the modelling process [60], [61]. As applied fields, there is a common focus on practical and applicable approaches to finding solutions to our energy challenges. This common applied approach enabled the team to break through academic discussion and focus on applications for tangible change in the world.

Commitments to Sustainable Energy Transitions

Broadly, both fields express commitments to transitioning towards a sustainable future. This focus on sustainable energy transitions in both the JET and energy modelling fields is critical to the formation of this interdisciplinary study. In climate justice and energy justice scholarship, scholars ground this commitment in an acknowledgement of existing environmental and social inequities [24], [30]. They advocate for more thoughtful dialogue and action on just transition away from fossil fuels and towards cleaner energy production, transmission, and consumption [9]. Climate justice activism has also identified pathways from extractive to regenerative economies as models for societal change [23]. Scholars in the environmental, climate, and energy justice fields clearly do not see energy transitions, sustainability, and justice as separate leading to the emergence of JET literature. In the energy modelling field, similarly, most studies first acknowledge that current energy systems are not sustainable and a transition is needed in the energy system to address sustainability. The focus, throughout the sustainable energy modelling literature, is on net-zero and Paris Climate Agreement compatible long-term energy plans. Across both fields, scholars have expressed clear commitments to sustainable energy transitions, with some explicitly naming connections to justice.

Interdisciplinary

Energy systems are complex, cross-sectoral, and touch on most parts of people's lives. Through the CLEWs framework, the SDGs, and adopting a systems approach, energy modelling is working with and across sectors and disciplines. There is an understanding that "reflective interdisciplinary 'conversations'" need to take place to ensure holistic and more just energy transitions [62]. JET scholarship is also rooted in a "willingness of some academics from different disciplines to engage with justice concerns in order to influence energy practitioners and decision-makers" [63]. Yet, as Heffron and McCauley argue, more interdisciplinary research is needed to facilitate energy transitions with Jenkins et al. articulating existing work is more multidisciplinary than interdisciplinary [9], [54]. While multidisciplinary research brings together knowledge and practices from multiple disciplines, interdisciplinary research aims to create new coordinated approaches based on different disciplines [7]. By crossing the wormhole, we wanted to not only discuss challenges and opportunities to connect our disparate disciplines but support better policy making for a more sustainable future.

Discussion and emerging themes

Building on our shared language around systems thinking and commitments to sustainability, and rooted in our applied and interdisciplinary approach, two emerging themes were identified that, together, provide a roadmap for moving both JET and energy modelling towards a more just and equitable future. These themes emerged through discussions within the team as well as through the shared literature and highlight how modelling can be improved with equity and justice indicators and also how community engagement needs to be core to both fields' approach to supporting a just and equitable energy transition.

Emerging Use of Equity and Justice Indicators

Establishing justice and equity indicators and metrics provides an opportunity to bring together rigorous qualitative analyses, JET analytical frameworks, and community engagement with quantitative models of the energy system. But how are qualitative concepts translated into quantitative elements of

computational models? This is important, as quantities are essential to monitor and modify justice and equity within energy systems and modelling.

Methodologies supporting JET research have traditionally relied on literature reviews, framework development, audits, and case study analyses. Within environmental justice, indicators typically reflect environmental burden (i.e., air quality, proximity to toxic waste facilities and industry, access to open space) or social factors that correlate to inequitable economic, social, and health outcomes (i.e., race, class, gender, age, ability, access to stable housing, access to health care) [25], [64]. These indicators are highly reliant on the credibility and geographic distribution of data, as well as the degree to which the metric corresponding to an indicator accurately represents the indicator. Within energy justice, indicators have been developed to assess equity, environmental, economic, and energy democracy in energy systems. These include collecting data on the numbers of city residents hired for clean energy programs, energy programs targeted at low-income households, and diverse representation on utility board composition [65].

Energy modelling has also developed equity and justice indicators. San Salvador del Valle et al. (2022) developed the 'justice in electricity costs' and 'hidden electricity costs' indicators to show electricity footprint and consumption of natural resources [66]. Other indicators have been used in mapping tools, such as EnviroScreen in New York City and CalEnviroScreen in California, where indicators included population health, socio-demographics, environmental risk factors, and potential pollution exposures [64]. The geographic and temporal data collected from these tools is used to support data-driven decision-making for state governments. These indicators represent attempts to acknowledge equity and justice considerations within energy systems modelling and offer different opportunities for how equity and justice indicators could be used within modelling scenarios.

Numerical indicators, however, will never be able to capture the full breadth of the community and stakeholder challenges and wishes. So, although indicators can be used to strengthen energy models, bringing in communities to discuss and highlight the implications of any given policy will ensure that decisions are based both in the technical realities and the social and equity realities. This brings us to the next emerging theme in our work: the importance of community engagement.

Importance of Community Engagement

Jenkins et al. call for energy justice scholars to "practice what we preach" and engage in radical research where societal engagement is embedded into research design [9]. Engaging a diverse set of stakeholders and co-producing knowledge can allow for greater inclusion of ideas in research design and implementation, and further center values of equity and justice [8]. In the energy modelling field, the importance of interdisciplinary work and community engagement is emerging. Scholars have identified a gap in research and want to understand the role that community engagement can play in informing energy modelling development and uses [67].

