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Justice-Embedded Requirements Engineering (JERE) for system design

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Abstract

We have a unique opportunity to consider justice in our design of a cleaner energy system. This paper introduces the Justice-Embedded Requirements Engineering (JERE) process, which was created to enable engineers to consider project goals, requirements, and potential project impacts on historically marginalized, climate-vulnerable communities. Given JERE's focus on energy technologies, we demonstrate the process using a concentrating solar power example. JERE provides engineers with a tool to better ensure justice is embedded in the system design process from the beginning.

Keywords: requirements engineering, sustainable design, socio-technical systems, energy justice, clean energy

1. Introduction

1.1. Frontline communities and the energy system

As various nations and intergovernmental bodies aspire to reach critical decarbonization targets, it has become imperative to develop and deploy clean and efficient energy technologies that work for all. Members of vulnerable and overburdened communities ("frontline communities") have historically been invisibilized and marginalized in decarbonization efforts despite facing the first and worst consequences of both climate change and the existing fossil fuel-based energy system (Baker *et al.*, 2019). Due to harms from both climate change and the current energy system, frontline communities face poor air and water quality, physical and mental health challenges, deeper social inequality, loss of livelihoods, higher energy burdens (ratio of energy expenditure to income), and energy insecurity (Baker *et al.*, 2019; Intergovernmental Panel on Climate Change (IPCC), 2023; National Academies of Sciences, 2021). Furthermore, frontline communities also struggle to access benefits associated with renewable energy technologies (Carley and Konisky, 2020; Sunter et al., 2019).

Governing bodies now seek to pursue a just energy transition that will remedy the injustices of the fossil-fuel based energy system and extractive economy while building a system of "dignified, productive, and ecologically sustainable livelihoods; democratic governance; and ecological resilience" (Baker et al., 2019). A just energy transition also aims to avoid future harms to individuals and communities who rely on the existing fossil fuel-based energy system for their livelihoods (National Academies of Sciences, 2021). Given 50% of technologies needed to hit decarbonization goals are in the prototype or demonstration stage (IEA, 2021), now is an opportune time to consider justice and equity dimensions in how we design the next generation of renewable energy technologies and the system they will beget.

This paper seeks to answer the research question: "How can justice be embedded in the creation and implementation of the next generation of sustainable energy technologies?" Here, we introduce the **Justice-Embedded Requirements Engineering** (**JERE**) process. JERE was created to enable engineers to consider justice in their design of next generation technologies, with a primary focus on energy technologies. JERE provides a detailed process for engineers to deeply consider project goals, requirements, and potential project impacts on frontline communities during early-stage system design.

1.2. Energy justice

A critical component of both JERE and the pursuit of a just energy system is the concept of energy justice. Energy justice is a principle with the goal of achieving equity in the participation in, and outcome of, the energy system, while also remediating social, economic, and health burdens on those historically harmed by the energy system (adapted from (Baker et al., 2019)). Here, "equity" is defined as recognizing and addressing each individual's, or group's, circumstances and allocating resources and opportunities needed to "level the playing field," or reach an equal, fair, or just outcome (adapted from (Ikeme, 2003; MPH@GW, 2020)). Although many energy justice concepts are found in the literature, five—distributional, procedural, recognition, restorative, and intergenerational justice—will be referenced in this paper. These concepts span the *where* (distributional), *how* (procedural), *who* (recognition), and *when* (restorative and intergenerational) dimensions of energy justice.

Distributional (or, distributive) justice deals with the equitable distribution of benefits and burdens of the energy system across a population. It can span geographical, social, economic, and temporal contexts. Distributional justice considers to whom benefits accrue, where burdens occur, and whether the burdens disproportionately affect frontline communities (Jenkins *et al.*, 2016). Procedural and recognition justice consider how to tackle injustice and for whom, respectively. Procedural justice focuses on equitable engagement, fairness, and transparency when allocating resources and adjudicating disputes. It involves understanding who has a seat at the proverbial table, who is involved in decision-making, and what concerns of inclusiveness and influence are at play in a process (Baker *et al.*, 2019; Jenkins *et al.*, 2016).

