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Understanding Socio-Technological Systems Change through an Indigenous Community-Based Participatory Framework

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Abstract: Moving toward a sustainable global society requires substantial change in both social and technological systems. This sustainability is dependent not only on addressing the environmental impacts of current social and technological systems, but also on addressing the social, economic and political harms that continue to be perpetuated through systematic forms of oppression and the exclusion of Black, Indigenous, and people of color (BIPOC) communities. To adequately identify and address these harms, we argue that scientists, practitioners, and communities need a transdisciplinary framework that integrates multiple types of knowledge, in particular, Indigenous and experiential knowledge. Indigenous knowledge systems embrace relationality and reciprocity rather than extraction and oppression, and experiential knowledge grounds transition priorities in lived experiences rather than expert assessments. Here, we demonstrate how an Indigenous, experiential, and community-based participatory framework for understanding and advancing socio-technological system transitions can facilitate the co-design and co-development of community-owned energy systems.

Keywords: Indigenous knowledge; community-based participatory approaches; socio-technological systems transitions; transdisciplinarity; environmental justice; medicine wheel; knowledge sharing

1. Introduction

The transition to a decarbonized energy system is now justifiable on purely economic grounds, given the rapid decline in the cost of solar, wind, and battery storage technologies [1]. However, this transition will involve a complex array of choices about which technologies to adopt, the scale at which to adopt them, and the sites for locating their development. These choices are ultimately social choices, shaped by existing solar relationships among individuals, communities, and institutions. As social choices, the socio-technological transition to renewable energy systems requires decision making frameworks that are attentive to how social relationships, including conditions of exclusion and inequity, shape decision processes.

This is particularly important given the impacts that the current energy system has on communities. The global impacts of climate change include increased vulnerabilities due to social, political, and economic systems of violence and oppression against Black, Indigenous, and people of color (BIPOC) communities [2,3]. Addressing these global challenges requires systemic change in the way that we sustain life, manage natural resources and,

a key focus here, develop and maintain energy systems. The field of socio-technological systems transitions (STST) provides insights into managing that change by identifying and analyzing complex considerations across multiple factors associated with technologies, economies, value systems, and cultures. Current energy frameworks associated with STST often emphasize one dimension at the expense of others [4]. For instance, work on energy law and policy prioritizes economics to the detriment of climate change mitigation and energy security [5]; work examining the physical and mechanical elements of energy systems often ignores human choice [6]; and frameworks describing energy consumption ignore the human body, focusing instead on the decontextualized and disembodied mind [7]. Even methodologically, social scientists studying STST often rely on surveys in lieu of field research, focus groups and interviews [8]; ignore Indigenous communities as sources of knowledge and provisioners of unique yet legitimate ontologies and conceptions of risk [9] and focus on a single case study rather than comparing cases across communities or countries, a practice that can result in stronger evidence, the identification of knowledge gaps [10], and greater insight into the significant role of culture and lifestyle in determining energy attitudes and behavior [11]. Indeed, most energy STST frameworks focus on technology, economics, or politics rather than embedded community, human and cultural values [8].

The success of renewable energy development is often very directly determined by public acceptance within a local community context, which provides one reason to center community values and priorities in any energy decision making framework [12,13]. However, there are many other reasons that we advocate for centering community engagement, participatory approaches, and allowing community priorities to drive energy system transitions. A large and robust body of research centered on energy justice recognizes the importance of procedural justice—the inclusive of just, fair, and transparent processes for making decisions about energy systems—as essential for a just energy system transition [14,15]. Participatory processes are [16], furthermore, essential for addressing the systematic exclusion, oppression, and myriad harms caused by the current energy system, features that are exacerbated by contemporary public health, political, and environmental crises [17] and that have for centuries silenced, downplayed, or ignored valid knowledge and forms of expertise that challenge the current status quo in energy systems [18,19].