When incorporating energy justice into models, the models must "be reflective of, and informative to, a wide range of stakeholders" [29]. However, there is still a significant challenge of incorporating stakeholder responses and energy justice frameworks and principles into technical energy models. The literature has identified different levels of community engagement, with the most basic being discussing production and consumption of energy with stakeholders, as demonstrated by Bar Gai [68]. Bar Gai also

identify the need to include low- and middle-income households in the engagement in a fair and equitable way. Inclusion of all members of the community in broader energy decisions requires more engagement and time but also adds value to the engagement activities [58]. Baker et al. analysed stakeholder engagement in energy systems in Ghana and provide a hierarchy highlighting the trade-offs and the social, economic, and technological factors that need to be measured in electricity models. These works illustrate both fields are engaging communities, yet additional work is needed to ensure these engagements are meaningful and beneficial to the communities [29].

Our discussions highlighted an emerging assertion that, during modelling activities, there are three distinct modelling phases where community engagement should be practiced: pre-modelling, during modelling and post-modelling as illustrated in Figure 2. The pre-modelling phase should engage the community in developing the objectives of the modelling activity and the specific insights that the group hopes to obtain from the model. This sets the stage for an effective modelling activity where the model is built and appropriate data is gathered to address these specific considerations. During the modelling activity, community engagement will allow for adjustments to the scope should data availability and/or model structure not allow for directly meeting the original objectives. During the post-modelling phase, the community should be engaged in discussion of the model outputs, what they mean in the specific context, and ensuring the scenarios run by the modellers address the community concerns. We note that these are iterative and any given modelling activity may cycle through these phases throughout a given project. Through these community engagement activities, the gaps in applying indicators to modelling can be closed by ensuring that additional considerations are included and analysed at each stage of the modelling activity.

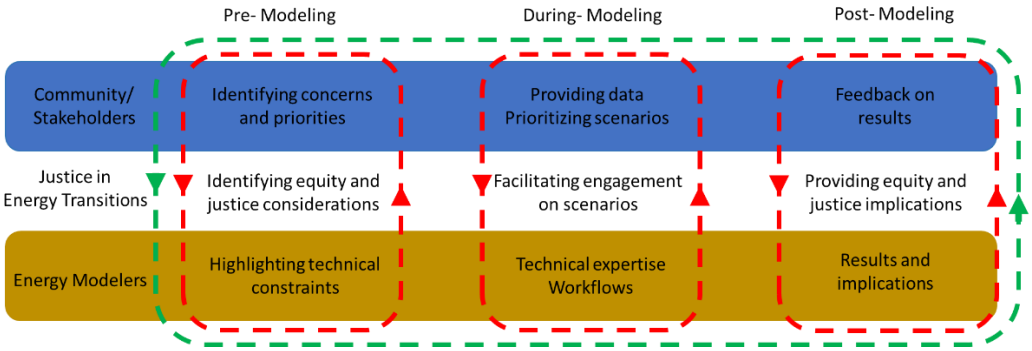

Figure 2: Community Engagement pre, during and post modelling indicating the roles of energy modellers, community/stakeholder groups and JET practitioners.

Applying this community-engaged approach across both the JET and energy modelling communities will build stronger, more resilient communities and enable both fields to ensure they are directly meeting the needs of the communities they serve. This also fits well within the applied nature of both disciplines and their commitments to sustainability as sustainable solutions need to be built with community support.

Conclusions and Policy Implications

There is significant opportunity to expand interdisciplinary approaches to JET and energy modelling and working together will strengthen both fields. When we started this work, we imagined that the

wormhole between the fields was vast, and through this work we found that there were actually many common and shared priorities. These include the focus on systems thinking, the applied nature of both disciplines, the commitments to a sustainable transition, and their interdisciplinary focus. We found that first establishing shared language was a large part of the effort, but the outcome helped both sides understand how the approaches of the other complimented their own field.

From the energy engineering side, there is significant value in bringing in discussions of justice and equity and finding ways to apply these in energy systems models. This will strengthen the ability to get community buy in and to provide effective and just policy recommendations. The challenge is finding ways to translate equity and justice indicators into model-relevant numerical indicators. The ability to work with JET practitioners, however, provides opportunity to learn and incorporate some of the less concrete equity and justice principles into modelling through community engagement. Conversely, JET focussed policy researchers can directly benefit from the numeracy and engineering approach taken by energy modellers to address the technical challenges of the energy transition.

In learning from our collaborative research effort, we offer the following policy agenda to drive future transdisciplinary research between JET and energy modelling research. First, policy makers, practitioners, and researchers from both energy modelling and social science fields are needed as collaborators to continue the conversation and keep the dialogue going. Second, including diverse communities in decision-making is needed to implement equitable practices with a community-centered perspective. Third, policy makers should keep transdisciplinary research collaborations in mind and take both energy modeling and social science perspectives into account in planning processes, particularly related to clean energy initiatives and climate mitigation efforts. Fourth, energy policy makers should be empowered to include equity, justice, and community opinions in their processes.

Related research is limited so far. A genuine framework needs to be built and should start from possibilities and gaps on the modeling side and needs and opportunities on the community side. Together, both fields will provide better policy and decision-making support to communities and stakeholders if they work together. We invite other JET and energy modellers to join us in our journey through the wormhole.

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