Intergenerational justice (or, intergenerational equity) considers multiple generations when evaluating the changing effects of energy technologies over time. Intergenerational justice considers a population's obligations to future generations and takes action that increases, rather than limits, the options of future generations (Brown *et al.*, 2020; Sovacool *et al.*, 2016). Restorative justice seeks to acknowledge, ameliorate, and address previous negative impacts and inequities from the current energy system, especially as it pertains to frontline communities (Baker *et al.*, 2019; McCauley and Heffron, 2018). If one views intergenerational justice as informed by the future, one can also view restorative justice as informed by the past. Understanding the geographical, cultural, and historical contexts of energy justice is particularly important given diverse views of justice across different regions, nations, cultures, and populations. This paper was written in the context of the United States with the hope that the work presented here could also be amended or broadened to apply to other nations, as well.

1.3. Designing more just systems

Designing more just technologies in order to construct more just systems is a goal of "systems justice," which "connects [a] bird's eye view of justice…to the distinctive position of each agent in a social system…it is a lens through which moral agents can see the world from different vantage points and motivate their distinctive contribution to global justice" (Ghazavi, 2018). Essentially, systems justice contends with the "problem of many hands," in which traditional understandings of responsibility for injustice break down in large, complex, and multi-actor systems (Ghazavi, 2018; van de Poel *et al.*, 2012). In these systems, it may be difficult, if not impossible, to pinpoint the group of responsible actors or perpetrators because injustices do not arise from individual agents, but rather from the collective. van de Poel *et al.* (2012) point to examples such as climate change to illustrate the problem of many hands because, in such cases, "the collective may be responsible for an undesirable outcome but none of the individuals in the collective is responsible."

Applying a perspective of systems justice, each energy engineer and practitioner is a moral agent with a role to play in pursuing a more just energy system; yet, current engineering practices and literature lack the necessary tools to enable engineers to meaningfully incorporate concepts of energy justice (Jenkins *et al.*, 2021). Energy justice, which is informed by community, environmental, and climate justice advocacy, has historically resided in social science, policy, and legal literature (Baker *et al.*, 2019; Jenkins *et al.*, 2021). This article aims to embed energy justice in the technology design process through the creation and introduction of the Justice-Embedded Requirements Engineering (JERE) process. Subsequent sections of this article will describe (1) literature that inspired the creation of JERE, (2) the JERE process that we developed, (3) examples of JERE's utility, and (4) its limitations.

2. Literature review: Justice-centered design

2.1. Review of design frameworks and methods for incorporating justice

Although systems justice applies to energy systems, we still lack well-developed, practical tools for energy engineers, developers, and practitioners to thoroughly embed concepts of justice into their work. Therefore, we carried out a literature review of the most common design frameworks and methodologies for embedding justice considerations, or similar values, into the technology design process. We particularly focused on frameworks and methodologies that provide practitioners with clearly defined steps. The major frameworks and techniques reviewed were: (1) Value-Sensitive Design (VSD), (2) Responsible Research and Innovation (RRI), (3) Design Justice, and (4) System Design for Sustainable Energy for All (SD4SEA). Other relevant design frameworks were also studied in this literature review and are mentioned alongside these major ones. However, there is a general lack of rigorous evaluation of methods used to incorporate justice in research, engineering, and design processes, making it difficult to fully understand the effectiveness and impacts of these techniques.

The literature around justice and design tends to be made up of two main branches. One branch involves the philosophical underpinnings and theories of justice in the context of design—what is meant by "justice," what are its socio-political implications in design, what are the designer's moral prerogatives, and so on (Albrechtslund, 2007; Carbajo and Cabeza, 2018; Owen *et al.*, 2012; van de Poel *et al.*, 2012; von Schomberg, 2012). The other branch focuses on integrating justice into design work, mostly by focusing on injustices and inequities that emerge from technologies or by encouraging designers to center marginalized communities in the design process using methodologies such as participatory design (Costanza-Chock, 2020; Ghazavi, 2018; van de Poel, 2015). When it comes to design processes that fall into the latter category, one will often find repeated themes of community empowerment, deep collaboration, continuous self-reflection, bias identification, and understanding of power dynamics in the design process (Anaissie *et al.*, 2021; Costanza-Chock, 2020; Stilgoe *et al.*, 2013).