Below, we propose a framework that is grounded in Indigenous knowledge and community participatory approaches. This framework focuses on understanding (1) the barriers and opportunities created by institutions, and (2) that Indigenous communities and institutions may have divergent perspectives about realities, possibilities, and priorities. The framework we offer encourages STST scholars and practitioners to honor Indigenous perspectives and the role they play in shaping the possibilities for systemic change. Our framework also acknowledges and builds upon findings from science and technology studies (STS). STS examines how scientific knowledge and technological design are constructed and co-produced within social institutions and networks [20]. While STS has emerged to bridge the socio-technological system gap, it remains largely a social science field [21] and continues to be epistemologically, methodologically, and geographically distinct from energy social science [22]. STS has contributed to understanding technological transitions, but remains focused on the social dimensions of transformations, with limited links to engineering, technical dimensions, and non-academic sectors [23–27]. An STST framework that incorporates perspectives from STS must move beyond narrowly defined disciplinary fields to include transdisciplinary considerations and deepen engagement, with the possibility of multiple and diverse ways of knowing and being across community contexts.

Before describing our STST framework in detail, we situate it in the literature by examining two existing STST frameworks: the multi-level perspective (MLP) [23,28] and systems dynamics modeling (SDM). Both frameworks are widely used and respected, yet vary with regard to their incorporation of Indigenous knowledge; their understanding

of the barriers and opportunities specific to Indigenous communities, such as energy justice, energy insecurity and energy sovereignty [17]; and their embrace of community-participatory methods.

2. Existing STST Frameworks

The review of existing STST frameworks provided below is intended to highlight both the strengths and limitations of two previously developed frameworks that can be applied to energy transitions research: the multi-level perspective and systems dynamics modeling. These descriptive summaries of each framework are provided based on a targeted review of existing literature intended to highlight the key features of each framework. Furthermore, both frameworks are analyzed with regard to how they address the full lifecycle of considerations for energy systems transitions and how they address issues associated with social relationships of power and influence, exclusion and vulnerability, and equity and inclusion.

2.1. The Multi-Level Perspective

The multi-level perspective (MLP) provides a means for examining large-scale, long-term system change across different levels and focuses on the interactive processes within and between incumbent regimes [23]. Within the MLP framework, the stability of a technology entrant is partly contingent on the dominant regime, which includes the public; however, the public's values, preferences, and priorities are not central to the interactions attended to in the MLP framework. It instead prioritizes institutional interactions and incumbent actors, and the role of radical niche-innovations. MLP also assumes deeply entrenched rules and norms, which by definition, are the rules and norms of the incumbent regime and actors [29]. In order for system change to occur, the MLP assumes that radical niche-innovations, or multiple linked innovations—which can include technologies as well as consumer practices, policies, infrastructures, business strategies, and cultural meanings [28]—enter small market niches typically on the periphery (an assumption which ensures that non-normative values, cultures, and discourses are relegated to the periphery). These innovations then improve in price and technical performance (first and foremost), gain support from powerful actors, enter cultural discourses, and ultimately must be supported by external sociotechnical landscape pressures or driven by internal persistent problems. By implication, understanding changes in technological innovation requires consideration of different perspectives involving users, institutions, the existing landscape, and the technology itself.

The MLP has, for the most, part ignored purposive transitions, such as those centering around energy sovereignty, energy justice, or decarbonization. These transitions tend not to rely solely on exploiting commercial opportunities or least-cost pathways, but come about instead as the result of community priorities, values, and incorporating different cultural meanings. These types of transitions elevate local policy, culture, and discourse as crucial drivers of innovation and adoption, and make them necessary units of analysis in an STST framework. Each has a role in shaping technologies, preferences, objectives, norms, and debate. Purposive transitions are different from those conventionally analyzed using the MLP, in that they are less about one-off radical innovations and more about multi-dimensional struggles between innovations and existing regimes, and they require expanding our analysis to include issue dynamics as well as innovation dynamics. An STST framework that builds off the MLP must allow for examination of whole-system change [23], as well as incorporate individual communities relegated to the periphery in previous iterations.

The MLP has also been criticized for ignoring interactions between systems; the adoption, modularization, or hybridization of innovations within existing systems; and the role of incumbents in resisting or delaying transition [30]. Geels [30], along with Newell and Paterson [31], identify that big business, fossil-fuel and electric utilities have amassed considerable structural power and influence developed as a result of states relying

on energy industries to provide jobs, taxes, and economic growth. This power stems from long-standing relational networks formed between business leaders and senior policymakers, an implicit internalization on the part of policymakers of the ideas and interests of industries, and finally, well-funded corporate political strategies. The cooperation is not always implicit, as industry-funded organizations like the American Legislative Exchange Council, or ALEC themselves draft and then promote legislation that benefits incumbents and sabotages efforts to speed transition [32]. This arrangement ultimately becomes legitimized in civil society via widely accepted discourses (except on the periphery) and can even alter low-carbon discourses to revolve around energy security and affordability, rather than on climate change or, as discussed here, energy sovereignty and energy justice.