2.2. Value-sensitive design

Value-Sensitive Design (VSD) is a design framework through which "researchers and designers can explicitly incorporate the considerations of human values into their work" (Davis and Nathan, 2021). Values may be broadly defined as "varieties of goodness" as deemed by the stakeholders (van de Poel, 2015). VSD has historically been applied in the field of human-computer interaction but has implications for fields ranging from technology design and engineering to policy and governance (Jenkins *et al.*, 2020; Mok and Hyysalo, 2018; van de Poel, 2015). VSD consists of three iterative steps: conceptual investigations, empirical investigations, and technical investigations (Davis and Nathan, 2021). Conceptual investigations involve identifying direct stakeholders (those who will use the product) and indirect stakeholders (those who are impacted by others' use), as well as identifying and defining the values implicated by use of the technology. Empirical investigations aim to understand the stakeholders, their experiences, actions, knowledge, and contexts. Related to energy justice, the empirical investigation could be used to enhance aspects of recognition justice. Finally, the technical investigation seeks to understand how values can influence various features of new or existing technologies (Davis and Nathan, 2021).

VSD will likely look different in energy system design given the expansive scope and broad range of values and stakeholders. This breadth is especially vast when considering intergenerational justice in which future generations will not necessarily be able to meaningfully inform contemporary design

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choices (Davis and Nathan, 2021). Because a technology's influence is shaped not only by features of its design but also by the context in which it is used and the people using it, a major limitation of VSD, and all other anticipatory frameworks, is the inherent lack of knowledge of how a technology's use will evolve with time (Albrechtslund, 2007). In an attempt to link VSD and energy justice, Jenkins *et al.* (2020) indicate that energy justice can further inform VSD by emphasizing the frontline communities who may be indirect stakeholders in the design process, providing ethical theory for VSD, and incorporating more of a systems-wide vantage for the application of VSD in the design of energy systems. VSD has also been used in the energy space via a case study for solar panel deployment in Finland in which researchers worked with stakeholders to install rooftop solar in a manner that aligned with stakeholder aesthetic values and cultural preferences (Mok and Hyysalo, 2018).

2.3. Responsible research and innovation

Responsible Research and Innovation (RRI) is a framework that aims to transparently and interactively create a situation in which "societal actors and innovators become mutually responsive to each other with a view to the (ethical) acceptability, sustainability, and societal desirability of the innovation process and its marketable products" (von Schomberg, 2012). RRI is often referenced in academia and policy at the intersection of technology and public good (Owen *et al.*, 2012). In practice, RRI is typically marked by four dimensions synthesized by Stilgoe *et al.* (2013): anticipation, reflexivity, inclusion, and responsiveness. Anticipation is meant to encourage researchers, innovators, and their organizations to ask "what if" questions to better understand issues that may arise from their research or new technologies (Stilgoe *et al.*, 2013). Reflexivity can be either institutional or individual. Stilgoe *et al.* (2013) define institutional reflexivity as "holding a mirror up to one's own activities, commitments and assumptions, being aware of the limits of knowledge and being mindful that a particular framing of an issue may not be universally held." Such institutional reflexivity seeks to scrutinize the value systems and theories that shape science, innovation, and their governance. In contrast, individual reflexivity is more of a reflection and self-critique by individual actors regarding their own work.

Similar to how the principle of anticipation is found in both VSD and RRI, along with several other justice-oriented design frameworks presented in the literature, reflexivity is another common principle found among many of the methodologies reviewed. This theme is apparent in design processes such as Liberatory Design, which strives to generate self-awareness for designers to curb habits that perpetuate inequity, shift the relationship between "the people who hold power to design and those impacted," empower those influenced by the design work, and "create conditions for collective liberation" (Anaissie *et al.*, 2021). The RRI principle of inclusion centers engaging new voices in the governance of science and innovation, while responsiveness focuses on responding to new knowledge and making changes as it emerges (Stilgoe *et al.*, 2013). As with applying energy justice principles, RRI seeks to positively impact society and can enable the inclusion of frontline communities in research and innovation, even though their needs are not necessarily the main focus of RRI. Attempts have been made to link RRI with concepts of energy justice, energy policy, and VSD, but overall, the RRI literature still remains lacking in concrete, direct applicability to engineers who seek to design more just energy technologies (Carbajo and Cabeza, 2018; Jenkins *et al.*, 2020).

2.4. Design justice

Design Justice, pioneered by Sasha Costanza-Chock and the Design Justice Network, is a framework that "rethinks design processes, centers people who are normally marginalized by design, and uses collaborative, creative practices to address the deepest challenges our communities face" (Costanza-Chock, 2020). Design Justice is characterized by community stewardship, expertise, and empowerment as well as reflective, collaborative, and non-exploitative design processes. It encourages the designer to reflect on the values, practices, narratives, locations, and pedagogies of design and more systematically address inequities. In an expansion of Design Justice, Das *et al.* present a framework for equitable engineering design and research, which provides a series of questions related to equity, ethics, and justice for engineers and designers to answer (Das *et al.*, 2023). Questions fall in a range of categories from equity, history, and values to problem scope, design beneficiaries, and sustainability.

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The expanded Design Justice framework structure, and several of the questions posed, resonate with a framework introduced by Romero-Lankao *et. al* to center justice in energy innovation, dubbed the "CJI framework" (Romero-Lankao et al., 2023). In the CJI framework, they present a series of questions to enable energy practitioners to view procedural, distributional, and recognition justice dimensions of the energy system across three increasing analytical levels—niche (research and development), regime (mature energy transition innovations), and landscape (broader cultural paradigms). The CJI framework is then applied to two case studies, one focused on wind energy in Mexico and another centered on the Los Angeles 100% Renewable Energy Study. The CJI framework enabled multilevel inspection of the justice aspects of these two case studies.

Although these frameworks enable engineers to think more holistically and reflect on the justice implications and contexts in which they work, engineers may still find it difficult to meaningfully apply their reflections to their typical design activities, especially without an accessible tool or protocol. Additionally, many methods that incorporate aspects of justice, or related concepts, may be inaccessible to energy engineers given they have likely specialized in particular technical areas within the energy sector. They may not have any philosophical grounding or knowledge of their work's potential sociotechnical impacts, especially if they have little interaction or familiarity with marginalized groups.

2.5. Energy system design for global development

Renewable energy design and implementation for global development oftentimes reflect the energy justice principles of procedural and recognition justice. This alignment is particularly apparent when it comes to the example of Vezzoli *et al.*'s (2018) attempt to design sustainable distributed energy systems and processes for use in the Global South. The process they introduce, "System Design for Sustainable Energy for All" or SD4SEA, incorporates concepts such as design for sustainability, human-centered design, and participatory design. The goal of SD4SEA is to design a sustainable product-service system to fulfill the demand for distributed renewable energy in low- and middle-income populations (Vezzoli *et al*., 2018). This framework considers the potential users (i.e., low- and middle-income populations), their circumstances, and how they are engaged (i.e., through deep user-centered collaboration) throughout the design process.

SD4SEA is broken into five stages: strategic analysis, exploring opportunities, designing system concepts, designing system details, and communication (Vezzoli *et al*., 2018). At the strategic analysis stage, the design team aims to understand local contexts, which enables them to design sustainable energy products in a specific location. Next, the design team explores opportunities through participatory design for various stakeholders to generate ideas at the system level. These ideas are then aggregated and distilled in order to design one or more system concepts. Afterwards, the detailed system design process begins, during which the design team develops the most promising system concept into a detailed version for implementation. Finally, the design team creates documentation for internal and external communications. Although SD4SEA was created to be used in the Global South, its thoughtful incorporation of procedural and recognition justice and guidance for thinking more holistically about integrating users, their satisfaction, and details of local contexts into energy technology design processes made this framework particularly relevant for understanding mechanisms for operationalizing justice in renewable energy design.

3. The justice-embedded requirements engineering process

3.1. Creating the JERE process

Although informed by all the design frameworks and methodologies reviewed, the Justice-Embedded Requirements Engineering (JERE) process presented here was particularly influenced by principles of VSD. More specifically, van de Poel's (2013) work on translating values to design requirements greatly influenced the structure of JERE. In van de Poel's framework, values are translated into technical requirements through "norms." The term "norm" is used for "all kinds of prescriptions for, and restrictions on, action" (van de Poel, 2013). van de Poel provides the example of "end-norms," which are particular objectives for a design process or attributes a designed artefact should possess. In the

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tripartite hierarchical framework of values-norms-requirements that van de Poel presents, values beget norms that influence actions in the design process, and norms then translate the impacts of those actions into requirements.