Moving beyond an MLP framework requires an interdisciplinary approach, as no single discipline or ontology is sufficient to understand socio-technical systems [23]. Geels et al. [29] have argued for creating “protected spaces” to prioritize network governance and innovation policies and to “encourage learning, network building, initial deployment, and articulation of visions and discourses.” Expanding the MLP to focus on “interpretations, interests, resources, and strategies of different actor groups” is key, as is improving opportunities for stakeholder involvement, social acceptance, and positive discourses [29] (p. 475). Unlike residential and even community solar projects, regime actors often champion large-scale technological solutions, such as onshore and offshore wind and utility scale PV, each of which fits well within their own practices and interests, but less so with local actors. These types of low-carbon transitions thus become more of a “techno-economic management challenge” rather than an “agonistic confrontation of competing visions of a different socio-ecological order” [33] (p. 226).

Previous iterations of the MLP tend to focus on a limited number of actors, conceptualize tame processes, and optimize a single dimension, failing to account for difficult tradeoffs or social controversy. Thus, a new STST framework must account for a wider range of actors and disruptive, contested values, objectives, and interests—as well as the tradeoffs between them. It must acknowledge that powerful industries will protect their vested interests, change will not be linear, and long-term objectives are uncertain and difficult to articulate or communicate. Finally, an STST framework that improves upon the MLP must explicitly account for and center energy sovereignty.

2.2. System Dynamics Modeling

The strengths of a system dynamics approach (SDM) to framing technology transitions lie in its ability to forecast long-term, large-scale dynamics and feedback [34], which can support discussions around policies and interventions [35,36]. System dynamics can be used to model technology adoption and to represent “what if” scenarios of how adoption might play out under different circumstances [37]. SDM can incorporate the preferences and values of potential adopters (when these are articulated in causal language) through participatory model-building, and the feedback effects of “word of mouth” on adoption dynamics [38,39]. In addition, the dynamics of adoption, dis-adoption, re-adoption, and partial adoption can be captured in a system dynamics framework. However, system dynamics models do not typically give insight into the technology development stage. Adoption modeling takes place once a technology and its attributes may be described. Therefore, integrating system dynamics with a technology development platform such as participatory design is necessary for a comprehensive framework for socio-technological transitions. In addition, ethical and cultural aspects of technology are under-described in the system dynamics literature, although in theory, they could be incorporated. SDM deals with aggregate groups of potential adopters and is not useful for simulating multiple types of actors which interact in heterogeneous ways; agent-based modeling is a more appropriate type of platform for these modeling problems.

Sociological research posits that both adoption and dis-adoption of technology are driven by reinforcing feedback loops involving trust [40]. As users adopt a technology

and have a positive experience with it, they share that experience with other potential users, encouraging their own adoption of the technology. The reverse can also be true for dis-adoption; users sharing their negative experiences with a technology can lead to a rapid decline in its use [41]. System dynamics modeling of this social learning phenomenon builds on the classic Bass diffusion model [42], which yields an S-shaped growth curve in technology adoption: adoption is slow shortly after the technology's introduction, then increases rapidly as positive word of mouth about the technology spreads, then slows again, as there are few remaining potential adopters. This literature helps us understand the dynamics of technology adoption as driven by social learning, and gives us insight into how interactions, communication, and experience with a technology—whether good or bad—drive adoption trajectories as much as (or perhaps more than) the attributes of the technology itself. While system dynamics are most commonly used to model an individual's choice of technology, the framework could also be modified to represent the collective choice of a household, community, or nation. Constraints on choices due to policy or economic considerations may also be built into system dynamics models.

System dynamics modeling using the Bass diffusion model framework has been used to represent adoption over time of conservation agricultural practices in Zambia [43], other agricultural technologies [44], and automotive technologies [45]. It may also be used to model potential adoption trajectories of a technology that does not yet exist, which is useful for assessing novel or emerging renewable energy technologies [46]. This modeling may be used in a participatory or engaged context, by involving stakeholders or community members in designing the model, especially around the decision-making process [47]. The strengths of a system dynamics framework for understanding technology trajectories lie in its flexibility and adaptability for use in a range of contexts, scales, and groups, and the ability of the framework to integrate multiple types of knowledge and perspectives, e.g. both quantitative and qualitative information [38]. However, the sophisticated mathematics behind the simulations are challenging for some users to navigate, so graphical representation is critical when communicating model structure and results to diverse audiences.

2.3. Assessing the MLP and SDM as STST Frameworks

The MLP prioritizes institutional interactions rather than interactions within or among publics or across human and non-human communities. In the MLP, the stability of a new technology entrant is partly contingent on the regime, which includes the public; however, the public's values, preferences, and priorities are not central to the interactions attended to in the framework. SDM is useful in predicting the long-term, large-scale dynamics of technology adoption; however, it provides little insight into the technology development stage and tends to ignore ethical and cultural aspects of technologies.

While each of these frameworks can provide useful insights into how new technologies are developed, disseminated, and adopted, there are several aspects of technological systems transition which they collectively fail to address (see Table 1). First, there is no single framework that is capable of analyzing an STST throughout its entire trajectory, from needs assessment, to conceptualization, development, dissemination, adoption, evaluation, and potentially re-design. Technological adoption is often conceptualized as a straightforward, if not linear, process which proceeds smoothly through these stages, and clearly, this conceptualization does not reflect the complexity and dynamism of a real-world context [48].

Table 1. Features of multi-level perspective (MLP) and systems dynamics modeling (SDM) Frameworks Compared to Understanding Needed in New Framework.

| Type of Feature | Features of MLP Framework | Features of SDM Framework | Understanding Needed in New Framework |
|-----------------|--|--|--|
| Scale | Represents large-scale system change across niches, regimes, and the socio-technical landscape | Represents both small- and large-scale systems, but generally not used across scales | System change can occur at various scales including both whole-system change and within individual communities |
| Interaction | At times lacks emphasis on interactions between systems | Can incorporate interactions between multiple systems | Interactions between systems and incumbents can impact system change |
| Change | Systems change occurs as innovations enter small market niches | Systems change occurs through feedback effects driven by adoption/disadoption dynamics | System change can occur via purposive transitions (e.g. energy justice, energy sovereignty) |
| Actors | Prioritizes institutional interactions and incumbent actors | Emphasis is on adoption/disadoption, not technology design | Centering of the public's values, preferences, and priorities |
| Focus | Focuses on a small range of actors | Aggregated categories of actors | Inclusion of a wider range of actors and disruptive, contested values, objectives, and interests |
| Disciplines | Used by single disciplines | Can be either single-discipline or interdisciplinary | Interdisciplinary, if not transdisciplinary |
| Equity | Under addresses issues of equity, inclusion and power | Under addresses issues of equity, inclusion and power | Addresses the power dynamics between actors involved in STST including equitable access to technology |

These two frameworks have also failed to sufficiently grapple with the power dynamics inherent in the relationships between actors involved in STST. For example, Sovacool et al. [20] argue that STST frameworks have so far failed to examine those processes by which historically marginalized communities, and Indigenous communities in particular, have become excluded from the development of innovative energy systems. There is also extensive literature documenting the unequal access to, and impacts of, technology on men and women in sub-Saharan Africa [49,50]. Who is at the table when the need for the technology is identified, when the technology is designed, and when the technology is disseminated and evaluated, clearly matters for effective and equitable systems transitions. Considerations of equity, inclusion and power remain under-addressed in both frameworks and the literature more broadly.

3. An Indigenous Community-Based Participatory STST Framework

The framework proposed below was developed based on previous experiences with energy systems transitions research [51–53], community engagement and collaborations regarding energy systems decision making [54], development of decision frameworks for other contexts, and engagement with Indigenous knowledges and tribal nations collaborative partnerships in research [55,56]. The methodology involved in developing this framework included the assessment of previously developed frameworks as explored above, deliberate communication among the research team regarding transdisciplinary research approaches to energy systems decision making, and intentional dialogue and interaction with tribal nations to ensure that the adapted framework is respectfully embedded within frameworks for Indigenous knowledge and decision making. The research team is now actively applying this framework to empirical research contexts [57,58] and is providing this extensive introduction to the framework to invite other scholars to similarly apply and adapt the framework proposed below when engaging with renewable energy decision making.