For the purposes of this paper, *requirements* will state the objectives of the system, technology, policy, or program that is created during a team's application of the JERE process. These requirements will define the success of the project along with other important aspects like a system's functionality, cost, and quality. *Specifications* will be used for the more concrete, often quantifiable objectives of a system (e.g., system dimensions, electric output, rotations per minute, thermal conductivity, etc.).

JERE was designed around a central problem statement: **Help engineers embed energy justice into their clean or renewable (or related) energy engineering design process.** Criteria that informed the creation of the JERE process are listed in Table 1. Each criterion is labeled either "Demand" or "Want" to indicate if the criterion *must* be included in the design intervention or that it *would be nice* for the criterion to be included in the design intervention, respectively. The list of criteria that led to the creation of the JERE process was inspired by our team's literature review, results of surveys and interviews with energy practitioners, and our team's prior research studying preliminary outcomes of incorporating energy justice metrics in energy research and development (Arkhurst *et al.*, 2023). Our team found several gaps that needed to be addressed to enable energy researchers and engineers to apply justice to their work, including the need for more specialized tools, early-stage interventions, support for more concretely connecting justice principles to technical work, and assistance with solution follow-through (Arkhurst et al., 2023). These findings informed the creation of the criteria listed below. These criteria center goals such as ensuring the intervention would be understandable and accessible to engineers, enhancing understanding of justice principles, and supporting justice-related problematization and solution identification in engineering projects.

Table 1. Criteria for creating the justice-embedded requirements engineering (JERE) process

Problem Statement: Help engineers embed energy justice into their clean or renewable (or related) energy engineering design process		
1	Demand	Make intervention understandable for engineers
2	Demand	Make intervention familiar to make it accessible to engineers
3	Want	Provide flexibility to account for project or work diversity
4	Want	Enhance perceived responsibility for engineers regarding energy justice considerations
5	Want	Enhance incentives for engineers to integrate energy justice
6	Want	Elucidate engineers' values
7	Demand	Enhance understanding of energy justice problem space
8	Demand	Enhance energy justice-based problematization for engineers
9	Want	Enhance understanding of energy justice solution space
10	Want	Provide energy justice assessment for engineers
11	Want	Provide justice-based decision support for engineers
12	Want	Enhance engineers' comfort with engaging with energy justice
13	Demand	Increase method uptake
14	Want	Enhance systems-level understanding or approach
15	Want	Enable meaningful consideration of diverse perspectives

3.2. JERE process overview

The Justice-Embedded Requirements Engineering process is broken down into four iterative stages.

Stage 1. Initial Assessment: Understand the project's information gaps and needs pertaining to energy justice or related considerations. JERE Stage 1 is broken down into the following three steps: i) a Spatial Justice Assessment, which focuses on a project's geographical distribution of benefits and burdens across technological, environmental, economic, cultural, and political dimensions; ii) a Structural Justice Assessment, which maps those benefits and burdens to 15 demographic characteristics (e.g., ethnicity, wealth, gender, and climate vulnerability); and iii) consolidation of gaps identified in

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this first stage of JERE. The Spatial and Structural Justice Assessments form the Distribution-Based Assessment found in JERE Stage 3. During the Spatial Justice Assessment, the team is prompted to consider where the technology will be designed, demonstrated, and eventually deployed. These considerations are brought to the forefront to highlight potential discrepancies in where the work is being done and where the outcomes of the project will be realized. Engineers are also prompted to consider the primary (directly engaged or influenced), secondary (indirectly engaged or influenced), and tertiary stakeholders (affected upstream or downstream of secondary stakeholders) and principal (most salient and direct), ancillary (secondary or indirect), and possible (potential with high uncertainty) benefits and burdens associated with their project.

The Structural Justice Assessment maps project benefits and burdens to fifteen demographic characteristics users can choose from: race/ethnicity, language, wealth/income, occupation, disability, climate vulnerability, social vulnerability/marginalization, age, body dimensions, housing status, gender, sexual orientation, religion, educational background, and regional issues of injustice. It encourages users to think more specifically and systematically about who is expected to be a beneficiary or adversely affected by their project. Along with the fifteen demographic considerations presented to users is an opportunity to consider aspects of intersectionality and other user-defined demographics. Users are encouraged to think through each demographic consideration across time, assessing the historical, contemporary, and anticipated benefits and burdens of project outcomes on each group. The final step of JERE Stage 1 is the “Gap Consolidation” step. In preparation for JERE Stage 2, the “Gap Consolidation” step guides users as they aggregate, arrange, and consolidate the information gaps and needs they identified in the Initial Assessment. Throughout JERE Stage 1, users are encouraged to keep track of information gaps that need to be filled as they go through the JERE process.