A new framework must be flexible enough to explore how individual and community actors navigate socio-technological transitions in the presence of incumbent regimes. A framework should address how community and individual actors navigate the decisions presented by the regime; how a regime can frame what “community” means; and how considerations that have little to do with the regime may be prominent in community discussions. A new model should address how communities approach the decisions an

incumbent regime presents them, but also the ways in which communities may organize to advocate for changes to incumbent regimes that may open new spaces of possibility. The need to address this dynamic is informed by the nature of the energy sector, which, in the United States, is heavily regulated by state and federal agencies, and frequently monopolized due to the historic necessity of large, up-front capital investments to fund energy generation and distribution infrastructure. Utility customers are often unable to choose their electricity provider, let alone dictate that the energy they consume is produced and distributed in a sustainable way. Their options are heavily dependent on the utility service territory where they reside, the priorities of their state legislature and public utility commission, and the machinations of their regional transmission operator.

Operating within the confines of a regime, an individual monopoly utility customer may go off-grid or implement efficiency measures to consume less energy. They might take advantage of incentives their utility offers to install small-scale distributed generation at their home or business. When all else fails, they may physically move their home or business to a utility service territory that is more to their liking. To change the system, they might participate in the regulatory process by submitting public comments or formally intervening in regulatory proceedings. Or, they could make change by lobbying their legislator or otherwise participating in the legislative process, as an individual or as a member of an organization. We believe that the two-way dynamic of STST, that of playing the hand one is dealt or deciding it is time to reshuffle, is not satisfactorily addressed in the MLP or SDM frameworks.

In the context of energy, we also see a mismatch between technology adoption and production that is largely unaddressed by the established models, which assume that actors will pick up or discard technologies based on their own preferences. In renewable energy transition, some communities must react to sweeping shifts in energy technology that may alter landscape and impact the livelihoods of many. For example, the prospect of utility-scale renewable energy development may alter the economy and landscape of a region, for the benefit of many who may live outside of that region. In navigating this transition, these changes are likely to be foremost concerns, not energy itself. Conversely, some communities must adapt to the closure of fossil fuel plants, and with that change, a loss of stable employment. This loss may impact how communities view renewable energy transition in a way that has little to do with sustainability or cost. This dynamic also pits the needs of an individual community against the financial interests of energy company owners and shareholders, and, given the nature of utility ratemaking, energy consumers more broadly.

3.1. Characteristics of the New Framework

Our work with communities and tribal nations in Michigan as part of the Michigan Community Anishinaabe and Rural Energy Sovereignty, or MICARES, research team has highlighted the need for an expanded STST framework in order to fulfill the goals of historically marginalized communities, including Indigenous communities and nations, when they engage in any technological transition. Specifically considering the work of energy transitions, many individuals and communities around the world have been harmed by extractive energy production and exploitative systems of distribution. Though Indigenous communities and nations have a wide range of experiences, the majority have been among the most impacted by extractive and exploitative energy systems, and they have also been among the most creative and effective in addressing their energy needs in a way that is environmentally and economically just. In some cases, their approach has been inspired by their relationships with, and responsibility to, the natural world, or what Indigenous scholar Kimmerer [59] calls a “covenant of reciprocity”. The covenant starts with the worldview that nonhuman beings such as plants are to be treated with the same respect that we give our human relatives [59]. This worldview changes the focus from looking at the land as a natural resource to be exploited to one of a balanced reciprocal relationship where the land and nonhuman beings are relatives. Additionally, Indigenous

peoples' perspectives are informed by their legal sovereignty, which arguably empowers them to envision an always already decolonized strategy designed to fulfill their unique priorities in concert with their values. In this, tribal nations have something to teach the denizens of majority non-Indigenous rural communities who are struggling with high energy and electricity costs, unreliable service, and unsustainable emissions offered them by fossil fuel corporations and investor-owned monopoly utilities.

The work of tribal nations can also inform researchers who are looking for a new framework through which to understand transitions more broadly. We propose that there is a need to address the weaknesses of previous STST frameworks to tackle questions of agency and sovereignty, such as the following: When evaluating the priorities surrounding transitions, whose needs are centered in the process? Who is at the table when the need for technology is addressed, and who gets to decide how the technology is designed, disseminated, and evaluated? Indigenous methodologies necessarily include these questions.

We propose a new framework for STST that incorporates all the dimensions of STS through community-based participatory and Indigenous research approaches. The core aspects of participatory research are nicely summarized by the phrase “research ‘with’ rather than ‘on’ people” [16] (p. 29). In other words, “all parties participate and share control over all phases of the research process” [60] (p. 50). This framework is dynamic, flexible, and centers on community-based participatory and Indigenous research approaches, including the utilization of Indigenous knowledges when working with Indigenous communities, as well as relationships between technology developers, technology users, and other people and systems impacted by the technology. (In order to recognize the complex diversity of histories, cultures, languages, and practices among Indigenous communities, we utilize the plural term “knowledges” in reference to Indigenous knowledges.) By their nature, transitions imply a change in the state and function of key variables over time. A dynamic framework is necessary to capture these changes at different stages of technology development, diffusion, and evaluation.

For the new STST framework to do this work, there needs to be a core that focuses on relationality and reciprocity, as well as responsibility and respect. Indigenous research approaches are characterized by relationship-building and reciprocity, as are community-based participatory research approaches. As Wilson [61] explains, an Indigenous research methodology occurs when “as a researcher, you are answering to all your relations when you are doing research,” and the researcher should be asking, “Am I fulfilling my role and obligations in this relationship?” (p. 178). While an indigenous axiology, “needs to be an integral part of the methodology so that when you are gaining knowledge, you are not just gaining in some abstract pursuit, you are gaining knowledge in order to fulfill your end of the research relationship” [61] (p. 179). As a result, Indigenous research and energy projects are about establishing and maintaining reciprocal relationships. As such, a framework built on indigenous and participatory values is necessarily dynamic and flexible and incorporates elements inadequately enacted in previous frameworks.

3.2. Example of the New Framework—The Medicine Wheel

The medicine wheel (see Figure 1) that is at the heart of the MICARES project is an example of the type of community-based participatory framework that is missing from previous STST frameworks. In particular, it is a case study of how Indigenous knowledges, including a focus on relationality, reciprocity, responsibility and respect, can be applied to STST [61,62]. Relationality refers to an accountability to relationships, both human and nonhuman [61,62]. Those relationships should be mutually beneficial or reciprocal and based on an understanding of the relationship holders' responsibilities and rights [61,62]. The medicine wheel is based on our tribal nation partners' Anishinaabeg teachings of the medicine wheel or sacred hoop symbol. This framework is significant because it acknowledges the nations and knowledge systems of the Anishinaabeg Three Fires Confederacy, whose ancestral, traditional, and contemporary lands MICARES' primary universities,

Michigan Technological University (MTU) and Michigan State University (MSU), occupy. The Anishinaabeg are one of the largest Indigenous groups in North America, with nearly 150 different bands living throughout their original homeland in present day United States and Canada. Together known as the Three Fires Confederacy, the Anishinaabeg are currently identified by various names: the Chippewa, Ojibway, Ojibwe, or Ojibwa, as well as the Ottawa or Odawa, and Potawatomi or Bodewadomi. As such, this framework is foundational to, and interwoven throughout, the MICARES project approach.