Stage 2. Process Planning and Pursuit: Embed equity into processes such as information gathering, communication, and public engagement to inform all other stages of JERE. This stage focuses on incorporating procedural justice into design processes and filling knowledge gaps identified in Stage 1. This portion of the JERE process consists of six steps: i) identifying the project’s information gaps and needs, particularly as they relate to justice considerations (completed through JERE Stage 1); ii) planning the project’s information-gathering protocol, which includes identifying equity-centered frameworks and data collection methods; iii) developing the project’s decision-making and communication protocols; iv) gathering the necessary information to fill gaps identified in JERE Stage 1; v) communicating results to team members, partners, stakeholders, etc.; and vi) incorporating the findings into the Distribution-Based Assessment (JERE Stage 3). JERE Stage 2 provides several examples of frameworks, techniques, and factors for users to consider applying to their projects, including project co-development, participatory design, VSD, and considerations such as transparency, compensation for partners, safety, and mediation to address power imbalances.

Stage 3. Distribution-Based Assessment: Identify and assess potential distributional justice implications of technology based on findings from Stage 2. This stage uses the same assessment in JERE Stage 1. Users are prompted to reconsider and re-evaluate the potential benefits and burdens associated with the project and how they may be distributed in time, space, and across demographics. The three steps of JERE Stage 3 are as follows: i) Spatial Justice Assessment; ii) Structural Justice Assessment, and iii) consideration and priority identification. After users revisit the Distribution-Based Assessment (Spatial and Structural Justice Assessments), the final step of JERE Stage 3 focuses on identifying the major considerations and priorities that arose from JERE Stages 1-3. Users take these priorities into the final stage of JERE, during which they identify requirements based on their findings.

Stage 4. Requirements Translation: Convert the information and priorities identified in Stages 2 and 3 to system requirements and specifications. During the final stage of JERE, users identify project objectives, constraints, and relevant justice considerations; reconcile tensions across these factors; and consolidate and clarify the project requirements and specifications. Stage 4 consists of seven steps: i) identifying areas of optimization for benefits; ii) identifying areas of mitigation for burdens; iii) understanding and addressing points of tension and trade-offs; iv) prioritizing considerations; v) translating considerations into requirements; vi) prioritizing requirements; and vii) translating requirements into specifications.

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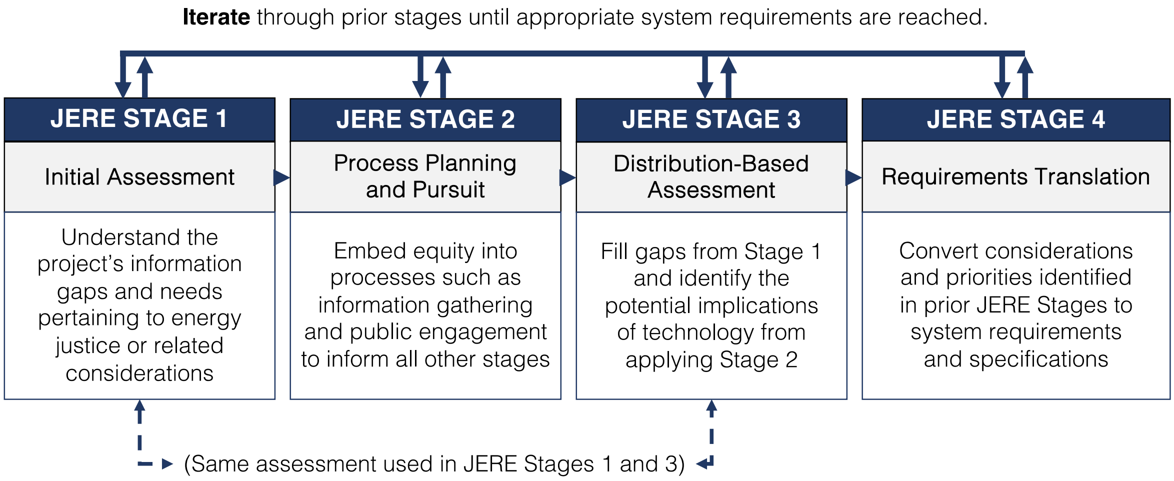