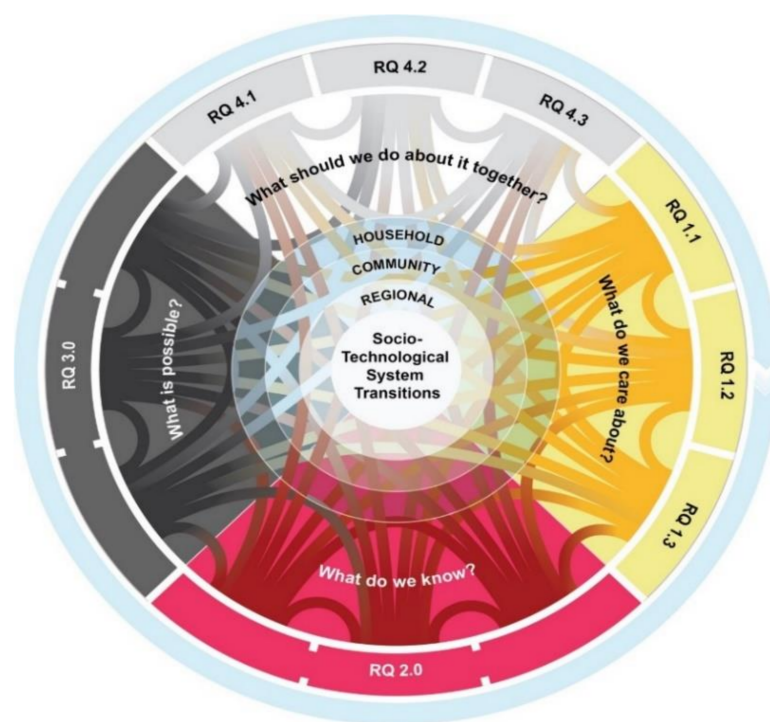


Figure 1. Michigan Community Anishinaabe and Rural Energy Sovereignty (MICARES) Medicine Wheel Framework.

This medicine wheel framework highlights the inherent relationality and the dynamic systems balance that must be sought when engaging in STST; technological systems and potential changes to them are always, and in every instance, deeply intertwined with social issues like exclusion and oppression, wellbeing and opportunity, control and dependency. They are also always intertwined with epistemological, as well as ethical questions about the knowledges we value and the forms of social organization believed to promote social justice, wellbeing, and quality of life. By asking the questions centered by this framework, scholars and practitioners alike can engage with the wisdom provided by Indigenous knowledge systems to engage in community-based and participatory inquiries that allow community knowledge, experience, values, and priorities to shape transitions.

Additionally, the cyclical nature of the medicine wheel elegantly addresses the gaps we identified in the MLP framework for communities navigating technology adoption in the context of an incumbent regulatory regime. The wheel's final question, "What should we do about it together?", may be answered by a community embracing solutions made readily available by the regime; by organizing to enact changes to the regime; or by doing some combination of the two concurrently. Regardless of what actions a community takes, when navigating their new reality they will once more face east and ask, "What do we care about?" to begin the cycle anew. The medicine wheel accommodates the nonlinear reality of STST and allows it to progress in fits and starts; it allows change actors to have complex, competing values that change over time; and it enables their decisions to be impactful on both a community- and regime-wide scale.

4. Discussion and Conclusions

The global crisis of climatic change caused by contemporary human activities clearly calls for proactive engagement with STST. The frameworks developed within the field of STS and beyond that are used to study, understand, and engage in STST all provide unique and novel insight. However, they also all fail to acknowledge that the conditions calling for rapid STST are not only environmental or ecological crises; human society globally also continues to grapple with systems of exclusion and oppression that disproportionately harm BIPOC communities, and the two crises of the global environment and of social injustice are linked and require a coherent framework that can acknowledge and attend to both.

Frameworks used to study STST that fail to acknowledge the inherent systems of knowledge production and systems of exclusion and oppression underlying current socio-technological systems are necessarily partial and lacking. Instead, we argue for a framework that centers on questions meant to force the consideration of issues regarding structures of power and systems of erasure. Asking communities directly about what they know and what they value and treating communities as experiential experts with valuable knowledge and expertise to share centers' community concerns and values rather than centering technical or economic priorities. Indigenous and community-based research practices offer methods for conducting this type of research that may be integrated into socio-technological systems transition work (examples include participatory design and participatory modeling). Given the diversity in knowledge systems and ways of knowing that characterize human communities, it is essential to interrogate and fully understand a community's knowledge system, rather than imposing or presuming a shared way of knowing across communities and with practitioners or decision makers. Furthermore, asking questions about what is possible forces consideration of the structures of power and systems of oppression that may shape barriers to, or impossibilities of, change.

We argue that an STST framework grounded in Indigenous ways of knowing and prioritizing community-based participatory approaches is essential for elucidating the relationships among the shared ecological and social crises facing humans in the contemporary world. Building this framework around the Medicine Wheel centers the relationality and reciprocity inherent within STST decision making. It also centers four core questions that can be used to better understand diverse ways of knowing and the role of exclusion and oppression in maintaining the status quo. This proposed framework can guide STST in ways that are necessary to create a more just and sustainable world.

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