Figure 1. Overview of the justice-embedded requirements engineering (JERE) process

3.3. Applying the JERE process: A concentrating solar power example

To demonstrate JERE's utility, we can use the hypothetical example of a team working on a next generation concentrating solar power (CSP) system. CSPs are solar thermal systems that can span hundreds of acres. They rely on a field of reflectors to concentrate solar power to a point on a receiver that heats up a "heat transfer medium" to either store thermal energy or transfer heat for manufacturing processes or electricity production. A team designing a new CSP system may seek to apply JERE to better understand some of the justice implications of their work. Although this example focuses on CSP technology, it should be noted that JERE was made to be broad enough to apply to technologies across the energy sector and beyond.

The team does the initial assessment in JERE Stage 1. An example outcome from JERE Stage 1 could be the team identifies gaps in their knowledge of potential distributive impacts of their heat transfer media options on local residents and plant workers. The team can then proceed to JERE Stage 2. At this stage, the team may decide to investigate potential heat transfer media impacts through community listening sessions, preliminary benchtop experiments, and literature reviews to identify major concerns that may arise or that may be posed by the local community. Using this information, the team iteratively revisits the assessment done in JERE Stage 1 and fills gaps they identified, which constitutes JERE Stage 3. Now, the CSP team is ready to carry out JERE Stage 4, the Requirements Translation stage. After completing JERE Stages 1 through 4, the CSP team would have system requirements and specifications that reflect their JERE findings. For example, if during listening sessions, the team discovered impacts on local volant wildlife (Ho, 2016), potential particulate emissions from particle-based heat transfer media, or impacts of concentrated solar glare on worker ocular health (Ho *et al.*, 2015) were major concerns for community members, they can now have these considerations meaningfully embedded in their system requirements and design processes, far upstream of technology deployment.

4. JERE implications and limitations

The Justice-Embedded Requirements Engineering process can provide engineers with a step-by-step guide to incorporate justice considerations in their technical design process, which can enhance the potential social impacts of their work. JERE enables engineering teams to catch potential adverse impacts on frontline communities earlier, make plans to remedy or mitigate these potential adverse impacts, and seek to actively benefit historically marginalized communities through their work. JERE was made to be applied early in the engineering design process as design requirements are created. Similar values-based requirement engineering techniques have also been found in software development (Aldewereld *et al.*, 2015; Thew and Sutcliffe, 2018), which indicates that although built for energy engineers, JERE may also be used for other systems and projects outside of the energy sector or applied in other technology development processes, such as the software development process.

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That being said, JERE is not without its limitations. The JERE process is intensive and thus will likely be time-consuming, particularly for teams who have never engaged with the sociopolitical aspects of their work or to whom sociopolitical elements are completely foreign. Additionally, it is up to the project team to decide the extent to which they want to engage with JERE and to what ends, meaning that it can be used to superficially engage with justice considerations rather than doing so in any intensive capacity. Finally, given JERE is a newly developed process, there will need to be more rigorous evaluation of it as a tool to determine if it does indeed inspire more justice-oriented requirements and, eventually, more just and equitable system outcomes.

5. Conclusion

Systems justice calls for a collective response to existing problems of injustice. Through this paper and the introduction of Justice-Embedded Requirements Engineering (JERE), we aim to encourage energy engineers, developers, and practitioners to reconsider, reevaluate, and adjust their work to better position it to aid in the pursuit of a more just energy system. JERE can be applied during project proposals, as teams brainstorm or plan projects, or may be useful for energy developers as they decide on where to site projects and populations to engage. As demonstrated by Lavi and Reich (2024), values embedded and reinforced by the systems we create and fortify are complex, multidimensional, and ever-evolving. Interdisciplinary teams and continuous re-examination of system values allow for more in-depth engagement with JERE and the justice principles it aims to embed in technical work. Realizing a more just and equitable future energy system requires a reimagining of our work as engineers, it will also call for enhanced engagement with frontline communities and a deeper respect for the knowledge, innovation, rich histories, and creativity members of frontline communities possess.

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